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Early Pliocene to Late Middle Miocene Planktonic Foraminifera from the Type Section of the Sagara Group, Central Japan

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Introduction

The Neogene Tertiary sediments are developed well in the western part of Shizuoka Prefecture on the Pacific coast of central Japan, so that a number of stratigraphers and paleontologists have investigated them since the beginning of this century. According to a synthetic work on their stratigraphy (UJIIÉ, 1963), the Neogene can be divided into two major sedimentary basins, separated from each other by a significant unconformity. The older one is represented by the Mikasa Group (UJIIÉ, 1958; 1963) of Early Miocene (the *Catapsydrax dissimilis* Zone through the *Globigerinatellia insueta/Globigerinoides bisphericus* Zone of SAITO, 1960, or N. 5 through N. 8 of BLOW's division), whereas the younger one is represented by the Sagara and Kakegawa Groups. MAKIYAMA (1941 et seq.) assigned the age of the Sagara Group to the late to middle Miocene and that of the Kakegawa to the Pliocene, and considered that the two groups are bounded by a distinct clino-unconformity. However, a thoroughgoing field work (UJIIÉ, 1963) revealed that the two groups are continuous in sedimentary process as well as in geologic structure on the whole, even though a local unconformable relation may be inferred in the northern part of the boundary. Thus, the gap between the Sagara Group and the Mikasa Group became much more significant for the geologic development of this region than that between the Sagara Group and the Kakegawa Group, as pointed out previously (UJIIÉ, 1958).

As a standard stage of the Japanese Late Miocene MAKIYAMA (1941 et seq.) proposed the Yuian on the basis of the molluscan fauna of the Sagara Group. But these molluscan fossils are almost restricted to a few localities of the uppermost horizons, and they are represented only by a few species of scarce and poorly preserved specimens. On the other hand, marine microfossils such as Foraminifera may prove useful to establish reliable biostratigraphic divisions because the Sagara Group regularly contains microfossil-bearing mudstone, the condition of which continues up to the Kakegawa Group, constituting a very thick marine sequence. Accordingly, ODA (1971) tried the planktonic foraminiferal zoning of the Sagara Group. He assigned the Sagara Formation, the principal member of the group, to Late Miocene ranging from N. 16 to N. 19 of BLOW (1969). Unfortunately, however, his faunal succession was compiled with the data obtained from three routes of sampling which are far apart from one another both geographically and stratigraphically (see Fig. 1 and text). We believe that a standard succession of stratigraphy ought to be established with data of a single route if possible. Another problem in ODA's paper is that it has a character of a preliminary report. He showed merely the SEM micrographs of some selected taxa without any taxonomic descriptions or comments. Besides, his selection of specimens for illustration was quite inadequate because any figure of age-determinant taxon was not represented by a specimen picked out from a decisive horizon, namely, near the taxon's initial appearance datum nor its last one. In other words, he failed to demonstrate the taxon's initial appearance nor its last. Moreover, his illustrations might bring about a few mis-identifications that would make his taxonomy doubtful.

In the present paper, we intend to show the planktonic foraminiferal zonation we carried out with a continuous section of the Sagara Formation. The remarkable continuity of outcrops along the section is not expected in the other routes of this region. The zonation reveals that the formation represents the planktonic foraminiferal zones of upper N. 14 through N. 18 (late Middle to Late Miocene) and N. 19 (Early Pliocene) of BLOW (1969). The superjacent Kakegawa Group may be of N. 21 and later zones, while the subjacent Sugegaya Alternation of the Sagara Group may include lower part of N. 14.

Here we briefly report the result of zonation together with documentation of fundamental data (i.e., field data and detailed occurrence chart) and with illustration of some critical taxa. Although several taxonomic comments are added, the comprehensive systematics will be given later when our serial work on the post Middle Miocene planktonic Foraminifera in the western North Pacific region has been completed.

Geologic Setting of the Sections Studied

Previously UJIIÉ (1963) published a detailed paper on the general geology and lithologic stratigraphy of the Sagara Group and the Kakegawa Group which includes the Pleistocene Ogasayama Conglomerate; the two groups are exposed over the whole area of a sedimentary unit, about 25 × 35 km. He called this unit the Sagara-Kakegawa Sedimentary Basin because of the continuity of sedimentary process and of structural development. Around the lower, or eastern, margin of the Basin the Sagara Group shows the northeast-southwest general trend of structures, among which the Megami Anticline is the most prominent feature. As a core of this southwesterly plunging anticline, we can recognize an isolated block of the Megami Formation. The formation may be equivalent to the upper part of the Mikasa Group since it includes several

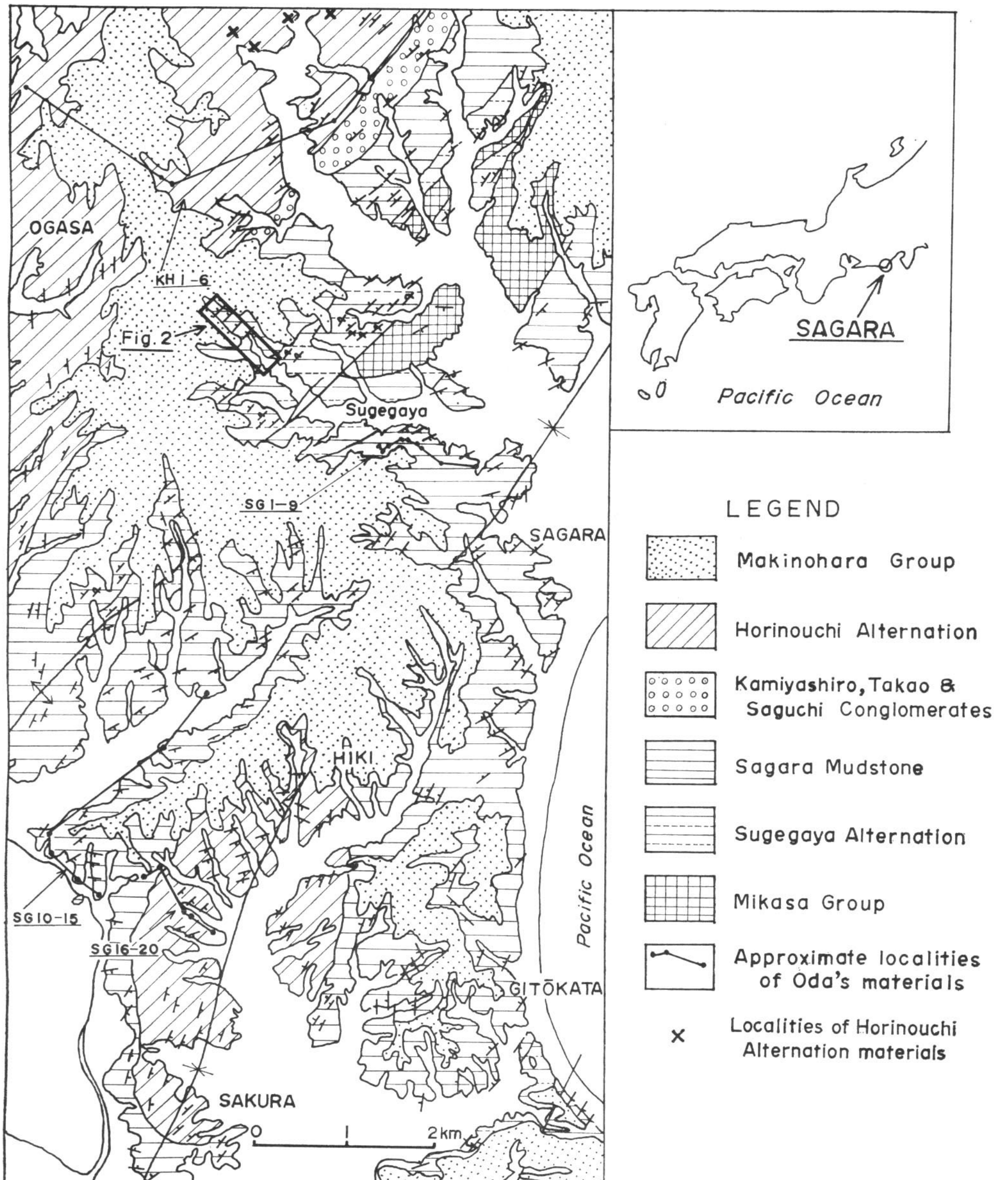

Fig. 1. Location map and geologic map (adopted from UJIIÉ, 1963).
Also indicated here is the location of ODA's (1971) samples from three different routes far apart from one another; particularly, those of the Sagara Formation were located in the southeastern limb of the Megami Anticline so that their stratigraphic positions in relation to the overlying Horinouchi Alternation are obscure.

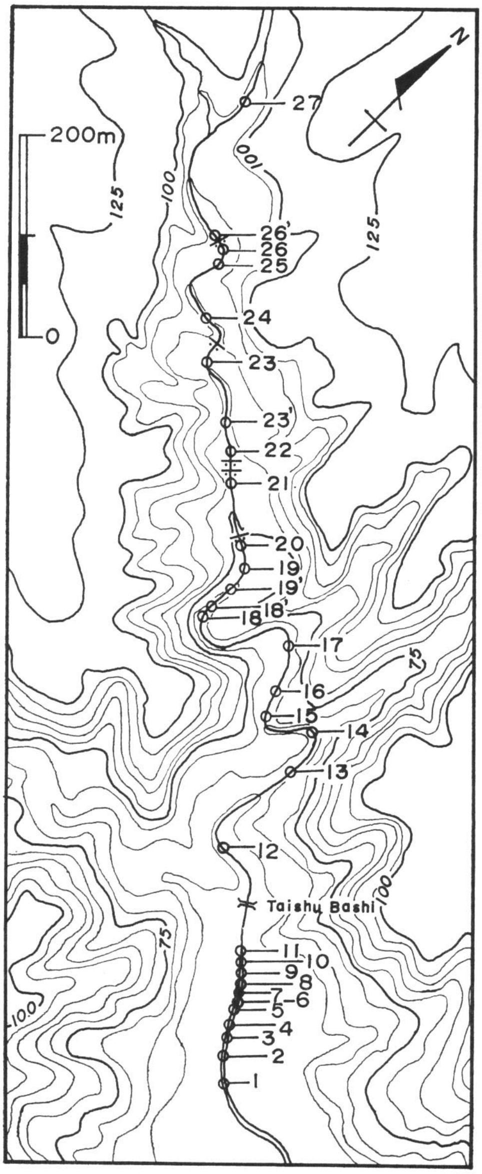

Fig. 2. Location map of the samples studied here along the Shinden-gawa, Sugegaya, Sagara-machi.

blocks of *Lepidocyclina japonica*-bearing limestone and a planktonic Foraminifera bearing mudstone (UJIIÉ, 1975b) which belongs to the *"Globigerinatella insueta/Globigerinoides bisphericus* Zone" of Saito (1960).

Around the southwesterly dipping Megami Formation, the Sugegaya Alternation is developed as the lower component of the Sagara Group. The Sugegaya consists of the strata grading from conglomeratic sandstone or very coarse-grained sandstone into siltstone upward. The psammitic layers are thicker and coarser in the lower horizons in general. Reflecting this lithology, the pelitic layers seldom contain planktonic Foraminifera, but commonly bear agglutinated Foraminifera such as *Haplophragmoides, Trochammina* and *Martinotiella,* which are found even in fresh samples from some new road cuttings under construction. The present foraminiferal fauna suggests a probably anoxic environment which is unfavorable for planktonic forms, agreeing with the lithofacies. The lithology also suggests a much faster deposition rate than that for the Sagara Formation.

The Sagara Formation conformably overlying the Sugegaya Alternation is composed mainly of argillaceous rocks frequently intercalated with layers of sandstone. Unless the weatherning has much advanced as is very common in this region, the Sagara Formation yields abundant planktonic Foraminifera being potential for the zonation.

The Sagara Formation rather conformably underlies the Horinouchi Alternation of the Kakegawa Group in the northwestern limb of the Megami Anticline. Although the Horinouchi is potential for planktonic foraminiferal zonation, the continuity from the Sagara to the Horinouchi

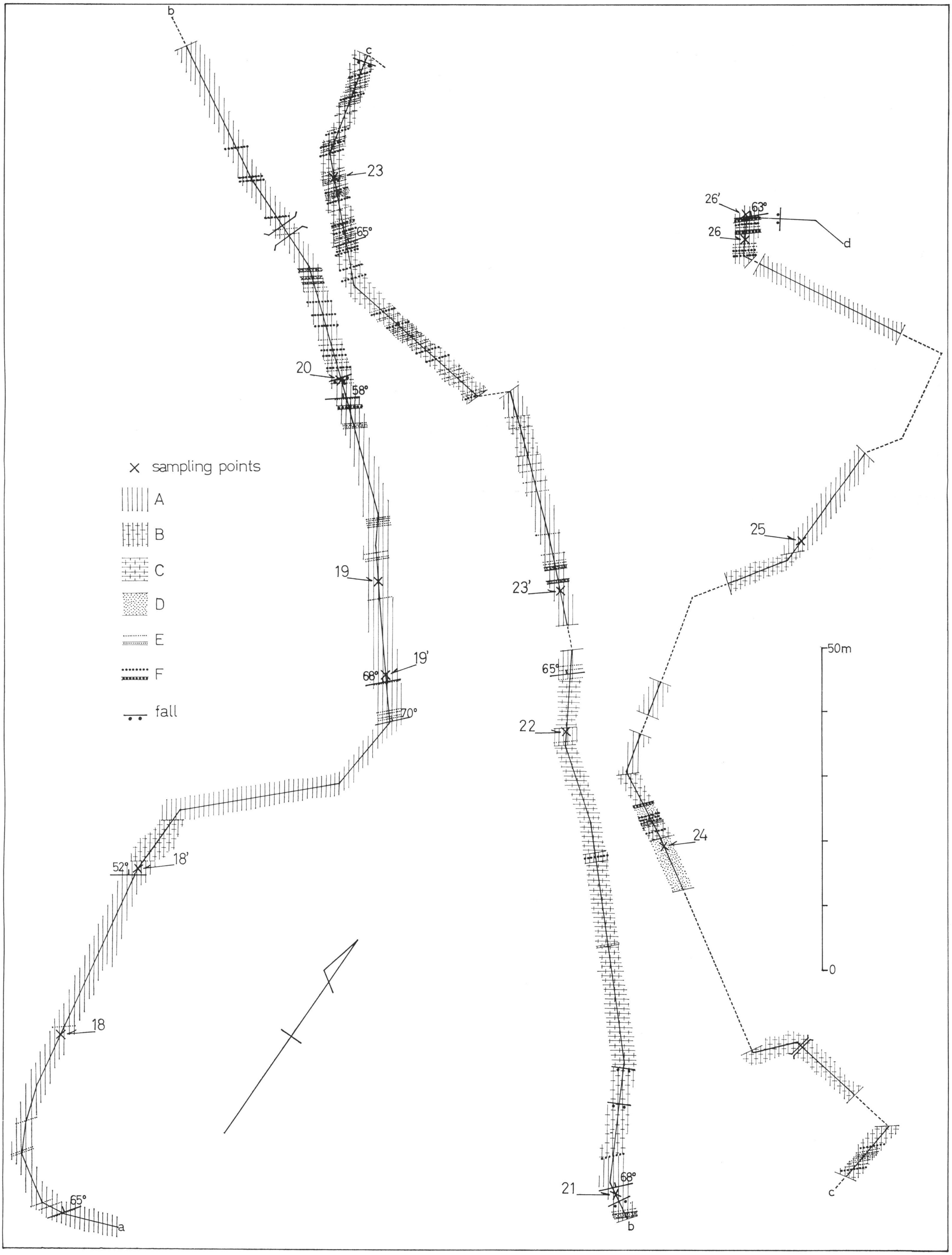

Fig. 3. Route map along the upper reaches of the Shinden-gawa.
A: massive siltstone; B: laminated siltstone; C: siltstone-rich alternation; D: alternation of laminated siltstone and sandstone frequently containing glauconitic sands to granules; E: laminated sandstone; F: thin sandstone layers; G: irregular layers of glauconitic sands to granules.

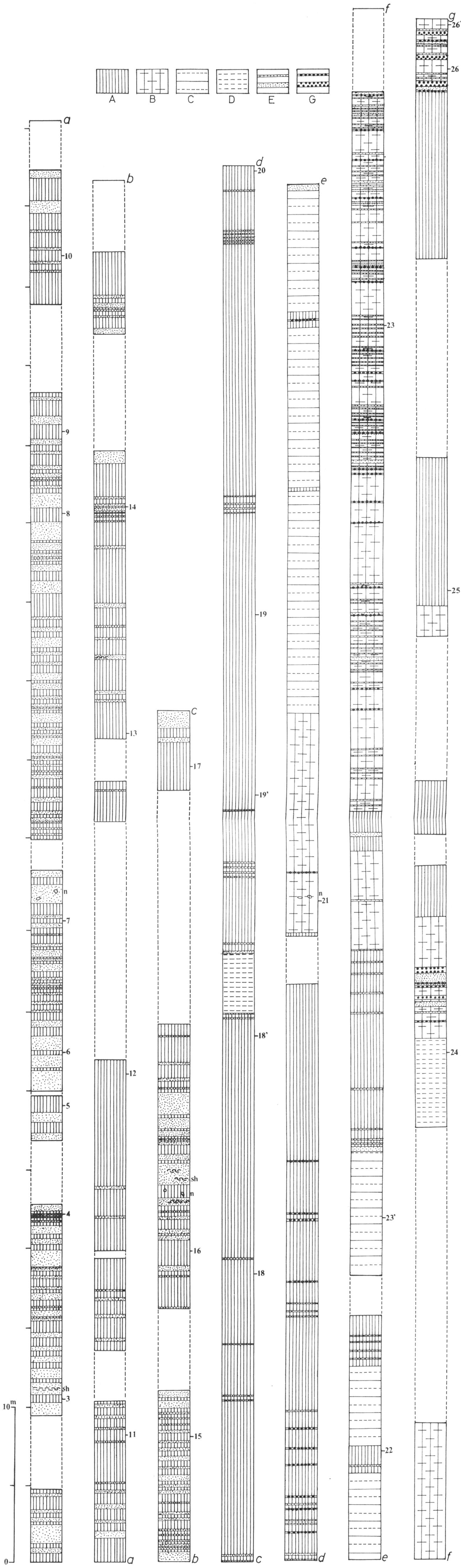

Fig. 4. Columnar section along the Shinden-gawa, also indicating the sampling horizons. Samples 1 and 2 are stratigraphically above 45 m and 19 m below Sample 3, respectively, and Sample 27 about 120 m above Sample 26′.
A: massive siltstone; B: laminated siltstone; C: siltstone-rich alternation; E: laminated sandstone; F: rather massive sandstone; G: glauconitic sandstone layers.

is interrupted by the insertion of the Saguchi and Takao Conglomerates (top conglomerate members of the Sagara Formation) and the Kamiyashiro Conglomerate (basal and/or marginal conglomerate member of the Horinouchi), particularly around the northern part of the boundary.

The section treated here exposes its uppermost portion (Loc. 27 of Fig. 2) which may be very close to the boundary, judging from the general trend of strike and from the frequent insertion of conglomeratic sandstone seams commonly containing glauconite, instead of conglomeratic members, although the contact with the Horinouchi cannot be ascertained because of the covering Pleistocene terrace deposits, the Makinohara Group. The section is chosen along the Shinden-gawa as the type section of the Sagara Formation since it is thickest here (ca. 620 m) and most continuous in exposure, showing the very contact with the underlying Sugegaya Alternation, type locality of which is in this area. Fig. 2 shows sampling points along the section on the originally 1/10,000 scale map. Fig. 3 is a columnar section of the major part; the column was compiled with a direct measurement of strata in field for the lower one-third and a route map (Fig. 4) of 1/500 scale for the upper two-thirds.

Treatment of Materials

Several hundred kilograms of every dried rock-sample were first crushed with a jaw crusher and sieved through a 1 mm screen in dry condition. Each 100 gr. of the crushed sample finer than 1 mm in diameter was treated by the maceration method of Maiya and Inoue (1937) but in a somewhat simplified and modified way; immediately after the 100 gr. sample was heated under an infrared lamp of 250 watts for about one hour, it was soaked with petroleum benzene and then left at room temperature for about one hour; thereafter, it was added with two or three tea-spoonfuls of sodium hexametaphosphate and, after about one hour it was boiled with water for twenty to thirty minutes. The material thus macerated was sieved through a 200 m mesh screen under water shower. The residue on the screen was sieved again with a 100 mesh screen in dry condition. From the fraction coarser than 100 mesh, well preserved 200-odd specimens of planktonic Foraminifera per sample were picked out under a binocular microscope. A total of 200-odd specimens give the minimum but sufficient amount for the faunal analysis on the statistical basis. In this work, remarkably deformed specimens were encountered so frequently that before we could get the sufficient number of well-preserved specimens a total of picked-up individuals largely exceeded 200 in many cases.

Planktonic Foraminiferal Zonation

Of the total 31 samples treated here, 21 samples were thoroughly analyzed about their planktonic foraminiferal faunas as shown in Table 1. The faunas of the remnant 14 samples were inadequate for the analysis because of their scantiness and/or of high concentration of deformed specimens. On the whole, the deformed shells are so fre-

Table 1.

	AGE	Mid. Mioc.						Upper Miocene										Lower Pliocene				
	PLANKTONIC FORAMINIFERAL ZONES INBLOW'S SENSE	N. 14	N. 15					N. 16			?	N. 17				?	N. 18	N. 19				
	SAMPLE NOS.	3	5	7	8	9	10	11	12	14	15	16	17	18	18′	19	20	21	22	23′	25	27
1	*Globigerina bulloides* D'ORBIGNY									1	7	12		2	8				5	6	2	2?
2	*Globigerina decoraperta* TAKAYANAGI & SAITO	16	15	60	12	10	6	12	15	3	16	11	13	8	8	24	20	8	7	11	6	4
3	*Globigerina nepenthes nepenthes* TODD	7	6	27			5	5	4	3	5	6		9			12	5	1			
4	*Globigerina nepenthes delicatula* BRÖNNIMANN & RESIG	2					2								3							
5	*Globigerina falconensis* BLOW	1	12	2	8	18	13	5	8	14	17	11	30	7	33	13	9	14	3	11	28	17
6	*Globigerina* cf. *foliata* BOLLI, and its var.	19	26	10	19	15	35	14	26	25	27	32	63	14	38	29	25	79	76	12	81	45
7	*Globigerina* cf. *conglomerata* SCHWAGER																		2	1?		
8	*Globigerina* aff. *parabulloides* BLOW	5				8	5			2						3	5	22	18		9	3
9	*Globigerina* sp. A							1				1			1				2?			
10	*Globigerina* sp. B	3								1		2				2					1	
11	*Globigerina* spp.	2	1	3	1	4	2	2	1	12	2	6					2				4	2
12	"*Globigerina*" *quinqueloba* NATLAND		1?												1	1		2		1?		
13	*Globigerina* ? sp. A					1		5	1	37	2	12	24	41	16	51	12		3		5	13
14	*Globigerina* ? sp. B						3			1			1									
15	*Globigerinoides emeisi* BOLLI	8	8	9	7	32	1	5		6				2	3		3	6	2	13		
16	*Globigerinoides extremus* BOLLI & BERMÚDEZ, and var.	7			9	5				1	11	1?	7		11		6	1		1	3	
17	*Globigerinoides obliquus* BOLLI		37	26	44	8	8	8	5		8	4	3	8	6	21	7	8	13	7	12	1
18	*Globigerinoides* aff. *japonicus* SAITO & MAIYA										23	10			1					15		
19	*Globigerinoides* aff. *japonicus* SAITO & MAIYA, var.	1?	6?												4					11		
20	*Globigerinoides quadrilobatus quadrilobatus* (D'ORBIGNY)	3?	4	5	7						5							1	2	5		

SAMPLE NOS.	3	5	7	8	9	10	11	12	14	15	16	17	18	18′	19	20	21	22	23′	25	27
21 *Globigerinoides quadrilobatus immaturus* LeRoy	48	9	44	27	12	16	30	15	19	42	18	14	7	33	15	7	7	5	59	3	3
22 *Globigerinoides* cf. *quadrilobatus trilobus* (Reuss)					1	4		1			2	1	2		3					1	
23 *Globigerinoides ruber* (d'Orbigny)	2	1?	6	2			1?				3							1			
24 *Globigerinoides* cf. *conglobatus canimarensis* Bermúdez	1?								2	1		1									
25 *Globigerinoides* aff. *tenellus* Parker								2						3							
26 *Globigerinoides* spp.	4	5	6												1				3		
27 *Globigerinita glutinata* (Egger)	33	51	31	34	50	73	74	93	27	19	13	29	6	57	13	15	13	7	31	21	4
28 *Globigerinita* aff. *glutinata* (Egger)	1	2	4					1	2	2				3					5	1	1
29 *Orbulina universa universa* d'Orbigny	14	6	17		2	1	2		6	7	1	4	4	1		5	4		11	2	
30 *Orbulina universa suturalis* Brönnimann	7								1					6							
31 *Orbulina parkerae* Brönnimann & Resig												1		1							
32 "Naked *Sphaeroidinella*" sp.		1							1					1				1	1		
33 *Sphaeroidinellopsis seminulina kochi* (Caudri)										2											
34 *Sphaeroidinellopsis seminulina seminulina* (Schwager)				2			1?		1										1		
35 *Sphaeroidinellopsis subdehiscens subdehiscens* (Blow)	1	5	11	13	5	8	14	11	8	13	12	15	6	1	7	5	3	7	45	12	1
36 *Sphaeroidinellopsis subdehiscens panaedehiscens* Blow															2	1					
37 *Sphaeroidinella dehiscens immatura* (Cushman)															1?		+	+	+		
38 *Globoquadrina altispira* (Cushman & Jarvis)	2	2	2	2	6		4	4		1	2	1?		2			1?	1	1		1
39 *Globoquadrina globosa* Bolli	1?	3	1?	2?			1?							2					2?		
40 *Globoquadrina dehiscens advena* Bermúdez	2	8	1	1		5		1						3							
41 *Globoquadrina dehiscens dehiscens* (Chapman, Parr & Collins)	1	5		1?	2		2	7	1		1?			2							
42 *Globoquadrina larmeui* Akers				2		1															
43 *Globoquadrina* aff. *obesa* Akers							1?	1	2				7								3?

	SAMPLE NOS.	3	5	7	8	9	10	11	12	14	15	16	17	18	18′	19	20	21	22	23′	25	27
44	*Globoquadrina* ? sp. A	1	2	2		4?				16		20		9	4	5	3	1	5	1?	8?	24
45	*Globoquadrina* ? sp. B	1	3	2	6		3	6	1?	4		3	4	35			2	2	1			10
46	*Globorotalia* (*Turborotalia*) *acostaensis acostaensis* BLOW							31	3			38	6	26	12	14	40	35	35	9	9	32
47	*Globorotalia* (*Turborotalia*) *acostaensis pseudopima* BLOW							1						1		1		3				2
48	*Globorotalia* (*Turborotalia*) *acostaensis humerosa* TAKAYANAGI & SAITO												5	2	2	8	1		4	1	13	
49	*Globorotalia* (*Turborotalia*) cf. *continuosa* BLOW		5																			
50	*Globorotalia* (*Turborotalia*) ? *pachyderma* (EHRENBERG)													28		5	23		35		10	3
51	*Globorotalia* (*Turborotalia*) ? *obesa* BOLLI					1			3					2	1			1				
52	*Globorotalia* (*Turborotalia*) *scitula scitula* (BRADY)	3				1?	1	1?		1	1		1?		1					5		
53	*Globorotalia* (*Turborotalia*) *lenguaensis* BOLLI			3		1	1			4	2											
54	*Globorotalia* (*Turborotalia*) cf. *inflata* (D'ORBIGNY)													1	2							
55	*Globorotalia* (*Turborotalia*) *siakensis* LEROY	5				1?																
56	*Globorotalia* (*Turborotalia*) aff. *peripheroacuta* BANNER & BLOW	5		4																		
57	*Globorotalia* (*Turborotalia*) ? aff. *hexagona* (NATLAND)																			3		
58	*Globorotalia* (*Turborotalia*) sp.								1?								1			1		
59	*Globorotalia* (*Globorotalia*) *cultrata cultrata* (D'ORBIGNY)	2	1	2		2?				1	2				7	2		1	2	3	2	
60	*Globorotalia* (*Globorotalia*) cf. *cultrata exilis* BLOW		3				4?	2								1	1					
61	*Globorotalia* (*Globorotalia*) aff. *miocenica* PALMER	1									3											
62	*Globorotalia* (*Globorotalia*) *margaritae* BOLLI & BERMÚDEZ	3?																	3			

	SAMPLE NOS.	3	5	7	8	9	10	11	12	14	15	16	17	18	18′	19	20	21	22	23′	25	27
63	*Globorotalia* (*Globorotalia*) *cibaoensis* BERMÚDEZ	5		3	1?		10															
64	*Globorotalia* (*Globorotalia*) aff. *cibaoensis* BERMÚDEZ										16	5		2?		2?	3?		3	2		
65	*Globorotalia* (*Globorotalia*) *sphericomiozea* WALTERS																					8
66	*Globorotalia* (*Globorotalia*) *tumida tumida* (BRADY)																3?	1			1	
67	*Globorotalia* (*Globorotalia*) *tumida plesiotumida* BANNER & BLOW											1					1?					
68	*Globorotalia* (*Globorotalia*) sp. A			6	2																	
69	*Globorotalia* (*Globorotalia*) spp.	1	1		2	1	2				2											
70	*Globorotalia* ? spp.		4	1	1	2		1				1	1			1			1			8
71	*Globigerinella siphonifera* (D'ORBIGNY)	3		5			1		2		3		3?		4			2			1	
72	*Globigerinella* sp.			1	2													3				
73	*Pulleniatina* ? sp.						3?	2	7									1				
74	Gen. et sp. indet.—deformed specimens	9	16		18	27	24	53	15	39	41	7	12	30	11	7	14	26	11	4	14	38
	TOTAL NUMBER OF SPECIMENS	230	251	296	225	229	237	284	228	241	280	235	239	259	292	232	223	250	259	279	249	225

quently contained even in the 21 samples analyzed here (see Table 1, bottom line) that they may be ascribed, at least in part, to the crustal movement which produced the Megami Anticline and associated structures. Of 5,243 specimens picked out from the 21 samples, 416 specimens were not identified due to the remarkable deformation of tests.

The remainder 4,827 specimens were classified in detail as far as possible, on the basis of the rather superficial morphology. Thus 69 taxa were discriminated, including a considerable number of taxa which might be invalid for the code of nomenclature. This taxonomic problem should be solved when the serial work on the western North Pacific materials has been accomplished.

We applied tentatively BLOW's scheme (1969) to the planktonic foraminiferal zoning of the Sagara Formation, like we did previously as part of the serial work (UJIIÉ and MIURA, 1971; UJIIÉ and SAMATA, 1973; UJIIÉ and OKI, 1974; UJIIÉ, 1975a).

Since *Sphaeroidinellopsis subdehiscens panaedehiscens* BLOW was found among the respective 200-odd specimens from Samples 19 and 20, we added the amount of rock materials of Samples 18′, 19, 20, 21, 22 and 23′, until it attains to about 1 kg in weight to look for *Sphaeroidinella dehiscens immatura* (CUSHMAN), and then recovered this descendant subspecies from Samples 21, 22 where it is particularly common, and 23′ (see Plate 1, figs. 4–7). According to BLOW's (1969) definition, therefore, the base of N. 19 can be placed between Samples 20 and 21 where the initial appearance of *S. dehiscens immatura* is supposed. ODA (1971) erroneously placed this datum plane near the boundary of the Sagara and Kakegawa Groups. At the same time, ODA reported the first occurrence of *Globorotalia* (*Turborotalia*) *tosaensis* TAKAYANAGI and SAITO from his lowermost Horinouchi sample (KH 3). But we found that the species also occurs in the other sample (KH 5) and in four samples of the Horinouchi taken from the horizons higher than ODA's localities. The location of the latter four samples is indicated by × in Fig. 1. Giving the superiority to the "initial appearance" of *S. dehiscens immatura* than that of *G.* (*T.*) *tosaensis* at the boundary of the two groups, ODA (1971) placed the N. 18/N. 19 boundary at the base of the Horinouchi and, consequently, he thought that *G.* (*T.*) *tosaensis* appeared there at the earlier time than previously reported. However, when the true initial appearance of *S. dehiscens immatura* is located within the Sagara Formation as revealed in this work, the *G.* (*T.*) *tosaensis* datum plane, probably at the top of the Sagara Group, must indicate the base of N. 21, agreeing with the original definition of BLOW (1969). N. 20 may be doubtful in its presence or, if presents, it may be of a short range because the initial appearance of *Globorotalia* (*Turborotalia*) *acostaensis pseudopima* BLOW defining the base of N. 20 has been observed in a much older age in many instances of the western North Pacific (BRÖNNIMANN and RESIG, 1971; UJIIÉ and SAMATA, 1973; UJIIÉ and OKI, 1974; UJIIÉ, 1975a) as well as in the Sagara Formation, where it seems to be located around the base of N. 16 (see Table 1).

Substantiating the above zonation, *Globigerina nepenthes* TODD disappeared between Samples 22 and 23′, that is, in the middle of N. 19 defined here. This extinction datum was proposed as the criterion subdividing the Lower Pliocene (=N. 19) by BERGGREN and VAN COUVERING (1973) and has been noticed in many places of the world (e.g., PARKER, 1967; BRÖNNIMANN and RESIG, 1971; UJIIÉ and SAMATA, 1971; UJIIÉ, 1975a). It seems that ODA (1971) reported a similar occurrence of the species. But we have excluded, from consideration, the single specimen reported by ODA from his Sample KH–5 of the lower Horinouchi Alternation, regarding it as a reworked specimen from the underlying strata. His *Globigerina vignalii* BERMÚDEZ and BOLLI found throughout the Sagara Formation might be *G. nepenthes* because his figure (Pl. 1, fig. 2) closely resembles a specimen without an aberrant last chamber of the latter species, especially when compared with similar specimens from the type locality of *G. nepenthes* shown by SAITO (1962; Pl. 52, fig. 2).

Therefore, the upper part of the Sagara Formation came to include the lower Pliocene, different from the previous ideas (e.g., CHITANI, 1929; MAKIYAMA, 1941 et seq.; SAITO, 1963; ODA, 1971). This age assignment might be supported by the occurrence of typical *Globorotalia* (*Globorotalia*) *margaritae* BOLLI and BERMÚDEZ from N. 19 (Sample 22 of this paper and ODA's Sample SG–28, figs. 1 and 2 of his Plate 2). BOLLI has emphasized a role of the biozone of *G.* (*G.*) *margaritae* which was restricted within the lower Pliocene since 1966, although there are some discrepancies in the detailed range between his data and BLOW's (1969) or UJIIÉ's (e.g., UJIIÉ and MIURA, 1971) data, probably owing to different views on taxonomy and/or to different regions studied. At least the ancestral forms of the species may go back to the age beyond the basal Pliocene, differing from the Caribbean and Mediterranean regions (e.g., BOLLI, 1970; LAMB and BEARD, 1972).

The lower boundary of N. 18 could not be precisely determined in the Sagara Formation because we seldom found *Globorotalia* (*Globorotalia*) *tumida tumida* (BRADY), initial appearance of which defines the boundary according to BLOW (1969). At a glance of Table 1, the species appeared first in Sample 20, namely, slightly below the base of N. 19. Nearly simultaneous appearances of *G.* (*G.*) *tumida tumida* and *Sphaeroidinella dehiscens immatura* were recognized at Sites 292 and 296 of the Deep Sea Drilling Project Leg 31 in the Philippine Sea. Differing from these Sites, the Sagara Formation yields, though rarely, *Globorotalia* (*Globorotalia*) *tumida plesiotumida*, direct ancestor of *G.* (*G.*) *tumida tumida*. Though ODA (1971) reported the initial appearance of the former subspecies in the middle of the Sagara Formation as the indication of the base of N. 17, his specific identification cannot be justified so far as his specimen figured (Pl. 1, figs. 11 and 12) is concerned; the specimen from his Sample SG–17 in the upper Sagara Formation (i.e., N. 19) is regarded undoubtedly as *G.* (*G.*) *tumida tumida*. When we follow BERGGREN and VAN COUVERING (1973, 1974), it may be possible that only Sample 20 represents N. 18 because of the very short duration of the zone, that is, within an error of radiometric measurements according to our opinion. The present position of N. 18 base is approximately compatible with the extinction datum of *Globoquadrina dehiscens* (CHAPMAN, PARR and COLLINS) between Samples 18′ and 19. BERGGREN and VAN COUVERING (1973, 1974) considered it as the datum plane around the Miocene-Pliocene boundary, i.e., around the base of N. 18.

However, we still intend to place the Miocene-Pliocene boundary at the base of N. 19 agreeing with BLOW (1969) on the basis of our previous discussion (UJIIÉ and OKI, 1974). In the discussion we failed to refer to the latest opinion of BERGGREN (1973) about the upper limit of the type Messinian (Late Miocene stage) because of the date of publication, but even after we have read his paper it necessitates no change in our view. His argument seems to depend largely upon the radiometric data rather than upon the field data or new observation of the foraminiferal faunas. At any rate, in the case of the Sagara Formation, it would be more practical and easier to set the base of Pliocene at the base of N. 19 than that of N. 18.

The lower boundary of N. 17 is also obscure owing to scantiness of the marker, *Globorotalia* (*Globorotalia*) *tumida plesiotumida*. A rather typical specimen was recovered from Sample 16 (Pl. 3, fig. 6), so the N. 17–N. 16 boundary is tentatively placed between Samples 16 and 15. This zonation involves an incompatible occurrence of *Globorotalia* (*Turborotalia*) *lenguaensis* BOLLI which is restricted below the boundary; BLOW (1969) stated that this globorotalid disappears near the top of N. 17.

Globorotalia (*Turborotalia*) *acostaensis acostaensis* BLOW occurs almost always above Sample 10 but not below Sample 9. Therefore, the base of N. 16 will be inferred between Samples 10 and 11, by accepting the appearance of the species as its true initial appearance, even though the so-called ancestral taxon, *G.* (*T.*) *continuosa* BLOW, can hardly be recovered from the Sagara Group. As is in this case, the similar "first appearance" of *G.* (*T.*) *acostaensis* was recognized at Sites 292 and 296 of DSDP Leg 31 (UJIIÉ, 1975a).

Top of N. 14 can be defined by the extinction datum of *Globorotalia* (*Turborotalia*) *siakensis* LEROY between Samples 3 and 5 by the definition.

In conclusion, we presumed that the Sagara Formation consists of six planktonic foraminiferal zones of BLOW (1969), namely, N. 19 (Early Pliocene), N. 18 through N. 15 (Late to Middle Miocene), and N. 14 (late Middle Miocene), whereas ODA (1971) distinguished only three (N. 18 to N. 16) for the approximately same interval of the Formation, lowermost portion of which is absent there as can be inferred in Fig. 1. In addition to some problems pointed out already, the portion representing N. 18 of ODA appears to be contradictorily thick and his N. 17 to be contrastively thin.

According to our zoning, N. 14 seems to represent the whole Sugegaya Alternation, about 600 m thick. This great thickness in comparison with the time duration may be ascribed to faster deposition of sediments. Much more contrastive time/thickness ratio will be expected for the Horinouchi Alternation of the Kakegawa Group, if we compile the results of planktonic foraminiferal zonation for the Group (MOROZUMI, 1972; KATO, 1973) after some correction of their data, and for the Sagara Formation indicated herein. About 1,900 m of the whole thickness of the Horinouchi Alternation may be represented by only a single zone, N. 21 of the Upper Pliocene; the time duration is estimated as about 1.2 m.y. on the scale of BERGGREN (1972 et seq.).

Interesting Occurrence of Some Taxa

From the standpoint of the zonation proposed above, we noticed some interesting occurrences of several taxa.

Dextral specimens of *Globorotalia* (*Turborotalia*)? *pachyderma* (EHRENBERG) appeared first at the middle of N. 17 and then became rather common upward. A cooling climate in the late Miocene time suggested by this species has not been recognized in the Philippine Sea and its adjacent land sections by UJIIÉ, but there are reports of occurrence of this species in the Miyazaki Group, southern Kyushu ("N. 18" to "N. 19", HUANG, 1971, as *Globigerina pachyderma*), in the Somachi Formation, Kikai-jima, Ryukyu Islands (HUANG, 1966, as *G. pachyderma*), and in an oil well on the western coast of Taiwan (HUANG, 1963, as *G. pachyderma*). The latter two cases leave a room for reconsideration, judging from our experience with the Miyako-jima materials of the Ryukyu Islands (UJIIÉ and OKI, 1974), in which no specimen of the species was encountered.

The cooling starting from the middle of N. 17 might be substantiated by the occurrence of "*Globigerina*" *quinqueloba* NATLAND, which became common after the first appearance in Sample 18′.

A few individuals referable to *Globorotalia* (*Turborotalia*) *inflata* (D'ORBIGNY) were found in the middle portion of N. 17 (Samples 18 and 18′) of the age distinctly earlier than the previous cases reported from the south of the Sagara region. Although these specimens are small and scarce, such an earlier occurrence might reflect the geographic position and the cooling climate. A number of typical specimens begin to occur rather abundantly from the lowermost portion of the Horinouchi Alternation (N. 21) upward. The same tendency has been recognized in Miyako-jima, Ryukyu Islands (UJIIÉ and OKI, 1974), in a piston core (UJIIÉ and MIURA, 1971) and at DSDP Site 296 both from the northern Philippine Sea.

Another interesting species probably of temperate water is *Globigerinoides japonicus* SAITO and MAIYA. The species has been recognized in the lowermost Middle Miocene (N. 9) on the Sea of Japan coast, i.e., in the Nishikurosawa Formation of the Oga Peninsula by the original authors (SAITO and MAIYA, 1973), and as a variation of *Globigerina woodi* JENKINS in the Nakanami Formation of the Noto Peninsula by UJIIÉ and HATSUKARI (1973). In the Middle Miocene time the climate may have been warmer than the present time but the coast was still under some influence of temperate water. It must be noted that a taxon resembling this species, though we have little knowledge of its geologic range and geographic distribution, was here recovered from the younger horizons and from the Pacific coast. In the Sagara materials, however, rather typical forms with a primary aperture opened at the junction of the last four chambers are always rather small in test size, while a variation with the aperture opened at the junction of the three chambers has a large-size test, as exemplified in Plate 1.

Three taxa to be mentioned lastly may belong to a single evolutionary lineage from

Globorotalia (*Globorotalia*) *cibaoensis* BERMÚDEZ (N. 14 and N. 15), through *G.* (*G.*) aff. *cibaoensis* (N. 16 to N. 19), to *G.* (*G.*) *sphericomiozae* WALTERS (Sample 27 of the top N. 19) (see Pl. 2, figs. 1–6, for morphologic change). This suggested lineage is homeomorphic with and nearly parallel to such lineage from *G.* (*G.*) *miozea* FINLAY (N. 7 to N. 15) through *G.* (*G.*) *conoidea* WALTERS (N. 14 to N. 19), to *G.* (*G.*) *sphericomiozea* (upper N. 17 to N. 19) as proposed first by WALTERS (1965) with the New Zealand materials, and later emended, particularly about their ranges (indicated in parentheses), by BERGGREN and AMDURER (1973) using the Atlantic Ocean materials. Although *G.* (*G.*) *miozea* described first from New Zealand might be a senior synonym of *G.* (*G.*) *cibaoensis* from the Caribbean region, we applied the latter species name to our specimens because we could strictly compare them with the topotypic materials of *G.* (*G.*) *cibaoensis* which were kindly sent to the senior author (H.U.) by P. BERMÚDEZ, but we were unable to do the same with those of *G.* (*G.*) *miozea*. On the other hand, *G.* (*G.*) aff. *cibaoensis* from the Sagara Formation may be an independent new taxon as discussed previously (UJIIÉ and OKI, 1974).

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Explanation of Plates

(All figures ×70; a: spiral view, b: umbilical view, c: edge and apertural view)

Plate 1

Fig. 1. *Globigerinoides* aff. *japonicus* SAITO & MAIYA, var.
A variation with the primary aperture opened at the junction of the last two chambers; from Sample 23′; Micropaleontology Collection, Natn. Sci. Mus. 866.

Fig. 2. *Globigerinoides* aff. *japonicus* SAITO & MAIYA
Rather typical but small specimen with the primary aperture opened at the junction of the last three chambers; from Sample 23′; Micropal. Coll. N.S.M. 865.

Figs. 3, 8. *Sphaeroidinellopsis subdehiscens panaedehiscens* BLOW
Both specimens with a rather large primary aperture bound by somewhat upturned margin but, differing from *Sphaeroidinellopsis sphaeroides* LAMB shown by LAMB and BEARD (1972), without the spherical shape of test; from Sample 20; Micropal. Coll. N.S.M. 868 and 867, respectively.

Figs. 4–7. *Sphaeroidinella dehiscens immatura* (CUSHMAN)
Examples provided with a slightly developed supplementary aperture on the spiral side; all specimens from the additional materials; 5: from Sample 22, Micropal. Coll. N.S.M. 869; 4, 6 and 7: from Sample 23′, Micropal. Coll. N.S.M. 870, 871 and 872, respectively.

Plate 2

Figs. 1, 2. *Globorotalia* (*Globorotalia*) *cibaoensis* BERMÚDEZ
1: an adult specimen with a very weakly developed marginal keel; 2: a young form; both from Sample 10; Micropal. Coll. N.S.M. 873 and 874, respectively.

Figs. 3–5. *Globorotalia* (*Globorotalia*) aff. *cibaoensis* BERMÚDEZ
3: a specimen somewhat similar to typical *G.* (*G.*) *cibaoensis*; 4: an adult specimen typical of this probably new species; 5: a young form somewhat resembling *G.* (*G.*) *sphericomiozea*; all from Sample 15; Micropal. Coll. N.S.M. 875, 876 and 877, respectively.

Fig. 6. *Globorotalia* (*Globorotalia*) *sphericomiozea* WALTERS
From Sample 27, Micropal. Coll. N.S.M. 878.

Plate 3

Fig. 1. *Globoquadrina*? sp. B.
A taxon frequently encountered in the Sagara Formation; in the general arrangement of chambers and in the coarsely and regularly pitted surface, this species resembles a young form of some unknown *Globoquadrina* species, although the primary aperture is still umbilical and the umbilical teeth not yet developed; from Sample 16; Micropal. Coll. N.S.M. 879.

Fig. 2. *Globorotalia* (*Turborotalia*) *acostaensis tegiilata* BRÖNNIMANN and RESIG
The only specimen of the subspecies found in the Sagara Formation; therefore, this is included in *G.* (*T.*) *acostaensis acostaensis* on the occurrence chart (Table 1), even though BRÖNNIMANN and RESIG (1971) proposed different geologic ranges for the two subspecies; from Sample 22; Micropal. Coll. N.S.M. 880.

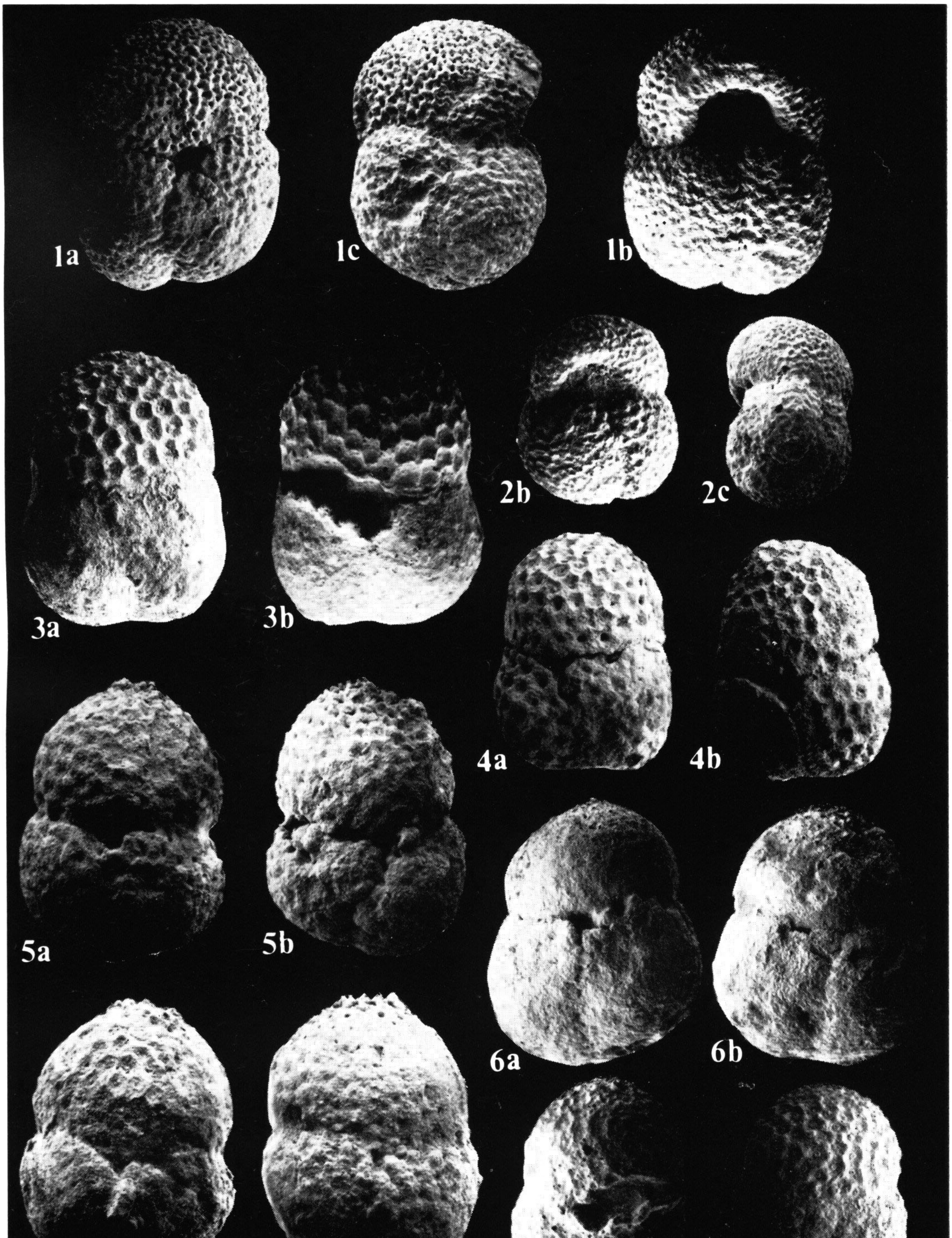
Figs. 3. *Globorotalia* (*Turborotalia*)? *pachyderma* (EHRENBERG)
A small dextral specimen showing the earliest occurrence (upper N. 17) in the Sagara Formation, from Sample 18; Micropal. Coll. N.S.M. 881.

Fig. 4. *Globorotalia* (*Turborotalia*) *lenguaensis* BOLLI
A specimen provided with somewhat fewer number of chambers in the last whorl and with slightly more vaulted umbilical side than those of typical specimens; from Sample 9; Micropal. Coll. N.S.M. 882.

Fig. 5. *Globorotalia* (*Turborotalia*) cf. *inflata* (D'ORBIGNY)
A young form showing occurrence earlier (upper N. 17) than the abundant occurrence of the typical forms which starts from the base of N. 21 in this region; from Sample 18; Micropal. Coll. N.S.M. 883.

Fig. 6. *Globorotalia* (*Globorotalia*) *tumida plesiotumida* BANNER & BLOW
A small but typical specimen making its first appearance at the base of probably N. 17; from Sample 16; Micropal. Coll. N.S.M. 884.

Fig. 7. *Globorotalia* (*Globorotalia*) *multicamerata* CUSHMAN & JARVIS
A typical specimen seldom found in the additional materials of large amounts; from Sample 23′; Micropal. Coll. N.S.M. 885.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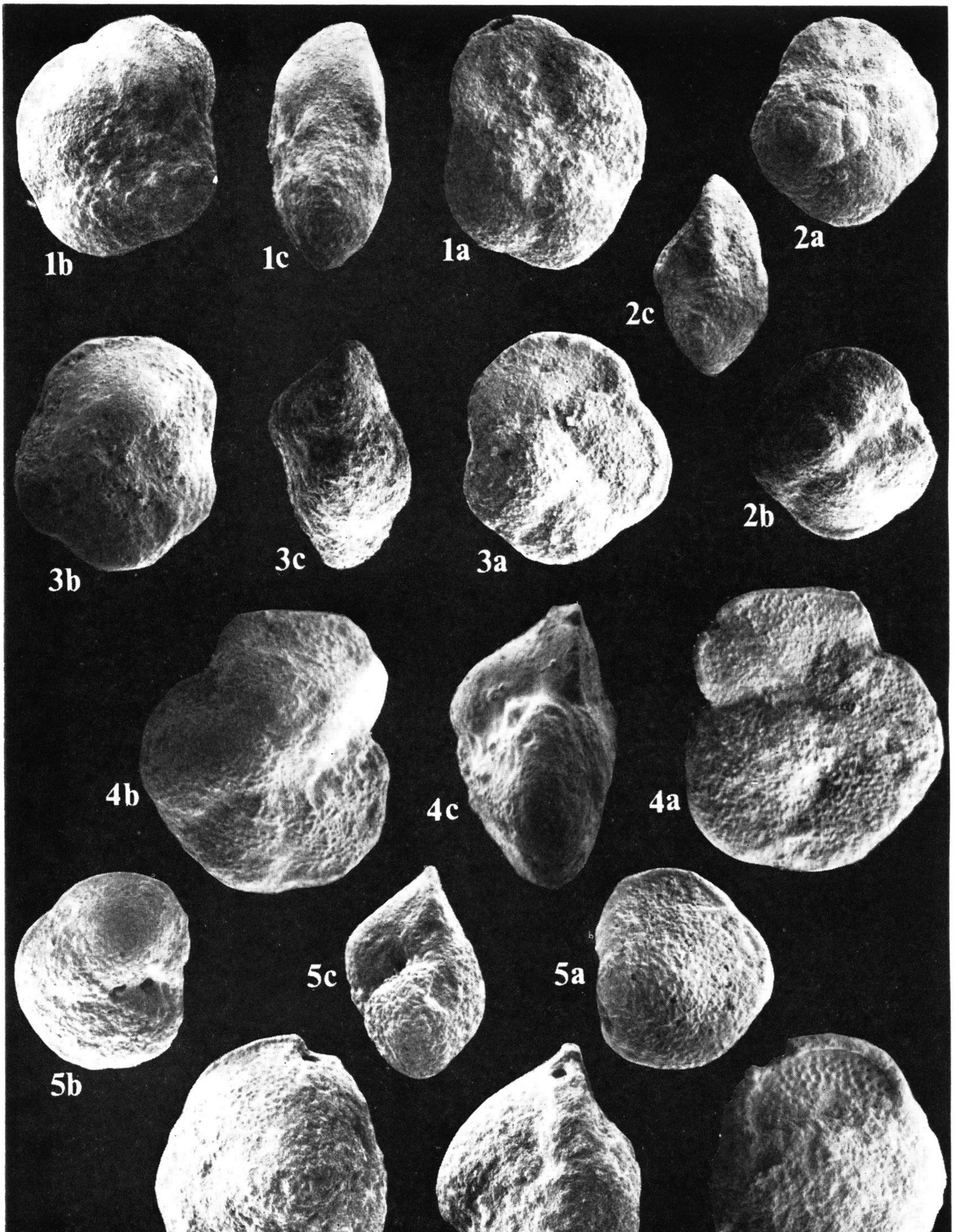
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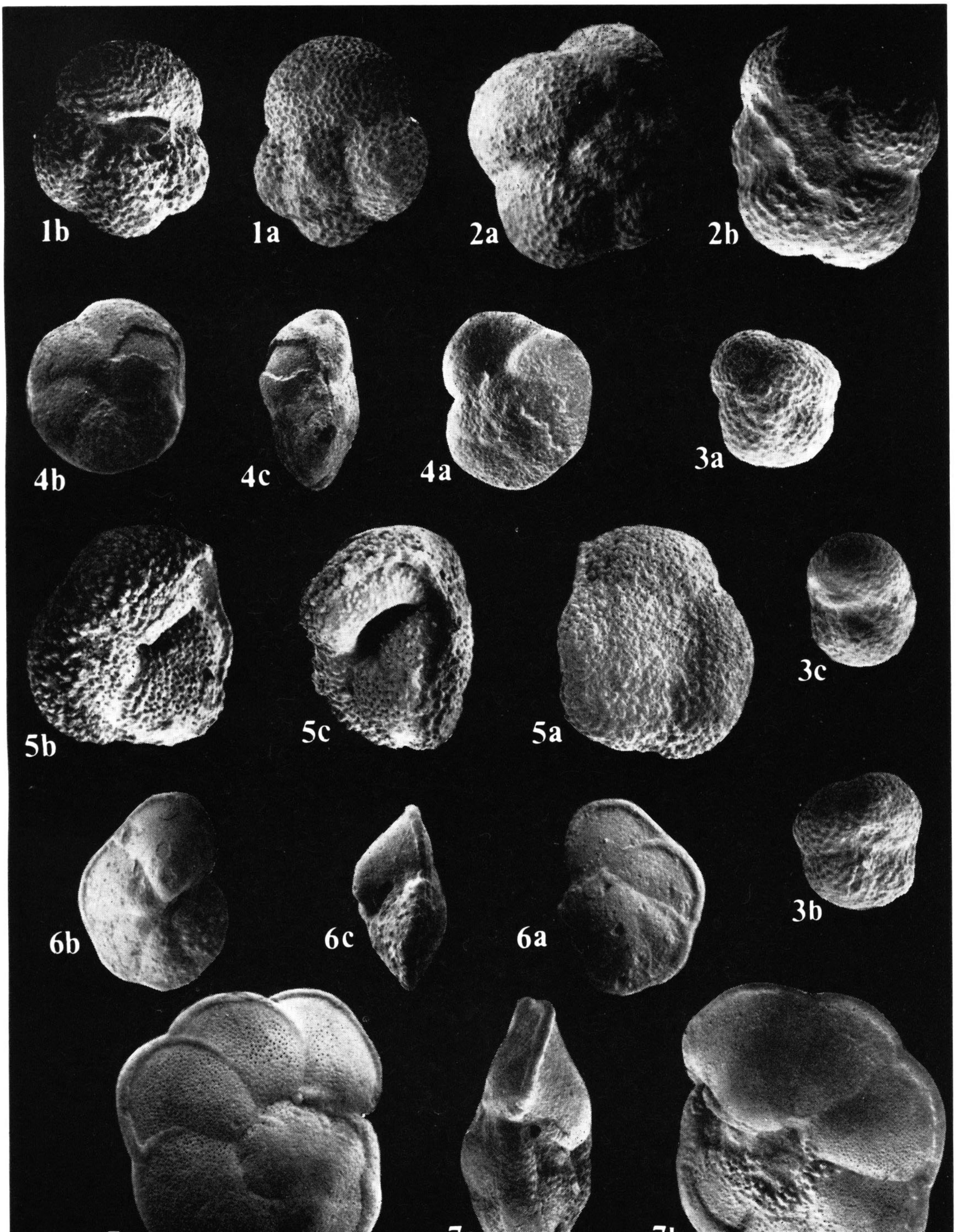
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