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Planktonic Foraminiferal Zonation of the Oligocene–Miocene Succession of Well H1-NC41, NW Offshore, Libya

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المنخربات الهوائم، الطباقية الحياتية للتتابع الطبقي لعصريْ الأوليجوسين والمايوسين للبئر H1-NC41، شمال غرب الرف القاري، ليبيا

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من خلال المحتوى الأحاتي للمنخربات الهوائم لعدد 183 عينة فتاتية ولبية من التتابع الطبقي لعصري الأوليجوسين والمايوسين في المقطع تحت السطح للبئر H1-NC41 في شمال غربي الرف القاري لليبيا أمكن تقسيم التتابع إلى أحد عشر نطاقاً حياتياً للمنخربات الهوائم والمرتبة تصاعدياً كما يلي:

1 – النطاق The *Globigerina ampliapertura* Zone

2 – النطاق The *Globorotalia opima opima* Zone

3 – النطاق The *Globorotalia kugleri* Zone

4 – النطاق The *Globoquadrina dehiscens* Zone

5 – النطاق The *Globigerinoides altiapertura* Zone

6 – النطاق The *Globigerinoides bisphericus* Zone

7 – النطاق The *Praeorbulina glomerosa glomerosa* Zone

8 – النطاق The *Orbulina suturalis* Zone

9 – النطاق The *Orbulina universa* Zone

10 – النطاق The *Globorotalia acostaensis* Zone

11 – النطاق The *Globigerinoides extremus* Zone

تمت مقارنة التتابع الطبقي الحياتي لعصري الأوليجوسين والمايوسين للبئر H1-NC41 مع الأنطقة الحياتية P-N، وكذلك مع الظواهر الطبقية الحياتية للأعمار مقدرة بملايين السنين، ومع الحدود الطبقية الأوروبية.

إن عدم وجود الأنطقة الحياتية P19, P18, P17 وكذلك احتمالية عدم وجود الجزء الأسفل من النطاق الحياتي P20 قد يدل على فترة تعرية وعدم ترسيب أثناء الحد الفاصل بين عصري الأيوسين والأوليجوسين. إن عدم وجود النطاق الحياتي P22 واحتمالية عدم وجود الجزء الأسفل من النطاق الحياتي N4a يدل على وجود فترة زمنية مفقودة خلال عصر هذيْن النطاقيْن، وكذلك فان عدم وجود الأنطقة الحياتية N10 (جزء)، N14, N13, N12, N11 (جزء) قد يعزي إلى وجود فترة عدم ترسيب، أو تغيير في البيئة الترسيبية أو كليهما. كما أن عدم وجود أعلى النطاق N17 يدل على وجود فترة عدم توافق في نهاية عصر المايوسين.

Abstract *Analysis of the planktonic foraminiferal contents of 183 cutting and sidewall core samples from the Oligocene–Miocene sequence of well H1-NC41, NW offshore, Libya enabled to subdivide the sequence into eleven planktonic foraminiferal zones, they are in ascending order:*

(1) *The Globigerina ampliapertura Zone.*
(2) *The Globorotalia opima opima Zone.*

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(3) *The Globorotalia kugleri Zone.*
(4) *The Globoquadrina dehiscens Zone.*
(5) *The Globigerinoides altiapertura Zone.*
(6) *The Globigerinoides bisphericus Zone.*
(7) *The Praeorbulina glomerosa glomerosa Zone.*
(8) *The Orbulina suturalis Zone.*
(9) *The Orbulina universa Zone.*
(10) *The Globorotalia acostaensis Zone.*
(11) *The Globigerinoides extremus Zone.*

The Oligocene–Miocene planktonic foraminiferal biosequence of well H1-NC41 has been correlated with P-N Zones, the biostratigraphic events age estimates in million years, and the European stage boundaries.

The absence of Zones P17, P18, P19, and possibly the lower part of the Zone P20 may indicate a period of erosion and non deposition at the Eocene/Oligocene boundary. In the Late Oligocene, Zone P22 and possibly the lowermost Zone N4a are missing indicating a hiatus at this interval. The missing of Zones N10 (part), N11, N12, N13, N14 (part) may due to nondeposition (hiatus), change in depositional environment or both.

The top of Zone N17 is also missing indicating unconformity at the end of the Miocene.

INTRODUCTION

The biozonation of the Oligocene–Miocene sediments of well H1-NC41 is part of the biostratigraphic study of the Oligocene–Pleistocene of the Tarabulus Basin, Pelagin Platfrom, NW offshore, Libya.

A large number of foraminiferal specimens were picked in order to precisely determine the character of the biozones, their age, boundaries, and to correlate them with the P–N Zones and the European stage boundaries. Utilizing the vertical extension of the planktonic foraminferal index species, several time gaps are postulated during the deposition of the Oligocene–Miocene sequence.

Well H1-NC41 is one among more than 60 exploratory wells drilled in the offshore area (Fig. 1), it is situated in the middle of the Tarabulus Basin (long. 12° 43′ 07″, lat. 33° 26′ 05″), and was drilled by NOC-Agip Name in 1979. It penetrated 12532 ft. (3820.7 m) sedimentary sequence ranging in age from the Palaeocene-to the Pleistocene.

The sea bed was encountered at 769 ft. (234.4 m), water depth at 662 ft. (201.8 m), and first recovery at D.D. around 1055 ft. (321.6 m) from the lower Pleistocene (*Hyalinea balthica* Zone) portion of the

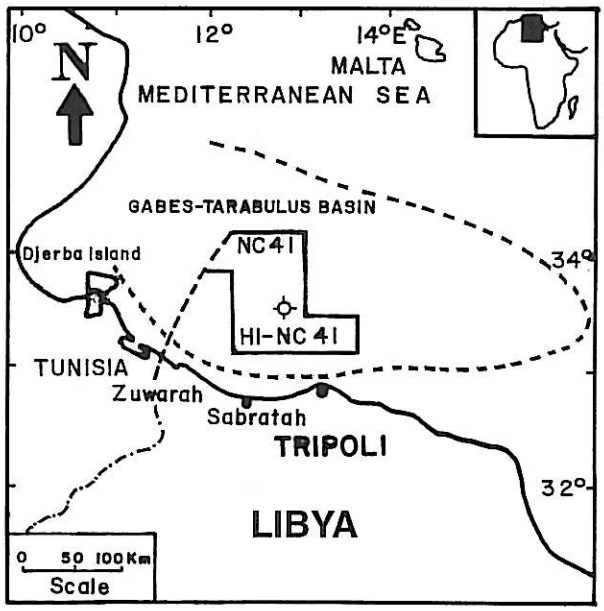


Fig. 1. Location Map

Sbabil Formation. The Oligocene–Miocene sedimentary sequence in this well is 7224 ft. (2202.4 m) thick (including 44 ft. belonging to the larger foram *Nummulites vascus* Zone).

The planktonic foraminiferal biostratigraphy of the Oligocene–Miocene of the subsurface, NW offshore, Libya have been investigated previously by Van Hinte *et al.* (1980, well B1-NC35A, Messinian–Tabianian), Cococcetta (1982, well H1-NC41, Palaeocene–Pleistocene, unpublished NOC-Agip Name report), Hammuda *et al.*, (1985, 16 wells, 32 rock units ranging in age from Triassic–Pleistocene), Duronio (1985, Bouri Field, 7 wells, 10 rock units and groups ranging in age from Palaeocene to Pleistocene), and Hammuda *et al.*, (1991, 11 wells, 15 rock units involving two rock groups, ranging in age from Santonian to Pleistocene). Salem and Spreng (1980) and Sherif (1991) dealt in detail with onshore (NW Libya) Al Khums Formation (Miocene).

One hundred and sixty one cutting and 23 sidewall core samples were supplied by NOC-Agip Name, Tripoli, Libya, they were processed using standard micropalaeontological techniques, the fossils contents of all size fractions were picked (in proportional quantity) and identified.

STRATIGRAPHY

The Oligocene–Miocene succession in well H1-NC41 is 7224 ft. (2202.4 m) thick sequence of distinct stratigraphic units unconformably overlying the Upper Eocene Samdun Formation of Tellil

Group and unconformably underlying the Pliocene–Pleistocene Sbabil Formation. The rock units are in ascending order.

1. Ras Abd Jalil Formation

The Ras Abd Jalil Formation is underlain by the open marine shallow water *Nummulites vascus* marker bed which is 44 ft. (13.41 m) (D.D. 9028 ft.–8984 ft.) nummulitic limestone of late Early Oligocene (late Rupelian) age. Ras Abd Jalil Formation is 2198 ft. (670 m) (D.D. 8984 ft.–6786 ft.) sandy shales, marl, and marly limestone sequence of deep water origin characterized by rich planktonic foraminiferal contents (ranging in apparent percentage from 56% to 99%) indicating 15.6 Ma time duration of deposition from the bottom of the *Globigerina ampliapertura* Zone (Late Oligocene) at 33.2 Ma to the top of the *Globigerinoids altiapertura* Zone at 17.6 Ma (Early Miocene, early Burdigalian).

The lower contact of Ras Abd Jalil Formation in well H1-NC41 is quite sharp corresponding to the change in fauna and lithology from dark grey shale above to whitish nummulitic limestone below, the contact is considered (at present) conformable with the *Nummulites vascus* marker bed. The upper contact with Al Mayah Formation is taken (at present) at D.D. 6786 ft. (below sample 6790) (in accordance with NOC-Agip Name, 1979) corresponding to the *Globigerinoids altiapertura/Globigerinoids bisphericus* zonal boundary, although no major change in lithology was observed as the boundary falls within a silty shale sequence.

2. Al Mayah Formation

Al Mayah Formation is 3806 ft. (1160 m) sequence of grey green silty shale, shale, sandstone, mudstone (H12), shale and sandstone of open shallow platform to middle neritic environment (30–100 m) indicated by a marked decrease in the planktonic Foraminifera up the section (the apparent planktonic foraminiferal percentage ranges from 4.66% to 84.86%). The planktonic Foraminifera indicate Upper Burdigalian (late Early Miocene, the *Globigerinoids bishpericus* Zone) to Early Tortonian (the *Globorotalia acostaensis* Zone, lower part) of slightly more than 7.4 Ma time duration.

The lower boundary of Al Mayah Formation at well H1-NC41 is taken (at present) at the Lower/Middle Burdigalian boundary. There is no clear lithological change at this level as the silty shale of Ras Abd Jalil Formation continues upward, however, the present boundary is following the well log. The upper boundary is taken at the change from silty marl and marl to fossiliferous limestone at D.D. 2980 ft. corresponding to the FA of *Borelis melo* within the Early Tortonian. NOC-Agip Name (1979) followed by Cococcetta (1982) put the boundary 262 ft. below the present boundary at the change from quartzose sand to silty marl, locally grading to shale, with thin levels of limestone corresponding to their *Borelis melo* Zone lower boundary.

3. Tubtah Formation

The Tubtah Formation is 908 ft. (276.8 m) (from D.D 2980 ft.–2072 ft.) thick oolitic, fossiliferous limestone with marly horizons of inner shallow platform (15–25 m water depth) indicated by the dominance of benthonic Foraminifera characterized by *Borelis* spp., *Elphidium* spp., miliolids, and rotaliids.

The planktonic Foraminifera are scarce found only in the marl iterbeds, however, they are characterized by species referable to this upper part of the *Globorotalia acostaensis* Zone and the lower part of the *Globigerinoids extremus* Zone indicating Tortonian age.

The rich and diverse benthonic foraminiferal fauna enabled the subdivision of the Tubtah Formation into two benthonic foraminiferal zones, a lower *Borelis melo* Zone, and an upper *Ammonia–Elphidium* Zone (the later zone continues into the overlying Marsa Zouaghah Formation).

The first introduction of gypsum within the limestone indicates the start of the Marsa Zouaghah Formation overlying the Tubtah Formation at D.D. 7072 ft.

4. Marsa Zouaghah Formation

Marsa Zouaghah Formation is 268 ft. (81.7 m) (D.D. 2072 ft.–1804 ft.) thick gypsum and limestone (fossiliferous, oolitic, miliolids) sequence characterized by poor planktonic and benthonic foraminiferal assemblages indicative of shallow water (± 9.14 m–15.24 m) of deposition of the tidal flat complex. The presence of scarce but variable planktonic species enabled to refer this depth interval to the upper part of the *Globigerinoids extremus* Zone (Messinian),

the benthonic Zone *Ammonia–Elphidium* is also extended to the Marsa Zouaghah Formation.

The Marsa Zouaghah Formation is unconformably overlain by the Sbabil Formation (Lower Pliocene–Pleistocene), the boundary is taken at D.D. 1804 ft. at the change from gypsum and limestone of the Marsa Zouaghah Formation below to the clay, sandy clay and marl of the Sbabil Formation above. The unconformity is indicated by change in lithology and fauna representing the transition from the Miocene to the Pliocene. The *Ammonia–Elphidium*–miliolids–Ostracoda faunal association indicative of shallow restricted marine environment of the Messinian (Late Miocene) Marsa Zouaghah Formation is overlain by the transgressive clays rich in planktonic Foraminifera (*Sphaeroidinellopsis, Globigerinoides, Globigerina, Globorotalia*) of Early Pliocene age.

BIOSTRATIGRAPHY

Based on rich and diverse planktonic Foraminifera of the Oligocene–Miocene characterizing the sedimentary succession of well H1-NC41 NW offshore, Libya, the sequence has been subdivided into eleven planktonic foraminiferal zones. This biosequence is proposed for well H1-NC41 by integrating the vertical planktonic foraminiferal characteristics of this section with equivalent sections in the Mediterranean and other parts of the world, the deviation from other zonal schemes is controlled by the local characteristics of the planktonic Foraminifera at this particular area of the Mediterranean as a result of climatic differentiations and sea level changes. This has resulted in scarcity of some diagnotic species (*Globorotalia peripheroacuta, Globorotalia conomiozea, Globigerinoids diminutus, Globigerinoids ruber, Globigerina nepenthes, 3 occurrence, Globigerinita insueta*, most of the Middle and Upper Miocene keeled *Globorotalias*), diachronous character species (*Catapsydrax dissimilis*,? *Globigerinoids obliquus*,? *Globigerinoids ruber*, *Praeorbulina transitoria*), and absence of other species (*Globorotalia fohsi fohsi, Globorotalia fohsi lobata, Globorotalia fohsi robusta*, and many other keeled *Globorotalia, Pulleniatina* ssp., *Catapsydrax stainforthi*, single occurrence).

The Oligocene–Miocene planktonic foraminiferal biosequence in well H1-NC41 in ascending order is

1. The *Globigerina ampliapertura* Zone

The *G. ampliapertura* Zone is defined by the interval range of the named zonal taxon from its FA immediately above the *Nummulites vascus* marker bed to its last occurrence. It is of Lower Oligocene age of 2.0 Ma time duration.

The zone covers a depth of 64 ft. (19.5 m) from D.D 8984 ft. to D.D 8920 ft. of the lower part of Ras Abd Jalil Formation. Lithologically this interval is dark grey shale grading to sandy marl.

Most characteristic planktonic foraminiferal species of this zone are: *Catapsydrax dissimilis, Globigerina ampliapertura, Globigerina ciperoensis* subspecies, *Globigerina goratanii, Globigerina ochitaensis* subspecies, *Globigerina praebulloides* subspecies, *Globigerina sellii, Globigerina tripartita, Globigerina venezuelana*, and many others including contaminated species occurring in the cutting samples (see Fig. 2).

Based on the analysis of the vertical distribution of *Globigerina ampliapertura, Globigerina ciperoensis angulisuturalis*, and *Globorotalia opima opima* (Blow, 1969, 1979; Berggren, 1969b, 1971: Stainforth *et al.*, 1975; Bolli and Saunders, 1985; Miller and Katz, 1987) the *Globigerina ampliapertura* Zone of well H1-NC41 is correlated with Zone P20 of Blow (1969), and the upper part of Zone P19/20 of Blow (1979) and equivalent P-Zones and biozones (see Fig. 3).

The time duration of the *Globigerina ampliapertura* Zone (=P20) is 2.0 Ma-2.5 Ma (Blow, 1969, 1979; Berggren, 1969b, 1971; Vail and Mitchum, 1979; Lidz, 1984, Bolli and Saunders, 1985; Haq *et al.*, 1987), accordingly a time duration of 2.0 Ma is assumed for the *Globigerina ampliapertura* Zone in well H1-NC41 (considering 0.5 Ma for the *N. vascus* Zone at the lower part of Zone P20). Based on this age estimation 0.97 cm/1000 years rate of sedimentation is calculated for the 64 ft. interval of the *Globigerina ampliapertura* Zone assuming constant rate of subsidence.

2. The *Globorotalia opima opima* Zone

The *Globorotalia opima opima* Zone is a partial range zone of 3.0 Ma time duration in the Oligocene defined by the range of the zonal marker from the LO of *Globigerina ampliapertura* to the LO of the zonal marker.

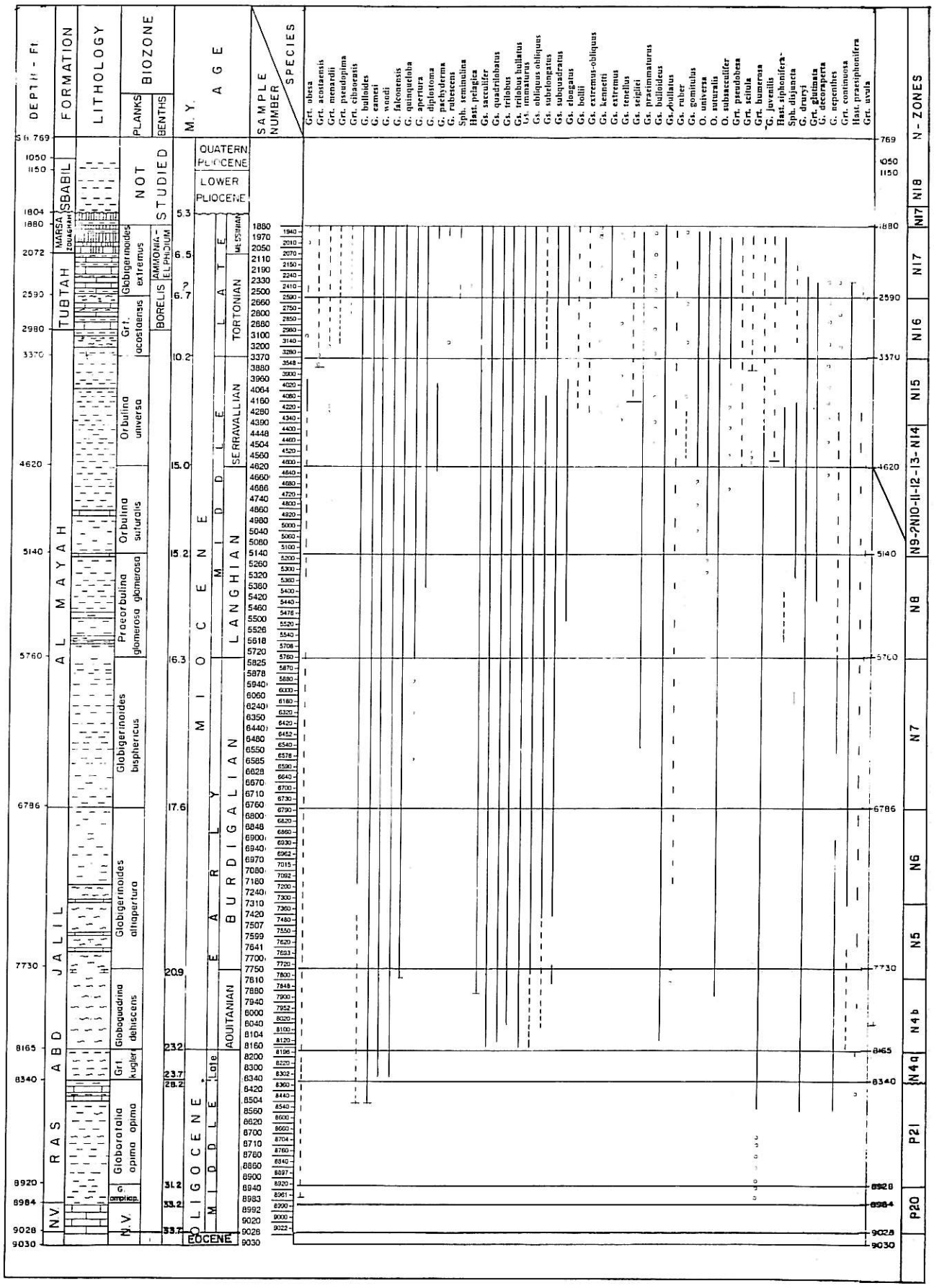


Fig. 2. Ranges of planktonic foraminifera (top occurrence) Oligocene – Miocene, well H1-NC41, NW offshore, Libya.

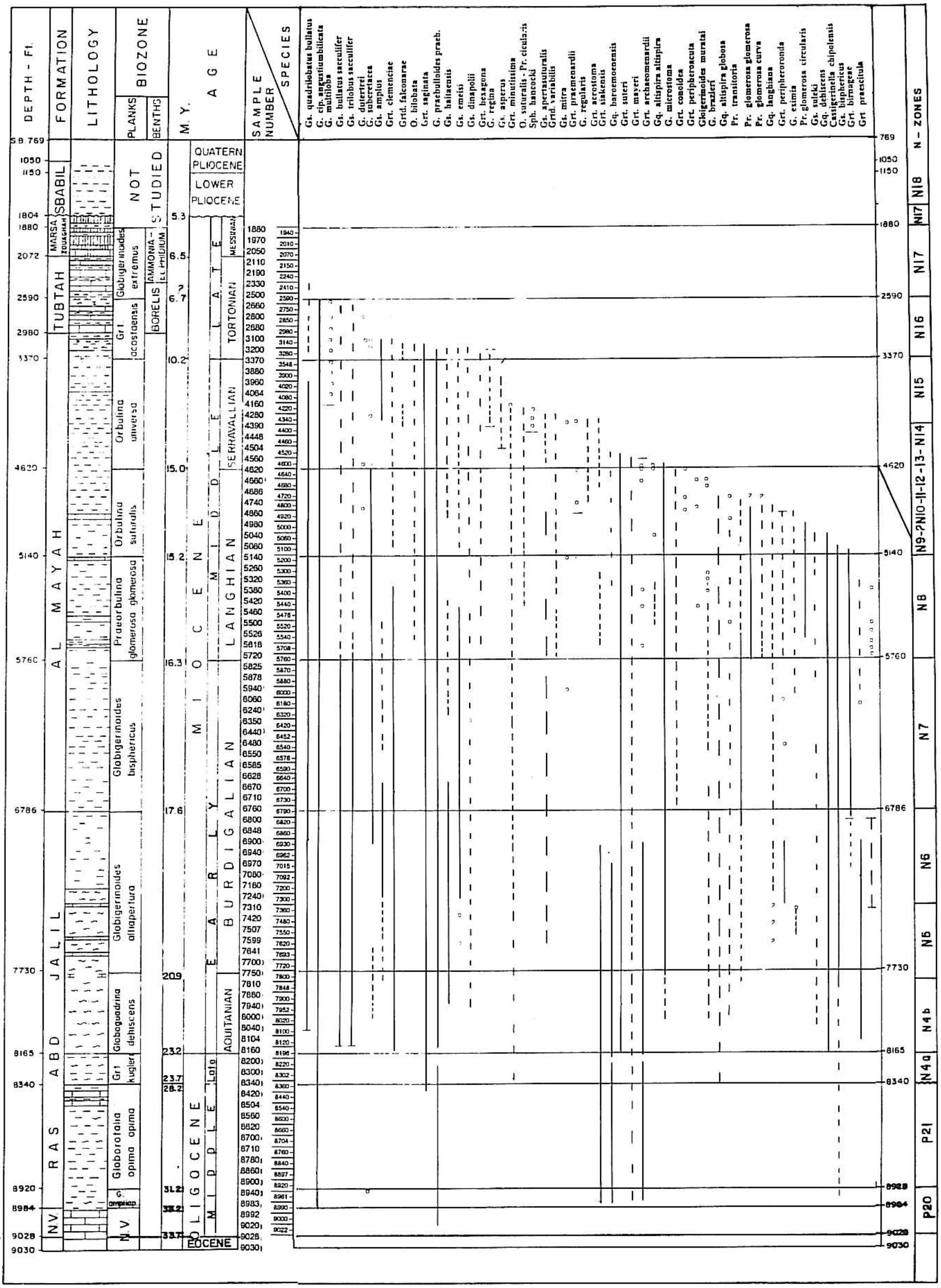

DEPTH - Ft.
FORMATION
LITHOLOGY
BIOZONE
PLANKS
BENTHS
M. Y.
AGE
SAMPLE NUMBER
SPECIES
N - ZONES
SBABIL
MARSA ZOUAGHAH
TUBTAH
AL MAYAH
RAS ABD JALIL
NV
NOT STUDIED
Globigerinoides extremus
Grt. acostaensis
Orbulina universa
Orbulina suturalis
Praeorbulina glomerosa glomerosa
Globigerinoides bispshericus
Globigerinoides altiapertura
Globoquadrina dehiscens
Grt kugleri
Globorotalia opima opima
AMMONIA - ELPHIDIUM
BORELIS
QUATERN
PLIOCENE
LOWER PLIOCENE
MIOCENE
LATE
MIDDLE
EARLY
MESSINIAN
TORTONIAN
SERRAVALLIAN
LANGHIAN
BURDIGALIAN
AQUITANIAN
OLIGOCENE
MIDDLE
Late
EOCENE
N18
N17
N16
N15
N9-N10-11-12-13-N14
N8
N7
N6
N5
N4b
N4a
P21
P20

Fig. 2. (Cont. 1).

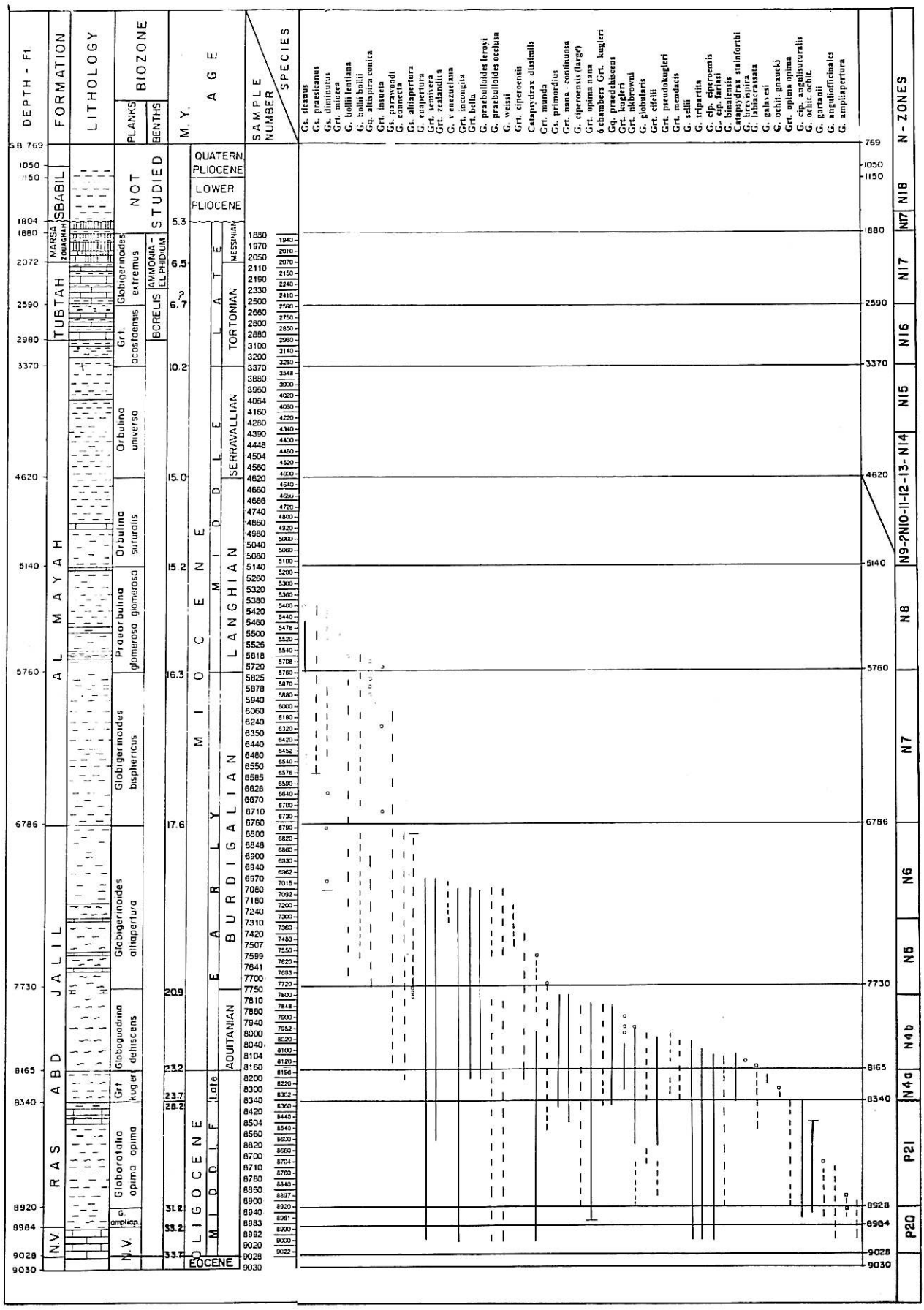

DEPTH - Ft
FORMATION
LITHOLOGY
BIOZONE
PLANKS
BENTHS
M.Y.
AGE
SAMPLE NUMBER
SPECIES
N - ZONES
RAS ABD
JALIL
TUBTAH
SBABIL
NOT STUDIED
QUATERN.
PLIOCENE
LOWER PLIOCENE
MESSINIAN
TORTONIAN
SERRAVALLIAN
LANGHIAN
BURDIGALIAN
AQUITANIAN
EOCENE
Globigerinoides extremus
Grt. acostaensis
Orbulina universa
Orbulina suturalis
Praeorbulina glomerosa glomerosa
Globigerinoides bisphericus
Globigerinoides altiaperturus
Globoquadrina dehiscens
Grt kugleri
Globorotalia opima opima
Gs. siganus
Gs. praesicanus
Gs. diminutus
Grt. miozea
G. bollii lentiana
G. bollii bollii
Gq. altispira conica
Grt. insueta
Gs. parawondi
G. connecta
Gs. altiapertura
G. euapertura
Grt. semivera
Grt. zealandica
G. venezuelana
Grt. incongita
Grt. bella
G. praebulloides leroyi
G. praebulloides occlusa
G. weissi
Grt. cipercensis
Catapydrax dissimilis
Grt. munda
Gs. primordius
Grt. nana - continuosa
G. ciperoensis (large)
Grt. opima nana
6 chambers Grt. kugleri
Gq. praedehiscens
Grt. kugleri
Grt. nkhrowai
G. globularis
Grt. cifelli
Grt. pseudokugleri
Grt. mendacis
G. sellii
G. tripartita
G. cip. ciperoensis
G. cip. farisei
G. binaiensis
Catapydrax stainforthi
G. birnageae
G. galavisi
G. ochit. gnauckl
Grt. opima opima
G. cip. angulisuturalis
G. ochit. ochit.
G. gortanii
G. angulofficinales
G. ampliapertura
P20
P21
N4a
N4b
N5
N6
N7
N8
N9-PN10-11-12-13-N14
N15
N16
N17
N18

Fig. 2. (Cont. 2).

The *Globorotalia opima opima* Zone of well H1-NC41 covers a depth of 580 ft. (176.8 m) from D.D. 8920 ft. to D.D. 8340 ft. within Ras Abd Jalil Formation. Lithologically this depth interval is grey sandy shale, sandy marl, and thin marly limestone.

Most characteristic planktonic foraminiferal species of this zone are: *Globorotalia opima opima, Globorotalia opima nana, Globorotalia mayeri, Globorotalia siakensis, Globorotalia acrostoma, Globorotalia nkbrowni, Globorotalia cifelii, Globorotalia munda, Globigerina praebulloides* subsp., *Globigerina euapertura, Globigerina sellii, Globigerina triapartita, Globigerina ciperoensis ciperoensis, Globigerina ciperoensis angulisuturalis, Globigerina cip. fariasi, Catapsydrax dissimilis, Globorotaloides suteri* and *Cassigerinella chipolensis.*

Based on the vertical distribution of the planktonic foraminiferal species characterizing the boundaries of the *Globorotalia opima opima* Zone (i.e. *Globorotalia opim opima, Globigerina ampliapertura, Globigerina ciperoensis angulisuturalis*) it is correlated with Zone P21 of Blow (1969, 1979) and equivalent P-Zones and biozones (Fig. 3).

The time duration of the *Globorotalia opima opima* Zone is 3.0 Ma (Berggren and Miller, 1988), accordingly the 580 ft. thick *Globorotalia opima opima* Zone sediments have 5.89 cm/1000 years calculated rate of sedimentation assuming constant rate of subsidence.

3. *The Globorotalia kugleri* Zone

The *Globorotalia kugleri* Zone is a partial range zone of 0.5 Ma time duration in the Late Oligocene defined by the range of the zonal marker from the LO of *Globorotalia opima opima* (coincident with the FA of the *Globorotalia kugleri* group and *Globigerinoids primordius*) to the FA *Globoquadrina dehiscens* (coincident with the FA of the genus *Globigerinoides* excluding *Globigerinoids primordius*).

The *Globorotalia kugleri* Zone is 175 ft. (53.35 m) thick dark grey shale and marl (D.D. 8340 ft.–8165 ft.) within Ras Abd Jalil Formation.

The *Globorotalia kugleri* Zone is characterized by many distinctive planktonic species, most characteristic are: *Globigerinoides primordius, Globorotalia opima opima, Globorotalia kugleri*: group, *Globoquadrina praedehiscens, Catapsydrax dissimilis, Globigerina euapertura, Globigerina sellii, Globigereina venezuelana, Globigerina tripartita, and Globigerina binaiensis.*

Based on the analysis of the vertical distribution of *Globorotalia kugleri, Globorotalia mendacis, Globorotalia pseudokugleri, Globigerinoides bullatus, Globigerinoids primordius, Globigerinoids quadrilobatus, Globorotalia opima opima, Globigerina ciperoensis* subsp. and *Globoquadrina dehiscens* (Fig. 2), the *Globorotalia kugleri* Zone of well H1-NC41 is considered equivalent to the lower part of Zone N4 of Blow (1969, 1979) and Bolli and Saunders (1985), Zone N4a of Kennett and Srinivasan (1983), Miller and Katz (1987), Berggren and Miller (1988, 1989) and equivalent N-Zones and biozones (see Fig. 3).

The time duration of the *Globorotalia kugleri* Zone as defined in this study is 0.5 Ma (FA of *Globorotalia kugleri* at 23.7 Ma to FA of *Globoquadrina dehiscens* at 23.2 Ma), the lower boundary is in accordance with Bolli and Saunders (1985), Miller and Katz (1987), and Berggren and Miller (1988), the upper boundary is in accordance with Iaccarino and Salvatorini (1982), Kennett and Srinivasan (1983), and Iaccarino (1985). The definition of Miller and Katz (1987), Berggren and Miller (1988, 1989) (FA of *Globorotalia kugleri* at 23.7 Ma to the LA of *Globorotalia kugleri* at 21.8 Ma =1.9 Ma time duration), and the definition of Bolli and Saunders (1985) (FA of *Globorotalia kugleri* =25.5 Ma to the FA of the *Globigerinoides primordius* =24.6 Ma =0.9 Ma time duration) are not coinciding with the present work definition. Thus in assuming continous sedimentation and a constant rate of subsidence through the *Globorotalia kugleri* Zone of well H1-NC41 time, the 175 ft. (=53.35 m) sediments may had been deposited at 10.67 cm/1000 years rate of sedimentation.

4. The *Globoquadrina dehiscens* Zone

The *Globoquadrina dehiscens* Zone is a partial range zone of 2.3 Ma time duration of Aquitanian age (Early Miocene) define by the range of the zonal marker from its FA (23.2 Ma) (coincident with the FA of *Globigerinoides immarturus* and *Globigerinoides quadrilobatus*) to the FA of *Globigerinoides altiapertura* (20.9 Ma).

The *Globoquadrina dehiscens* Zone is 435 ft. (132.6 m) thick (D.D. 8165 ft.–7730 ft.) dark brown to grey shale and marl within Ras Abd Jalil Formation.

The planktonic Foraminifera are very rich in this zone ranging in apparent percentage from 86.30% to 98.93% dominated by the genus *Globigerinoides*

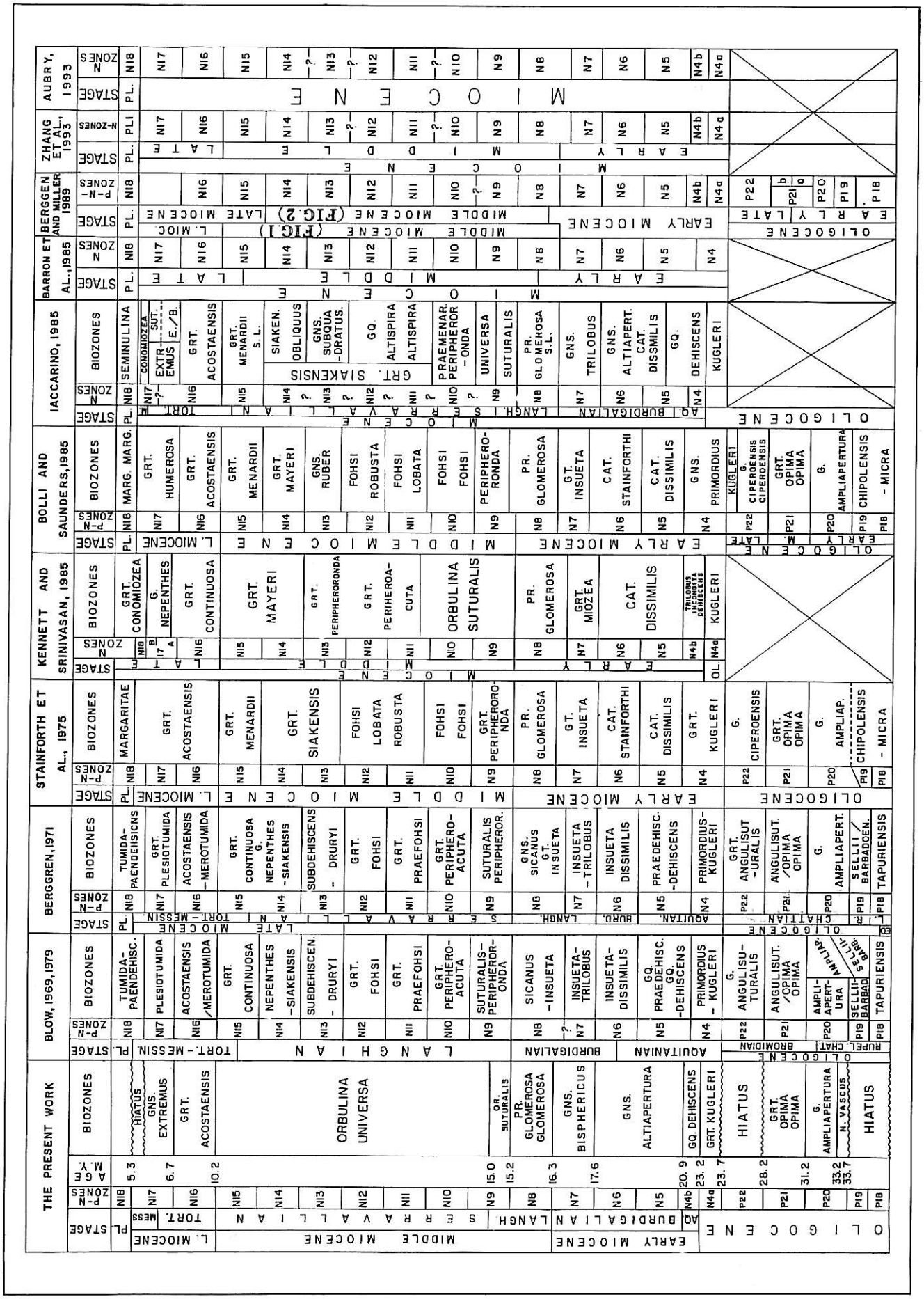


Fig. 3. Correlation of the Oligocene – Miocene zonal schemes of some authors with well H1-NC41 NW offshore, Libya.

(37 species and variants). Most characteristics are the disappearance of *Globigerinoides primordius* and *Globorotalia kugleri* at the top of the zone, the disappearance of *Globorotalia nkbrowni, Globorotalia cifellii, Globorotalia mendacis*, and *Globorotalia pseudokugleri, Globigerina sellii, and Globigerina tripartita* within this zone, and the FA of *Globoquadrina dehiscens* at the lower boundary of the zone.

Based on on the vertical distribution of *Globoquadrina dehiscens* and *Globigerinoides altiapertura*, the *Globoquadrina dehiscens* Zone as defined here can be correlated with the upper part of Zone N4 and the lowermost Zone N5 of Blow (1969, 1979), Berggren (1969b, 1971);? the upper of Zone N4 of Stainforth *et al.*, (1975),? Bolli and Saunders (1985), Zone N4 and lowermost Zone N5 of Iaccarino (1985); Zone N4b and lowermost Zone N5 of Zhang *et al.* (1993); Zone N4b of Kennett and Srinivasan (1983), Miller and Katz (1987), and Berggren and Miller (1988, 1989) and equivalent biozones.

The time span for the *Globoquadrina dehiscens* Zone as defined here from the FA of *Globoquadrina dehiscens* (23.2 Ma) to the LA of *Globorotalia kugleri* coincident with the FA of *Globigerinoides altiapertura* (20.9 Ma) is 2.3 Ma (Berggren and Miller, 1989; Zhang *et al.*, 1993) accordingly, the calculated rate of sedimentation is 9.47 cm/1000years assuming constant rate of subsidence.

5. The *Globigerinoides altiapertura* Zone

The *Globigerinoides altiapertura* Zone is a range zone of 3.3 Ma of early Burdigalian (M. Miocene) age defined by the first evolutionary appearance of *Globigerinoides altiapertura* at 20.9 Ma to its last occurrence at 17.6 Ma coincident with the first evolutionary appearance of *Globigerinoides bisphericus* (not *Globigerinoides sicanus*).

The thickness of the *Globigerinoides altiapertura* Zone is 944 ft. (287.8 m) from D.D. 7730 ft. to D.D. 6786 ft., lithologicaly this depth interval is brown shale and marl representing the upper part of Ras Abd Jalil Formation.

The planktonic Foraminifera are very rich ranging in apparent percentage from 76.67% to 97.32% dominated by the genus *Globigerinoides* (64 species and variants) characterized by the FA of *Globigerinoides altiapertura, Globigerinoides amplus, Globigerinoides subquadratus*, and *Globigerinoides murataii* at or near the lower boundary, the disappearance of *Globigerinoides altiapertura* at the upper boundary, and the disappearance of *Catapsydrax dissimils* within its lower part.

Based on the zonal criteria of the *Globigerinoides altiapertura* Zone(total range of the zonal marker) coincident with the first evolutionary occurrence of *Globigerinoides bisphericus* (not *Globigerinoides sicanus*) at its upper boundary and assuming synchronous first and last occurrence of *Globigerinoides altiapertura*, the *Globigerinoides altiapertura* Zone is considered equivalent to Zone N5 and N6 (or most of it) of Blow (1969, 1979, excluding lowermost Zone N5), Bolli and Saunders (1985, excluding the uppermost Zone N6), Zhang *et al.* (1993, excluding the lowermost part of Zone N5) and equivalent biozones (see Fig. 3).

The N5/N6 zonal boundary is generally based on the FA of *Globigerinita insueta* (18.1 Ma, Barron *et al.*, 1985) (see Blow, 1969, Berggren, 1971; Stainforth *et al.*, 1975; Kennett and Srinivasan, 1985; Barron *et al.*, 1985; Bolli and Saunders, 1985), however, Iaccarino (1985), and Zhang *et al.* (1993) found that the FA of *Globigerinita insueta* is diachronous, it is also scarce in the Mediterranean area, which seems true for well H1-NC41 (Kassab *et al.*, 1995–1996) and the Sirt Basin (Berggren, 1969a), accordingly Zhang *et al.*, (1993) preferred the FA of *Globorotalia praescitula* (19.0 Ma) distinct between the N5/N6 Zones, however, the last and first appearance of *Globorotalia praescitula* seems diachronous as well (Blow, 1969, 1971; Stainforth *et al.*, 1975; Kennett and Srinivasan, 1983; Barron *et al.*, 1985; Bolli and Saunders, 1985; Iaccarino, 1985; Zhang *et al.*, 1993).

The time of deposition of the *Globigerinoides altiapertura* Zone is 3.3 Ma, thus the rate of sedimentation during the deposition of the *Globigerinoides altiapertura* Zone (total thickness 287.8 m would be 8.7 cm/1000 years.

6. The *Globigerinoides bisphericus* Zone

The *Globigerinoides bisphericus* Zone is a Lower Miocene (Upper Burdigalian) partial range zone of 1.3 Ma time duration defined by the range of *Globigerinoides bisphericus* (not *Globigerinoides sicanus*) from its first evolutionary appearance coincidint with the LO of *Globigerinoides altiapertura* (17.6 Ma by correlation with N6/N7 zonal boundary) to the FA of *Praeorbulina glomerosa glomerosa* (16.3 Ma, Iaccarino, 1985, by correlation with Cowie and Basset, 1989; Miller and Katz, 1987; Zhang *et al.*, 1993; Aubry, 1993) and the first

evolutionary appearance of *Globigerinoides sicanus* (16.6 Ma; 16.3 Ma).

The *Globigerinoides bisphericus* Zone covers a thickness of 1026 ft. (312.8 m) from D.D. 6786 ft. to D.D. 5760 ft. in the lower part of Al Mayah Formation. This depth interval is made of quartzose sand, shale, silty and glauconitic horizons.

The Planktonic Foraminifera show a marked decrease in number of individuals relative to the underlying zone, the apparent percentage of the planktonic Foraminifera ranges from 22.4% to 84.86% dominated by the genus *Globigerinoides* (63 species and variants). Most characteristics are the FA of *Globigerinoides bisphericus* (not *Globigerinoides sicanus*) at the lower boundary and the disappearance of *Globigerinoides altiapertura* close to the lower boundary, also characteristics is the abundance of *Globigerinoides immaturus, Globigerinoides obliquus, Globigerinoides quadrilobatus, Globigerinoides sacculifer*, and *Praeorbulina transitoria.*

Assuming synchronous LA of *Globigerinoides altiapertura* and synchronous FA of *Pr. glomerosa glomerosa*, therefore, and in accordance with the zonal definition of the *Globigerinoides bisphericus* Zone (first evolutionary appearance of *Globigerinoides bisphericus*, coincident with the LA of *Globigerinoides altiapertura* to the FA of *Pr. glomerosa glomerosa* coincident with the FA of *Globigerinoides sicanus*) the *Globigerinoides bisphericus* Zone of well H1-NC41 can be correlated with Zone N7 (and may be the lower part of Zone N8) of Bolw (1969, 1979), Zone N7 of Stainforth *et al.* (1975), Iaccarino (1985), Bolli and Saunders (1985, excluding the lowermost part), the upper part of Zone N7 and the lowermost part of Zone N8 of Kennet and Srinivasan (1983), Zone N8 of Barron *et al.* (1985), Miller and Katz (1987), and Zone N7 and the lowermost Zone N8 of Zhang *et al.* (1993).

The lower limit of Zone N7 is widely taken corresponding to the LO of *Catapsydrax dissimilis* (Blow, 1969, 1979; Stainforth *et al.*, 1975; Keller, 1981; Kennett and Srinivasan, 1983; Lidz, 1984; Barron *et al.*, 1985; Bolli and Saunders, 1985; Iaccarino, 1985; Miller and Katz, 1987; Berggren and Miller, 1989, Zhang *et al.*, 1993).

The last occurrence of *Catapsydrax dissimilis* in well H1-NC41 is within the upper part of Zone N5 (similar observation was noted by Zhang *et al.*, 1993, p.302 for diachronous LO of *Catapsydrax dissimilis* in borehole Eureka 68–136, upper De Soto Canyon, NE Gulf of Mexico), thus it is not in the reach of limiting Zone N7 in well H1-NC41, therefore, the taxa *Globigerinoides bisphericus* (not *Globigerinoides sicanus*), and *Globigerinoides altiapertura* are used to limit the lower boundary of the N7 Zone. The N6/N7 boundary is at 17.6 Ma (LA of *Cat. dissimilis* at 17.6 Ma, Barron *et al.*, 1985; Zhang *et al.*, 1993; Aubry, 1993). Accordingly the *Globigerinoides altiapertura/Globigerinoides bisphericus* zonal boundary is considered at 17.6 Ma by correlation with the N6/N7 zonal boundary. Assuming constant rate of subsidence, the rate of sedimentation during the time of deposition (1.3 Ma) of the *Globigerinoides bisphericus* Zone (thickness 312.8 m) is 4.06 cm/1000 years.

7. The *Praeorbulina glomerosa glomerosa* Zone

The early Langhian (Middle Miocene) *Praeorbulina glomerosa glomerosa* Zone is a partial range zone of 1.1 Ma time duration defined by the range of *Pr. glomerosa glomerosa* from its FA (16.3 Ma, Iaccarino, 1985 by correlation with Cowie and Basset, 1989; Miller and Katz, 1987; Zhang *et al.*, 1993; Aubry, 1993) coincident with the FA of *Globigerinoides sicanus* to the FA of *Orbulina suturalis* (15.2 Ma, Iaccarino, 1985 by correlation with Cowie and Basset, 1989).

The zone covers 620 ft. (189.0 m) from D.D. 5760 ft.–to D.D. 5140 ft. thickness of grey green shale; sandy, pyritic glauconitic, and fossiliferous limestone thin levels of the lower part of Al Mayah Formation.

The Planktonic Foraminifera show a noticeable decrease in number of individuals in this zone, their apparent percentage ranges from 9.66% to 60.29%.

The genus *Globigerinoides* is consistent in its dominance of the planktonic Foraminifera (51 species and variants). Most characteristics are the FA of *Pr. glomerosa glomerosa, P. glomerosa curva, Globigerinoides. sicanus, Globigerinoides elongatus, Orbulina bilobata, Globorotaloides variabilis, Grtd. hexagona, Sphaeroidinellopsis* spp., and *Sphaeroidinella* spp.

Based on the zonal definition (range of *Pr. glomerosa glomerosa* from its FA coincident with the FA of *Gns. sicanus*, to the FA of *Orbulina suturalis*), the *Pr. glomerosa glomerosa* Zone is correlated with most of Zone N8 of Blow (1969, 1979), and Berggren (1969b, 1971), Zone N8 of Stainforth *et al.* (1975), most of Zone N8 of Kennett and Srinivasan (1983), Barron *et al.*, (1985), Zone N8 of Bolli and Saunders (1985, part), Iaccarino (1985), Miller and

Katz (1987), Berggren and Miller (1989), and most of Zone N8 of Zhang *et al.* (1993) and equivalent biozones (see Fig. 3).

Assuming constant rate of subsidence, the rate of sedimentation during the time of deposition (1.1 Ma) of the *Pr. glomerosa glomerosa* Zone (189 m) at well H1-NC41 is 17.27 cm/1000 years.

8. The *Orbulina suturalis* Zone

The Upper Langhian (Middle Miocene, 0.2 Ma time duration) *Orbulina suturalis* Zone is a partial range zone of 520 ft. (158.5 m) thickness from D.D. 5140 ft. to D.D. 4620 ft., it is defined by the range of *Orbulina suturalis* from its FA (15.2 Ma, Barron *et al.*, 1985; Zhang *et al.*, 1993; Aubry, 1993) to the FA of *Orbulina universa* (15.0 Ma, Iaccarino, 1985 by correlation with Cowie and Basset, 1989). Lithologically it is grey green shale with levels of limestone, silstone and marl falls within the upper part of Al Mayah Formation.

The planktonic Foraminifera range in apparent percentage from 7.07% to 68.87%. The genus *Globigerinoides* still the dominant planktonic genus (44 species and variants). Most characteristics of the zone is the FA of *Orbulina suturalis* and the disappearance of the *Praeorbulina glomerosa* group in this zone.

The zonal criteria of the *Orbulina suturalis* Zone as defined by the FA of *Orbulina suturalis* to the FA *Orbulina universa* correlates it with the lower part of Zone N9 and equivalent N-Zones (Blow, 1969, 1979; Berggren, 1969b, 1971; Stainforth *et al.*, 1975; Kennett and Srinivasan, 1983; Bolli and Saunders, 1985; Iaccarino, 1985; Miller and Katz, 1987) and possibly the lower part of Zone N9 of Barron *et al.* (1985), Berggren and Miller (1989), and Zhang *et al.* (1993) and equivalent biozones (see Fig. 3).

The 158.5 m thick *Orbulina suturalis* Zone of 0.2 Ma time duration is thought to have been deposited at a rate 79.25 cm/1000 years in case of constant rate of subsidence.

9. The *Orbulina universa* Zone

The *Orbulina universa* Zone is a partial range zone of Middle Miocene age (Serravallian) of 4.8 Ma time duration (in well H1-NC41). It is defined by the range of the zonal marker from its FA (15.0 Ma, Iaccarino, 1985 by correlation with Cowie and Basset, 1989) to the FA of *Globorotalia acostaensis* (10.2 Ma, Miller and Katz, 1987; Berggren and Miller, 1989; Zhang *et al.*, 1993). It is made of 1250 ft. (381 m) (D.D. 4620 ft. to D.D. 3370 ft.) of thin grey marly limestone, grey marl, grey green shale, and quartzose sandstone of the upper part of Al Mayah Formation.

The planktonic Foraminifera range in the apparent percentage from 4.66% to 61.22%. The genus *Globigerinoides* is represented by 49 species and variants (most of them are rare to very rare), most characteristics are the FA throughout this zone of *Globigerinoides seigliei, Globigerinoides Kennetti, Globigerinoides tenellus*,? *Globigerinoides conglobatus* and transitionals, *Globorotalia scitula, Globorotalia humerosa, Globorotalia menardii, Globorotalia pseudobesa, Globigerina regina, Globigerina praenepenthes, Globigerina umblicata, Globigerina multiloba, Globigerina pachyderma, Globigerina nepenthes, Sph. hancocki, Grtd. falconarae*, and *Orbulina universa*.

Based on the present definition of the *Orbulina universa* Zone (FA of *Orbulina universa* to the FA of *Globorotalia acostaensis*), the lower boundary of the zone may fall within the middle of Zone N9 or the lower third of it (Blow, 1969, 1979; Stainforth *et al.*, 1975; Kennett and Srinivasan, 1983; Bolli and Saunders, 1985; Iaccarino, 1985). The upper boundary of the *Orbulina universa* Zone has been drawn differently. Iaccarino (1985) put the upper boundary corresponding to the FA of *Globorotalia praemenardii* at the base of Zone N-10 in the Lower Serravallian, Hammuda *et al.* (1991) put it at the FA of *Globorotalia fohsi lobata-robusta* or the FA of *Borelis melo* at a similar stratigraphic position to Iaccarino (1985), while Cita and Premoli Silva (1971–1973 in 1976), Borsetti *et al.* (1979), Agip Minerraria (1980), and Duronio (1985) extended the upper boundary of the *Orbulina universa* Zone almost to the end of the Serravallian (and by correlation within Zone N15 or the base of N16, fide Kassab *et al.*, 1995–1996). Similarly in well H1-NC41, the *Orbulina universa* Zone upper boundary coinciding with the FA of *Globorotalia acostaensis* at the base of Zone 16.

The planktonic Foraminifera indicative of Zones N10–N15 are either very scarce (*Globorotalia mayeri, Globorotalia praemenardii, Globorotalia peripheroacuta, Globorotalia siakensis, Globigerina nepenthes*), or absent (*Globorotalia fohi fohsi, Globorotalia fohsi lobata, Globorotalia fohsi robusta*).

A possible hiatus within the *Orbulina universa* Zone may be questionably concluded due to the

ill representation (or absence) of the planktonic Foraminifera indicative of N-Zones (10, 11, 12, 13,? 14). However, in case of continuous deposition the *Orbulina universa* Zone of well H1-NC41 is correlated with the upper part of Zone N9-N15 of Blow (1969, 1979) and equivalent N-Zones and biozones (Blow, 1969, 1979; Berggren, 1969b, 1971; Stainforth *et al.*, 1975; Thunell, 1979; Kennett and Srinivasan, 1983, Bolli and Saunders, 1985; Iaccarino, 1985) (see Fig. 3).

Assuming constant rate of subsidence during the time of deposition of the *Orbulina universa* Zone (4.8 Ma) in the area of well H1-NC41, the 381.09 m would have been deposited at rate of 7.93 cm/1000 years.

10. The *Globorotalia acostaensis* Zone

The *Globorotalia acostaensis* Zone is a partial range zone of Lower Tortonian (low Upper Miocene) age. It is defined by the range of *Globorotalia acostaensis* from its FA (10.2 Ma Zhang *et al.*, 1993; 11.3 Ma, Bolli and Saunders, 1985; 10.0 Ma, Kennett and Srinivasan, 1983) to the first evolutionary occurrence of *Globigerinoides extremus* (6.7 Ma, Zhang *et al.*, 1993; 8.2 Ma, Bolli and Saunders, 1985; 7.7 Kennett and Srinivasan, 1983).

The *Globorotalia acostaensis* Zone is 690 ft. (210.3 m) thick (from D.D. 3280 ft. to D.D. 2590 ft.) sandstone, shale, silty clay, fossiliferous limestone, bryozoan limestone, marly limestone, and *Borelis* limestone representing the uppermost part of Al Mayah Formation and the lower part of the Tubtah Formation.

The planktonic foraminiferal assemblage of this zone is rather poor, its apparent percentage ranges from 0.76% to 35.34%. The genus *Globigerinoides* shows noticeable decrease in number of individuals and to a less extent in the number of species (44 species and variants, 34 of them are rare to very rare). Other Planktonic genera are also poorly represented. *Globorotalia acostaensis, Globorotalia cibaoensis, Globigerinoides? conglobatus, Globigerinoides elongatus*, and *Globigerinoides seigliei* made their FA in this zone. *Globigerinoides extremus* limits its upper boundary.

Based on its definition (the range of *Globorotalia acostaensis* from its FA to the FA of *Globigerinoides extremus*), the lower boundary of the *Globorotalia acostaensis* Zone is correlated with the lower limit of Zone N16 (Blow, 1969, 1979; Strainforth *et al.*, 1975; Kennett and Srinivasan, 1983; Bolli and Saunders, 1985; Iaccarino, 1985; Miller and Katz, 1987; Berggren and Miller, 1989; McLaughlin, 1989; Zhang *et al.*, 1993)

The FA of *Globigerinoides extremus* is within Zone N16 (Blow, 1969, 1979 lower part, Iaccarino, 1985, middle part), within lower part of Zone N17 (Zhang *et al.*, 1993), and at the base of Zone N17 corresponding to the FA of *Globorotalia humerosa* and *Globorotalia plesiotumida* (Kennett and Srinivasan, 1983; Barron *et al.*, 1985; Bolli and Saunders, 1985; McLaughlin, 1989). The restriction the FA of *Globigerinoides extremus* to the base of Zone N17 is in accordance with the last four authors.

Accordingly, the *Globorotalia acostaensis* Zone is correlated with Zone N16 of Blow (1969, 1979) and equivalent N-Zone and biozones (ignoring the FA of *Globigerinoides extremus* at the lowest part of Zone N16 of Blow, 1969, 1979).

The *Globorotalia acostaensis* Zone is of 3.5 Ma, 3.1 Ma, 2.3 Ma time duration (Zhang *et al.*, 1993; Bolli and Saunders, 1985, Kennett and Srinivasan, 1983) and in assuming a continuous deposition in the area of H1-NC41, the 210.3 m of sediments could have been accumulated at a rate of 6.0 cm/1000 years, 6.7 cm/1000 years, or 9.1 cm/1000 years.

11. The *Globigerinoides extremus* Zone

The Upper Miocene (Upper Tortonian-Lower Messinian) *Globigerinoides extremus* Zone is a partial range zone defined by the range of the zonal marker from its first evolutionary appearance (6.7 Ma, Zhang *et al.*, 1993; 7.7 Ma, Kennett and Srinivasan, 1983; 8.2 Bolli and Saunders, 1985) to the top of the studied section just below the unconformity separating the Miocene/Pliocene boundary.

The 710 ft. (216.46 m) thick interval depth from D.D. 2590 ft. to D.D. 1880 ft. covered by *Globigerinoides extremus* Zone is lithologically made of (in ascending order *Borelis* limestone, oolitic limestone, marly limestone, anhydrite, marl, gypsum, fossiliferous oolitic limestone, and gypsum belong to the upper part of the Tubtah Formation and most of the Marsa Zoughah Formation.

The planktonic Foraminifera are extremely rare (with exception of 2 samples which gave a good yield from the fine size fraction), the planktonic foraminiferal percentage ranges from 1.82% to 50.0%. The genus *Globigerinoides* is represented by 29 species and variants most of them are rare to

very rare. Other planktonic genera are also poorly represented.

The base of the *Globigerinoides extremus* Zone as defined here (the first evolutionary appearance of *Globigerinoides extremus*) marks the base of Zone N17 (Kennett and Srinivasan, 1983; Barron *et al.*, 1985; Bolli and Saunders, 1985; McLaughlin, 1989).

The top of the zone in well H1-NC41 is marked by unconformity at the Messinian (Upper Miocene)/Lower Pliocene boundary, therefore, the *Globigerinoides extremus* Zone of the present work is considered equivalent to most part of Zone N17 of Blow (1969, 1979) and equivalent N-Zones and biozones.

The top of this zone is not determined due to missing samples, however, the top of the Marsa Zouaghah Formation may represent the top of this zone and in any case an unconformity is indicated at the top of the Marsa Zouaghah Formation (NOC-Agip Name, 1979; Cococcetta, 1982, well H1-NC41 report), indicating missing time at the end of the Miocene, therefore an age older than 5.3 Ma is supposed for the top of the *Globigerinoides extremus* Zone in well H1-NC41, in this case the calculated time duration of the *Globigerinoides extremus* Zone in well H1-NC41 would be < 1.4 Ma, < 2.4 Ma, and < 2.9 Ma (see definition), accordingly the calculated rate of sedimentation would be: $>$ 15.46 cm/1000 years, $>$ 9.0 cm/1000 years, or $>$ 7.46 cm/1000 years.

HIATUSES

1. Eocene/Oligocene

Previous studies of the Eocene–Oligocene sequences in the subsurface NW offshore, Libya, assumed unconformable relations between the Upper Eocene Samdun Formation and the overlying Lower Oligocene *Nummulites vascus* marker bed (Panci *et al.*, 1976, well A1-NC41; NOC-Agip Name, 1979, well H1-NC41, 1981, well P1-NC41; 1982, well N1-NC41; Bristot, 1982, well M1-NC41). Eocene/Oligocene unconformity has also been detected between the Oligocene-Lower Miocene Ras Abd Jalil and Dirbal Formations and the underlying Tellil Group (Samdun Formation) (wells NC41: R1, S1, F1, F2, J1, B1-B8, C1-C8, well D1-NC35A; NOC-Agip Name, 1979, 1980, 1981, 1982, 1984, 1989, 1994, 1995; Drughi, *et al.*, 1978; Bristot and Cassan, 1982; Sirt Oil Co., 1983; Hammuda *et al.*, 1985; Duronio, 1985; Hammuda *et al.*, 1991). Assuming the Eocene–Oligocene boundary (i.e. the Priabonian-Rupelian boundary) is at 36.5 Ma (Berggren and Miller, 1988, 1989; Cowie and Basset, 1989) and consequently considering this boundary coinciding with the P17/P18 Zone (*T. cerroazulensis/Cassigerinella chipolensis* Zone), and as this planktonic foraminiferal boundary is not usually well detected in subsurface NW offshore, Libya due to the non-planktonic dominant foraminiferal fauna of the Upper Eocene–Lower Oligocene in the south central part of the basin, an unconformable relation is expected. Hammuda *et al.* (1991) considering the Lower Oligocene base of 37.0 Ma postulated unconformity ranging in magnitude from 4.5 Ma to 18.5 Ma for 9 wells in the NW offshore, Libya subsurface across the Eocene/Oligocene boundary.

The time span for *Cassigerinella chipolensis-pseudohastigerina micra* Zone may be in the range 2.5 Ma–3.0 Ma (see Bolli and Saunders, 1985; Berggren and Miller, 1988, 1989). In well H1-NC41 the *Globigerina ampliapertura* Zone (Zone P20) is underlain by the *Nummulites vascus* Zone (0.5 Ma by correlation with Ben Ferjani *et al.*, 1990), marks the base of the Oligocene, the time duration of both zones is around 2.5 Ma (*Globigerina ampliapertura* Zone is 2.0 Ma–2.5 Ma according to Blow, 1969, 1979; Berggren, 1969, 1971; Vail and Mitchum, 1979; Lidz, 1984; Bolli and Saunders, 1985; Haq *et al.*, 1987) consequently it is concluded that the hiatus time span at the base of the *Nummulites vascus* Zone (base of Oligocene) in well H1-NC41 may range from 2.5 Ma to 3.0 Ma (uppermost Zone N17, Zone P18, Zone P19,? lowermost Zone P20).

2. Oligocene

Based on the analysis of the vertical distribution (first and last occurrence) of the planktonic foraminiferal species *Globorotalia opima opima* (LA 28.2 Ma, Aubry, 1993), *Globorotalia kugleri*, (FA 23.7 Ma-LA 21.8 Ma, Zhang *et al.*, 1993), *Globigerina ciperoensis* (FA $\pm$35.5 Ma-LA $\pm$2.5 Ma, Bolli and Saunders, 1985), *Globigerinoides primordius* (FA $\pm$26.7 Ma-LA $\pm$23.7 Ma, Berggren and Miller, 1989), and *Globoquadrina dehiscens* (FA 23.2 Ma, Zhang *et al.*, 1993, Aubry 1993), it is possible that Zone P22 of Blow (1969, 1979) (equivalent to the *Globigerina ciperoensis* Zone of Bolli 1957, and *Globigerina angulisuturalis* Zone of Blow, 1969, 1979), and lowermost part of Zone

N4a are not represented in well H1-NC41 as it is explained by the overlap of the vertical ranges of *Globorotalia opima opima*, *Globorotalia kugleri* s.1. and *Globigerinoides primordius* (see Fig. 3). The duration of Zone P22 is 4.5 Ma (Berggren and Miller, 1988, 1989). This interval or at least most part of it (3.0 Ma–4.5 Ma) is not represented because of the overlap of the Zone N4 zonal markers with the P21 Zone (FA event of *Globigerinoides primordius* may start within the upper part of Zone P22, according to Miller and Katz, 1987; Berggren and Miller, 1988, 1989), accordingly this would give 1.0 Ma time of Zone P22 may be questionably represented in well H1-NC41.

3. Oligocene/Miocene

The present planktonic foraminiferal analysis does not reveal missing time at the transition from the Oligocene *Globorotalia kugleri* Zone to the Miocene *Globoquadrina dehiscens* Zone. However, previous studies by Panci *et al.* (1976, well A1-NC41), and Sirt Oil Co. (1983, 1984, 1985, wells NC35A D1, H1, I1) show unconformable relation across the Oligocene/Miocene boundary. Moreover, further studies may include the *Globorotalia kugleri* Zone within the Miocene, thus indicating unconformity at the base of the Miocene.

4. Middle Miocene

In well H1-NC41 the *Orbulina universa* is in normal biosequential relation with the underlying *Orbulina suturalis* Zone within Zone N9. The biozonal sequential relationship with the overlying biozones is not exactly determined due to the scarcity of the well known zonal markers. The planktonic Foraminifera indicative of Zone N10-N15 are either very scarce or absent. A possible hiatus within the *Orbulina universa* Zone may be questionably concluded due to the ill representation (or absence) of the planktonic Foraminifera indicative of N-Zones (10, 11, 12, 13,? 14)

5. Miocene/Pliocene

The uppermost Miocene is not determined due to missing samples, however, NOC-Agip Name (1979 well log) followed by Cococcetta (1982, well H1-NC41 report) indicated missing time at the end of the Miocene involving part of the Messinian, it includes the top of Zone N17 (*Globigerinoides extremus* Zone of the present work), therefore, an age older than 5.3 Ma is supposed for the top of the Miocene in well H1-NC41.

CONCLUSIONS

(1) Based on the vertical distribution of the planktonic Foraminifera, eleven planktonic foraminiferal biozones are recognized and are correlated with P-N Zones, and by their integration enabled to determined possible hiatuses as follows:

(a) The *Globigerina ampliapertura* Zone (2.0 Ma) is underlain by the *N. vascus* marker bed (0.5 Ma) both representing Zone P20 (2.5 Ma) with Zone P18-P19 of the Lower Oligocene missing.

(b) The *Globorotalia opima opima* Zone is correlated with Zone P21 (3.0 Ma).

(c) The *Globorotalia kugleri* Zone (0.5 Ma marking the top of the Oligocene is correlated with the Zone N4a (lower part of Zone N4) with Zone P22 (3.0 Ma-4.5 Ma) missing.

(d) The *Globoquadrina dehiscens* Zone (2.3 Ma) marking the Lower Miocene (Aquitanian) is correlated with the upper part of Zone N4 and the lowermost part of Zone N5.

(e) The *Globigerinoides altiapertura* Zone (3.3 Ma) (Lower Burdigalian) is correlated with Zone N5 (excluding its lowermost part) and Zone N6. Its lower boundary marks the Aquitanian/Burdigalian boundary.

(f) The *Globigerinoides bisphericus* Zone (1.3 Ma) (Upper Burdigalian) is correlated with Zone N7. Its upper boundary marks the Burdigalian/Langhian boundary.

(g) The *Praeorbulina glomerosa glomerosa* Zone (1.1 Ma) (Lower Langhian) is correlated with Zone N8. Its lower boundary marks the Burdigalian/Langhian boundary.

(h) The *Orbulina suturalis* Zone (0.2 Ma) (Upper Langhian) is correlated with the lower part of Zone N9. Its upper boundary marks the Langhian/Serravallian boundary.

(i) The *Orbulina universa* Zone (4.8 Ma) (Ser-

ravallian) is correlated with the upper part of Zone N9 to N15, however, there is a possibility of missing Zones N10 (part)–N15 (part) due to scarcity or absence of zonal index planktonic Foraminifera, the possibility of a hiatus in the Serravallian is not excluded. The top of this zone marks the Serravallian/Tortonian boundary.

(j) The *Globorotalia acostaensis* Zone (3.5 Ma, 2.3 Ma, 3.1 Ma) (Lower Tortonian) is correlated with Zone N16.

(k) The *Globigerinoides extremus* Zone (< 1.4 Ma, < 2.4 Ma, < 2.9 Ma) (Upper Tortonian/Lower Messinian) is correlated with Zone N17. The upper part of Zone N17 is considered missing and the top of the *Globigerinoides extremus* Zone unconformably marks the Messinian/Lower Pliocene boundary.

(2) The Eocene/Miocene boundary is taken at 33.7 Ma involving a hiatus older than 2.8 Ma.

(3) The Oligocene/Miocene boundary is taken at 23.2 Ma corresponding to the base of the *Globoquadrina dehiscens* Zone (base of Aquitanian).

(4) The Aquitanian/Burdigalian boundary is taken at (20.9 Ma) corresponding to the *Globoquadrina dehiscens/Globigerinoides altiapertura* Zones boundary.

(5) The Burdigalian/Langhian (Early Miocene/ Middle Miocene boundary) (16.3 Ma) is taken corresponding to the *Globigerinoides bisphericus/Pr. glomerosa glomerosa* Zones boundary.

(6) The Langhian/Serravallian (15.0) boundary is taken corresponding to the *Orbulina suturalis/Orbulina universa* Zones boundary.

(7) The Serravallian/Tortonian (Middle Miocene/ Late Miocene boundary) (10.2 Ma) is taken corresponding to the *Orbulina universa/ Globorotalia acostaensis* Zones boundary.

(8) Due to the scarcity of planktonic Foraminifera in the Late Miocene of well H1-NC41, the Tortonian/Messinian boundary is taken within the *Globigerinoides extremus* Zone following the NOC-Agip Name (1979, well log).

(9) The Miocene/Pliocene boundary is at the top of Marsa Zouaghah Formation possibly at the top of the *Globigerinoides extremus* Zone (+5.3 Ma).

(10) Based on the planktonic foraminiferal contents of the studied rock units, they are considered of Oligocene–Miocene age as follows:

(a) Ras Abd Jalil Formation (Lower Oligocene–Lower Miocene, lower Burdigalian).

(b) Al Mayah Formation [late Lower Miocene (upper Burdigalian) – early Upper Miocene (lower Tortonian)].

(c) Tubtah Formation (lower upper Miocene, Tortonian).

(d) Marsa Zouaghah Formation (upper Miocene, Messinian). The uppermost Miocene is not represented and the Lower Pliocene Sbabil Formation is unconformably overlying the Marsa Zouaghah Formation.

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