The contribution of Trinidad Micropaleontology to global E&P

BY BARRY CARR-BROWN, MANAGING DIRECTOR, BioSTRATIGRAPHIC ASSOCIATES (TRINIDAD) LTD

The development of micropaleontology in Trinidad has played an integral role in petroleum exploration and exploitation both locally and internationally. The planktonic foraminiferal zonation of the Cenozoic developed in Trinidad became the standard biostratigraphy used worldwide in the petroleum industry and in paleoceanographic work. Had it not been for John B. Saunders' contribution in particular on the *History of Trinidad Biostratigraphic Studies* in *A History of Trinidad Oil* by George E. Higgins in 1990, and articles by Saunders and Dr Hans M. Bolli in earlier publications of the *Fourth Latin American Geological Congress*, held in Port of Spain in 1979, and in the publication by the *Swiss Geological Society* commemorating Dr Hans G. Kugler's 80th birthday in 1974, these commercially and scientifically important contributions would have otherwise been overlooked and gone unacknowledged, except in the somewhat esoteric world of international micropaleontologists. In a newspaper article in 2002 on the history of the local biostratigraphic services sector, Barry Carr-Brown of BioSTRATIGRAPHIC ASSOCIATES (TRINIDAD) LIMITED, highlighted the role of this sector in the local petroleum industry and its historical origins since 1917. In commemorating the centenary of Trinidad's oil industry, it is therefore both timely and appropriate to recognise Trinidad's remarkable global contribution in the field of industrial micropaleontology and biostratigraphy.

In the context of industrial paleontology, one microfossil group in particular, the foraminifera, has played an integral role in tackling the multiplicity of geological challenges in petroleum exploration and exploitation. Their utility derives from their abundance and wide distribution in marine sedimentary rocks and because of their small size they are not destroyed by the drill bit and are recovered intact. They are represented by both benthic and planktonic forms which produce microscopic tests (shells) which readily fossilise. The benthics form ecologically controlled seafloor communities whose distributional characteristics on the one hand make them invaluable for the interpretation of depositional environments, reservoir seal and reservoir provenance and geometries, but for this very reason limits their use for long range synchronous correlation. The planktonics on the other hand occupy the surface and near-surface depths of the marine water column and are widely distributed by currents across oceans and shelf seas, and on death finally settle to the seafloor and are preserved in sediments occupying a wide range of environments. This factor, and their rapid evolution which is evident in the fossil record, makes the planktonic foraminifera invaluable for biochronological resolution, local and long-range correlation and age determination.

Origins of Industrial Micropaleontology in Trinidad

Early studies focused on the benthic foraminifera not only in Trinidad, but everywhere else. This was simply because micropaleontologists found it easier to distinguish benthic taxa than planktonic taxa, the morphological characteristics distinguishing the former being more readily apparent than in the latter. It was not until the 1940s that planktonic foraminiferal studies were initiated on a sustained basis, lead by micropaleontologists in Trinidad.

In Trinidad, studies of fossil foraminifera were published as early as 1863 by Robert J. Lechmere Guppy, a remarkable Trinidadian naturalist whose prolific publications on Trinidad natural history covered a wide range of scientific topics (Figure 1).

His 1863 paper was one of the earliest publications on fossil foraminifera in the Western Hemisphere. It was followed by others in 1873, 1894 and 1904 on the Cenozoic fossil foraminifera of Trinidad, which included several new species, which were the references for early 20th century industrial micropaleontological studies (Figure 2). Today, Robert J. Lechmere Guppy is principally remembered worldwide for the popular aquarium fish originally named for him – *Girardanus guppyi*, or the 'Guppy' which he had collected from the St Ann's River in Port of Spain.

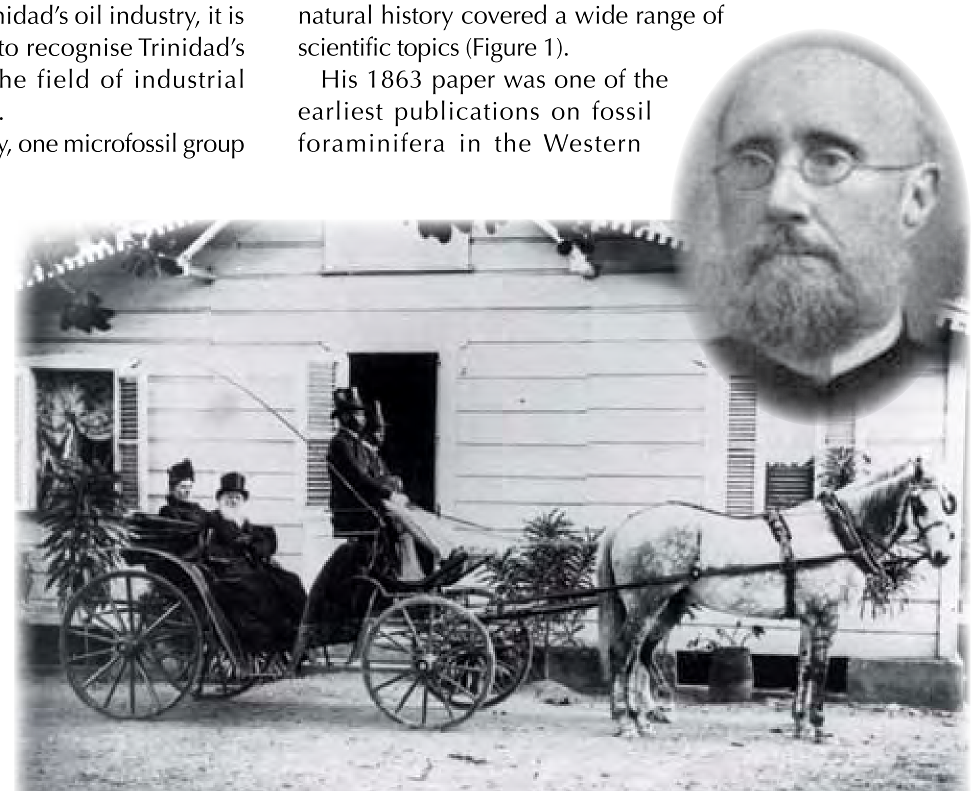


Figure 1: Robert J. Lechmere Guppy (inset), Trinidad naturalist and first micropaleontologist, 1836-1916. And again with his youngest daughter, Yseult, whose book 'Child of the Tropics – Victorian Memoirs', remains a firm favourite among Trinidadians to this day

Although Guppy's work preceded the drilling of Captain Walter Darwent's Aripero oilwell in 1867 and Randolph Rust's early twentieth century wildcatting efforts in Aripero and Guayaguayare, it was not until after 1913 that the industrial potential of foraminifera for geological correlation was fully appreciated in Trinidad. This was 16 years after the first demonstration in Poland in 1897 by Professor Josef Grzybowski of the stratigraphic utility of fossil foraminifera for surface and subsurface geological correlation in the oilfields of Galicia, and coincided with the creation in 1919 of the first industrial micropaleontological laboratory in the United States (US) by the Humble and Rio Bravo Oil Company.

The value of foraminifera for the oil industry in Trinidad was first visualised by Dr August Tobler in 1913. Tobler was a consultant geologist to the Central Mining and Investment Corporation which was owned by Goldfields of South Africa, and which later established Trinidad Leaseholds Ltd (TLL), the predecessor of Texaco Trinidad Inc and the present day successor, the Petroleum Company of Trinidad and Tobago Ltd (Petrotrin). While sampling the Cipero coast south of San Fernando with his young field assistant, Hans G. Kugler, Tobler with remarkable prescience articulated his vision of the use of foraminifera for worldwide geological correlation. This inspired Hans G. Kugler's immediate interest and later support for the development of industrial micropaleontology in Trinidad and for the establishment of the first paleontological laboratory at Pointe-a-Pierre in 1929 (Figure 3).

Forty-four years after Tobler's observations, the planktonic foraminiferal zonation of the Cipero Formation beds exposed on the Cipero Coast, which was part of the larger Cenozoic zonation of the island, made this coastal strip the 'holy grail' of local and visiting micropaleontologists. Today, unfortunately, this historically important exposure is covered by the San Fernando city dump and is no longer accessible.

With encouragement from Hans G. Kugler, W.F. Penny first demonstrated the use of foraminifera for geological correlation in Trinidad, as well as in Western Venezuela. Penny had arrived from Romania in 1917, later becoming chief geologist of TLL. It is interesting to speculate that, coming from Romania as he did, he may have been aware of Josef Grzybowski's success in the Polish oilfields, which would have made him particularly

Figure 2: Plate from publication by Robert J. Lechmere Guppy, 1894, illustrates the first new species of foraminifera to be described from Trinidad. These are all benthics. (From J. B. Saunders, Fourth Latin American Geological Congress, 1979)

Figure 3: Paleontology building, TLL Geological Laboratory, Pointe-a-Pierre, 1946 (Hans M. Bolli, Fourth Latin American Geological Congress, 1979)

PRESUMED AGE today	PRESUMED AGE when erected	ZONE	FORMATION	AUTHOR, YEAR
MIOCENE M	MIOCENE L	Globorotalia menardii	Lengua	Stainforth, 1948
	OLIGOCENE U	Globorotalia fohsi	Cipero	Cushman & Stainforth, 1945
MIOCENE L	OLIGOCENE M–U	Globigerinatella insueta		Cushman & Stainforth, 1945
		Globigerina dissimilis		Cushman & Renz, 1947
OLIGOCENE U	L	Globigerina concinna		Cushman & Stainforth, 1945
EOCENE U	EOCENE U	Hantkenina alabamensis	Hospital Hill	Stainforth, 1948

Figure 4: The first planktonic foraminiferal zones erected in Trinidad, 1945-48 (John B. Saunders and Hans M. Bolli, Fourth Latin American Geological Congress, 1979)

receptive to Hans G. Kugler's urging to assess and develop the potential of foraminifera in oil exploration in Trinidad.

Remarkably, however, it was Percy W. Jarvis, a keen microscopist and a manager of Barclays Bank in San Fernando (where there is a Jarvis Street today), who under Penny's direct influence in 1918, started collecting and studying foraminifera from different formations, and established their geological credentials for geological mapping and petroleum exploration. He established the first commercial micropaleontological consultancy in Trinidad which flourished between 1918 and 1933, preparing and selling type slides of microfossils at WI$100 each which were bought by the major companies who retained him as a consultant. In the end he was defeated by his own success, when his clients, who included TLL, TPD (Trinidad Petroleum Development Company) and UBOT (United British Oilfields of Trinidad – later Shell Trinidad Ltd), recognising the value of his work, established their own paleontological laboratories. Jarvis offered his services to the TLL Pointe-a-Pierre laboratory at WI$150 per month (about TT$17,500 today); TLL advised him that this was too expensive and anyway they were planning to employ a full-time paleontologist. Hans G. Naegeli was brought out from Switzerland as the first supervisor of the Pointe-a-Pierre laboratory, and Jarvis was retained for training. Although his commercial work came to an end by 1933, he continued his micropaleontological research and gained international recognition from several scientific publications on the Cretaceous and Cenozoic foraminifera of Trinidad, co-authored between 1928-33 with Joseph A. Cushman, the famous pioneer of the commercial application of foraminifera in North America. Jarvis described with Cushman the first new planktonic foraminifera from Trinidad. Jarvis' collaboration with Joseph A. Cushman, and succeeding collaborations between 1945-48 with Cushman by the early micropaleontological staff of the TLL Geological Laboratory in Pointe-a-Pierre, notably Hans H. Renz and R.M. Stainforth, were the beginnings of planktonic foraminiferal biostratigraphy in Trinidad.

Despite the abundance of planktonic foraminifera in the Cretaceous and Paleocene to Middle Miocene formations of Trinidad, this phase of work by oil company laboratories in Trinidad focused almost exclusively on the benthic foraminifera for geological correlation. As mentioned earlier, this was a consequence of the apparent morphological monotony of the planktonics perceived by micropaleontologists at the time here and in the industrial micropaleontological laboratories in North America, and nearby Venezuela. Exhaustive compilations in internal company reports in Trinidad formed the basis of the benthic zonations and correlations which were pushed to the limit in surface and subsurface mapping. This had some practical application in the short-range correlation of the Upper Miocene to Pliocene deltaic-marine producing horizons of the Cruse, Forest and Gros Morne formations of southern Trinidad, in which planktonics were scarce or absent, and there was no other choice but to work with the benthics.

THE TRINIDAD SCHOOL OF BIOSTRATIGRAPHY

The Response to New Exploration Incentives – Beginnings of Planktonic Foraminiferal Biostratigraphy

Because of the structural and stratigraphic complexity of the Cretaceous and Paleocene to Middle Miocene formations of Trinidad, which were coming under active exploration after WWII in the late 1940s to 1950s, a new micropaleontological approach had to be found which would provide greater accuracy in correlation for both surface and subsurface mapping in oil exploration. This prompted a movement to the planktonic foraminifera, which are abundant in most of these formations, and whose potential for long-range cross-formational correlation

Figure 5: The Cenozoic planktonic foraminiferal zonal scheme developed in the Caribbean area, 1957-1973 (John B. Saunders and Hans M. Bolli, Fourth Latin American Geological Congress, 1979). ▬ Zone established in Trinidad (Bolli, 1957, Bulletin 215). — Zone established in eastern Venezuela (Bolli and Bermudez, 1965). • Zone established in Caribbean DSDP (Bolli, 1970; Bolli and Premoli-Silva, 1973; Premoli-Silva and Bolli, 1973)

AGE		PLANKTONIC FORAMINIFERAL ZONES		FORMATIONS IN SOUTH AND SOUTHEAST TRINIDAD: Rich in planktonic foraminifera	FORMATIONS IN SOUTH AND SOUTHEAST TRINIDAD: Predominantly benthic foraminifera
HOL		Globorotalia truncatulinoides truncatulinoides	• Globorotalia fimbriata		
PLEIST.			• Globigerina bermudezi	Planktonic foraminifera are poorly represented in this interval	Cedros; Erin; Palmiste
			• Globigerina calida calida		
			• Globorotalia hessi		
			• Globorotalia crassaformis viola		
PLIOCENE	U	• Globorotalia truncatulinoides cf. tosaensis			
	M	• Globorotalia miocenica	• Globorotalia exilis		
			• Globigerinoides trilobus fistulosus		Morne l'Enfer
	L	Globorotalia margaritae	Globorotalia margaritae evoluta		Forest; Mayaro
			Globorotalia margaritae margaritae		
MIOCENE	U	Globorotalia dutertrei			Cruse; Gros Morne
		Globorotalia acostaensis			Lower Cruse
	M	Globorotalia menardii		Lengua	
		Globorotalia mayeri			Karamat
		Gloigerinoides ruber		Hiatus	
		Globorotalia fohsi robusta		Cipero	
		Globorotalia fohsi lobata			Herrera Mbr.
		Globorotalia fohsi fohsi			
		Globorotalia fohsi peripheroronda			
	L	Praeorbulina glomerosa			
		Globigerinatella insueta			
		Globigerinita stainforthi			
		Globigerinita dissimilis			Nariva
		Globigerinoides primordius			
OLIGOCENE	U	Globorotalia kugleri			
		Globigerina ciperoensis ciperoensis			
	M	Globorotalia opima opima			
		Globigerina ampliapertura			
	L	Cassigerinella chipolensis/ Hastigerina micra		Hiatus	
ECOCENE	U	Globorotalia cerroazulensis s.l.		San Fernando	
		Globigerinatheka semiinvoluta		Navet	
	M	Truncorotaloides rohri			
		Orbulinoides beckmanni			
		Globorotalia lehneri			
		Globigerinatheka subconglobata subconglobata			
		Hantkenina aragonensis			
	L	Globorotalia palmerae		Upper Lizard Springs	Pointe-a-Pierre
		Globorotalia aragonensis			
		Globorotalia formosa formosa			
		Globorotalia subbotinae			
		• Globorotalia edgari		Hiatus	
PALEOCENE	U	Globorotalia velascoensis		Lower Lizard Springs	Chaudière
		Globorotalia pseudomenardii			
	M	Globorotalia pusilla pusilla			
		Globorotalia angulata			
	L	Globorotalia uncinata			
		Globorotalia trinidadensis			
		Globorotalia pseudobulloides		Hiatus	Hiatus
		Globigerina eugubina			

AGE		STAGES	CRETACEOUS PLANKTONIC FORAMINIFERAL ZONES: Applied in DSDP Leg 40, S. Atlantic	CRETACEOUS PLANKTONIC FORAMINIFERAL ZONES: Applied in Trinidad	FORMATIONS
CRETACEOUS	UPPER	MAASTRICHTIAN	Globotruncana mayaroensis	Abathomphalus mayaroensis	Guayaguayare
			Globotruncana gansseri	Globotruncana gansseri	
			Globotruncana havanensis	Globotruncana lapparenti tricarinata	
		CAMPANIAN	Globotruncana calcarata		Hiatus
			Globotruncana ventricosa	Globotruncana stuarti	Naparima Hill
			Globotruncana fornicata	Globotruncana fornicata	
		SANTONIAN	Globotruncana concavata carinata	Globotruncana concavata	
			Globotruncana concavata		
		CONIACIAN	Globotruncana primitiva	Globotruncana renzi	
		TURONIAN	Globotruncana sigali		
			Globotruncana helvetica	Globotruncana inornata	
			Hedbergella portsdownensis		Hiatus
		CENOMANIAN	Rotalipora cushmani		
			Rotalipora reicheli		
			Rotalipora greenhornensis		
			Rotalipora gandolfii	Rotalipora appenninica appeninica	Gautier
			Rotalipora brotzeni		
	LOWER	ALBIAN	Rotalipora appenninica		
			Planomalina buxtorfi	Favosella washitensis	
			Rotalipora ticinensis	Rotalipora ticinensis ticinensis	
			Biticinella breggiensis	Praeglobotruncana rohri	Maridale Marl Mbr
			Ticinella primula		
		APTIAN	Ticinella bejaouensis	Planomalina maridalensis	
			Hedbergella trochoidea		
			Hedbergella gorbachikae		
			Globigerinelloides algeriana	Leupoldina protuberans	Cuche
			Schakoina cabri		
			Globigerinelloides blowi		
		BARREMIAN	Hedbergella sigali	Lenticulina ouachensis ouachensis	Toco
				Lenticulina barri	

Figure 6: Trinidad Cretaceous planktonic foraminiferal zonation and later modern zonal scheme.
▬ Zones established in Trinidad (Bolli, 1957 and 1959)

had been already recognised. Considerable effort was directed into resolving the systematics (scientific classification) of the planktonic foraminifera, establishing their geological ranges, and evaluating their effectiveness for biostratigraphic correlation. The success of this work was due to a small group of dedicated micropaleontologists in the TLL laboratory at Pointe-a-Pierre. Their effort was actively encouraged by Hans G. Kugler, who became chief geologist of TLL in 1922, and who influenced company management to allow the early publication of their results. The chief geologist of UBOT/Shell Trinidad Ltd at the time, Dr Terpstra, shared Hans G. Kugler's vision for the commercial and scientific potential of planktonic foraminiferal micropaleontology, and a more limited parallel effort was made in the UBOT/Shell laboratory in Point Fortin. However, UBOT/Shell never published their results, limiting knowledge of their progress internally, so relinquishing centre stage to the work of the TLL laboratory in Pointe-a-Pierre.

The early TLL micropaleontological staff included Hans H. Renz, who was in charge of the Pointe-a-Pierre laboratory from 1937-47, and expanded it considerably. He was joined by Bramine Caudri from 1939-42, and R.M. Stainforth from 1939-44, before moving on to Venezuela.

Collaborative efforts of Joseph Cushman with R.M. Stainforth and Hans H. Renz from 1945-47, and independent work by R. M. Stainforth in 1948, produced the first crude planktonic foraminiferal zonations of the Miocene Lengua and Cipero formations, and the recognition of the first Upper Eocene zone of the Navet formation (Figure 4).

This was the beginning of a concerted effort by TLL micropaleontologists who produced a succession of publications between 1948-57 which refined the systematics of the planktonic foraminifera and resulted in a definitive planktonic foraminiferal zonation for the Paleocene to Middle Miocene (and Upper Cretaceous) formations of Trinidad, which became a worldwide standard for middle to low latitude planktonic foraminiferal biostratigraphy (Figures 5, 6). These micropaleontologists included Paul Brönnimann from 1946 to 1952; Hans M. Bolli from 1946-58; Walter H. Blow from 1953-56; Jean-Pierre Beckmann from late 1953-57; and John B. Saunders from 1951-75. Brönnimann, Bolli and Saunders were successive supervisors of the Pointe-a-Pierre laboratory between 1947-75, followed by John Frampton and Robert D. Liska after 1975, and Barry Carr-Brown from 1985-90 (then the Trinidad and Tobago Oil Company Geological Services Laboratory). Both John Frampton and Barry Carr-Brown of BioSTRAT began their professional careers in micropaleontology under John B. Saunders in the Pointe-a-Pierre laboratory after Texaco's acquisition of TLL and came into close association early in their careers with Hans M. Bolli while he was with Shell in Venezuela and afterwards when Professor of Geology and Chairman of the Geology Department at the Swiss Federal Institute of Technology (ETH) in Zurich, and following retirement, as Emeritus Professor at the University of Zurich.

The Bible of Industrial Micropaleontology – *Bulletin 215*
Most of the published work on the planktonic foraminifera was done over the 10-year period between 1948 and 1957 by Paul Brönnimann, Hans M. Bolli, Jean-Pierre Beckmann, and to an extent by Walter Blow. This was synthesised and carried to its apotheosis by Hans M. Bolli with his 1957 publication of a series of papers in *Bulletin 215 – 'Studies in Foraminifera'* – of the US National Museum on the systematics of the planktonic foraminifera and planktonic zonation of the Upper Cretaceous and Paleocene to Middle Miocene formations of Trinidad. *Bulletin 215* immediately became the 'Bible' of planktonic foraminiferal micropaleontology and biostratigraphy for industry professionals.

First Modern Geological Map of Trinidad
Armed now with a better means for geological dating and correlation, work commenced on the production of the first modern geological map of Trinidad. The stratigraphy of thousands of surface samples was revised and well sections were re-examined. Maps and cross-sections at a scale of 1:50,000 were constructed by Hans G. Kugler, and then, with the sponsorship of the Petroleum Association of Trinidad, a coloured 1:100,000 geological map and cross-sections was published in 1961. This was updated in 1998 by John B. Saunders with the financial and technological support of Amoco Trinidad Oil Company, and published by the Ministry of Energy and Energy Industries. A significant revision of the correlation of the Upper Miocene to Pleistocene formations was contributed by BioSTRATIGRAPHIC ASSOCIATES (TRINIDAD) LIMITED (BioSTRAT). Their new interpretation was based on the results of modern multidisciplinary sequence-based biostratigraphic analysis of over 13,000 metres of outcrops surveyed and sampled by BioSTRAT in the first – and only – comprehensive geological field programme undertaken in Trinidad since 1955.

Export of Trinidad Industrial Micropaleontology and Biostratigraphy
The global export and usage of Trinidad planktonic foraminiferal micropaleontology and biostratigraphy established what has been referred to in 1975 as the *Trinidad School of Biostratigraphy* by R.M. Stainforth and collaborators at the Exxon Production Research Company in Houston and *The Trinidad Connection* by Australian paleontologist-geologist Brian McGowran of the University of Adelaide in his definitive publication on modern biostratigraphy in 2005.

This phase began in 1948 when Hans H. Renz recognised the uppermost Trinidad Lower Miocene (*Globigerinatella insueta*) and Middle Miocene (*Globorotalia fohsi*) zones in Falcon, Western Venezuela. At the same time R.M. Stainforth compared planktonic foraminifera of Trinidad with coastal Ecuador, and in 1953 the same thing was being done on the Paleocene of Denmark by Paul Brönnimann while head of the

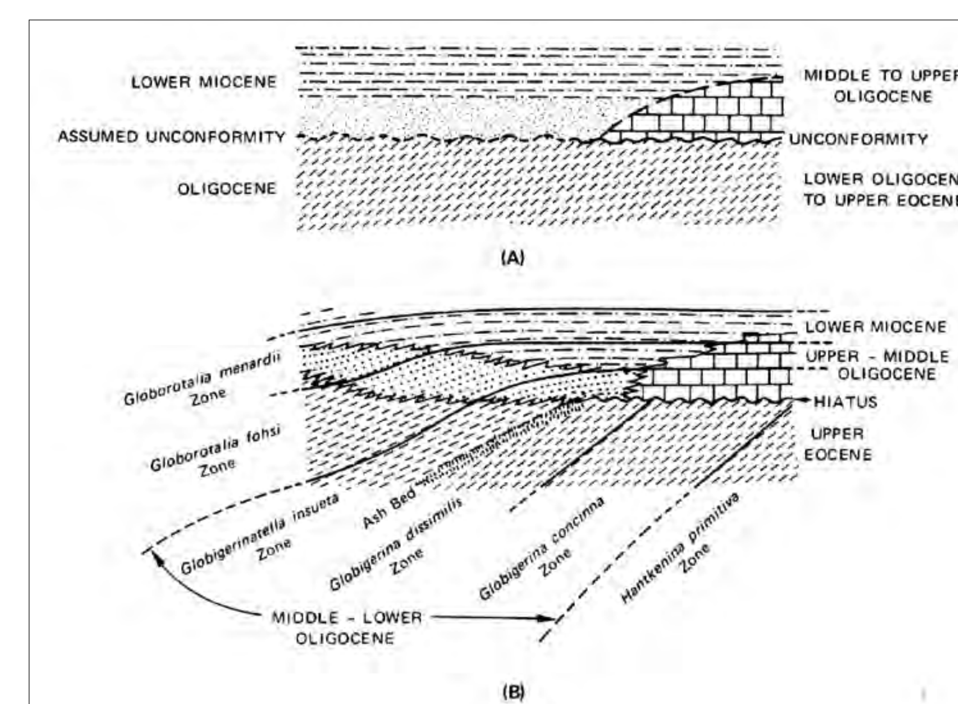
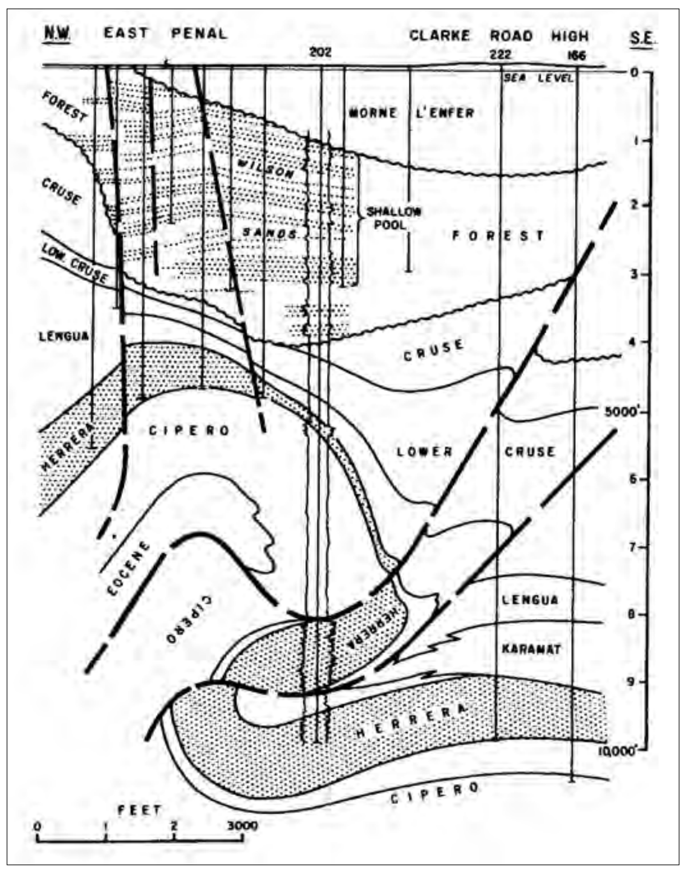


Figure 7: Cross-sections of Borbon basin flank exposures northwestern Ecuador, showing (A) initial interpretation based on field reconnaissance and limited fossil evidence, and (B) revised interpretation and correlations from planktonic foraminiferal analysis and application of early Trinidad planktonic foraminiferal biostratigraphy, by R.M. Stainforth around 1950 (Article 62, Univ. of Kansas Paleontological Contributions, 1975)

TRINIDAD MICROPALEONTOLOGY



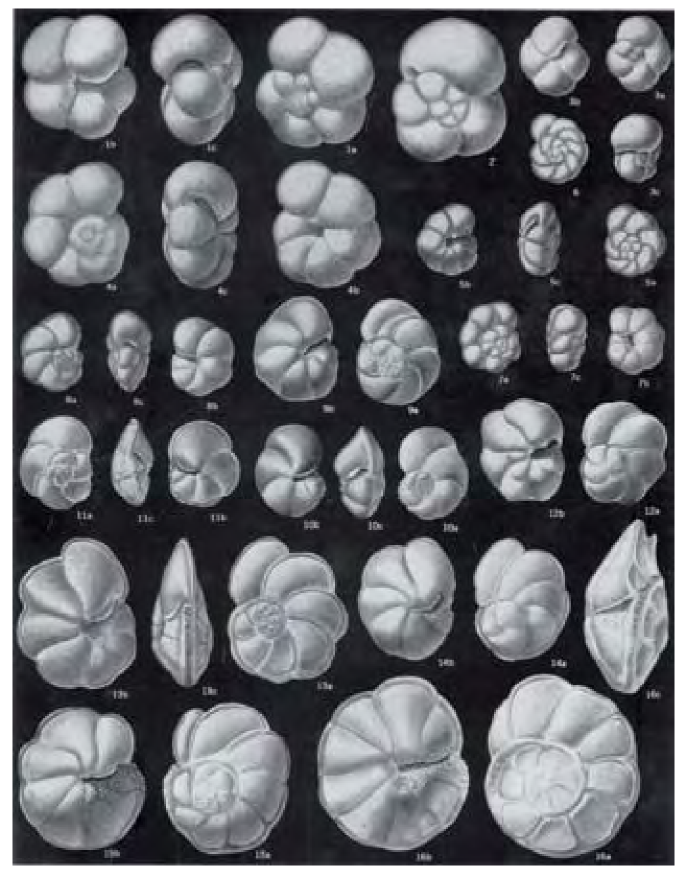


Figure 8a (above left): Subsurface structure of the East Penal oilfield using planktonic foraminiferal control (Peter Bitterli, 1958, reproduced from Trans. 4th Caribbean Geological Conference, 1965)

Figure 8b (above right): US National Museum Bulletin 215 plate, showing Globorotalia marker species used for the planktonic foraminiferal zonation of the Cipero formation. The four-fold zonation of the Middle Miocene Herrera sandstone member, based on the evolutionary lineage of the Globorotalia fohsi subspecies (8-16), made possible the correlation of the Herrera reservoirs and recognition of the overturned structure

Gulf Oil Company geological laboratory in Cuba. Brönnimann, with N.K. Brown, further extended this work on the Upper Cretaceous of Cuba in 1955. In 1958 Jean-Pierre Beckmann and P.H. Martin-Kaye (also an alumnus of the TLL Pointe-a-Pierre laboratory) successfully applied the Trinidad Paleocene to Eocene and Oligocene to Miocene planktonic foraminiferal zonations in Cuba and in the southeast Caribbean island of Carriacou, respectively. Shortly after, in 1959, W.H. Blow produced a Lower to Middle Miocene zonation of eastern Falcon, Venezuela, virtually identical to the Trinidad planktonic foraminiferal zonation. Blow went on to direct planktonic foraminiferal studies at the BP Research Centre at Sunbury-on-Thames, where he drew heavily on his Trinidad experience.

A year later, in 1960, the Trinidad Paleogene (Paleocene to Oligocene) planktonic foraminiferal micropaleontology and zonation were extended to northern Italy by Hans M. Bolli and M.B. Cita of the University of Milan. In 1965 Hans M. Bolli and Pedro Bermudez extended the planktonic foraminifera zonation of the Cenozoic above the Middle Miocene, when they established the Upper Miocene and Lower Pliocene zones in northern Venezuela. From 1965 the Trinidad zonation was applied to the Eocene to Miocene of Barbados by John B. Saunders, who cooperated closely in the remapping of the island's complex geology which was critical to future oil exploration efforts. In 1966 Bolli demonstrated that the late Neogene planktonic succession of Java was similar to that of the Caribbean. After this point in time, Trinidad and Caribbean planktonic foraminiferal biostratigraphy entered a new phase of development with the advent of the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES) Deep Sea Drilling Project (DSDP), when the Cenozoic zonation was completed and refined.

Commercial Impact – Three Classical Examples from Trinidad, Venezuela and Ecuador

Three classical examples of the impact of the early applications of Trinidad planktonic foraminiferal biostratigraphy to surface and subsurface geological mapping are R.M. Stainforth's work in northwestern Ecuador, Peter Bitterli's reinterpretation of the structure of the Penal field in Trinidad, and James Lamb's reinterpretation of the Quiriquire field in eastern Venezuela.

The first is the demonstration around 1950 by R.M. Stainforth of the utility of the evolving Trinidad planktonic foraminiferal zonation for correlating paleoenvironmentally and lithologically dissimilar deposits mapped at surface in northwest Ecuador for petroleum exploration (Figure 7).

In 1958 correlation based on the planktonic zonation of the Cipero formation was applied successfully by Peter Bitterli of Shell Trinidad to working out the extremely complicated geological structure and correlation of the overturned and thrust faulted Herrera sandstone reservoirs of the Penal-Barrackpore oilfields and made possible their successful exploitation (Figures 8a-8c). The resulting gas production fuelled the Trinidad and Tobago Electricity Commission's (T&TEC's) first gas turbine-powered electricity generating plant in Trinidad, located at Penal.

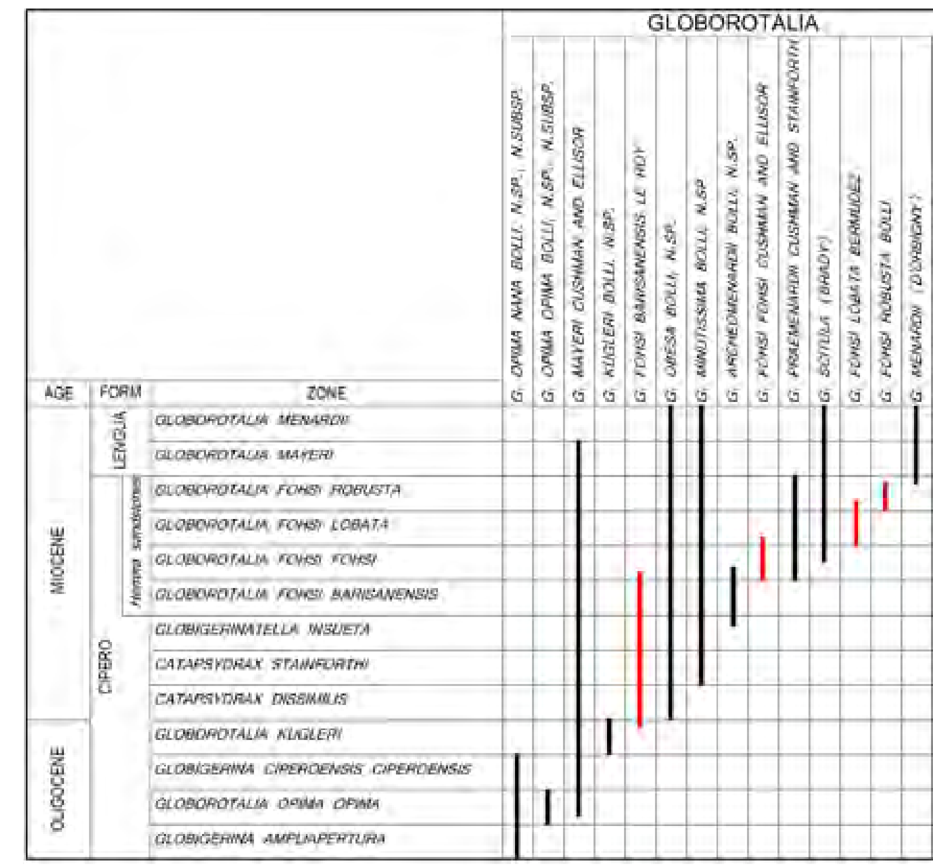


Figure 8c: Geological ranges of Globorotalias used for the planktonic zonation of the Cipero and Lengua formations, with the Globorotalia fohsi subspecies used for correlation of the Herrera sandstone reservoirs highlighted in colour (based on figure in US National Museum Bulletin 215)

The third example is a reinterpretation of the structure and stratigraphy of the huge Quiriquire oilfield in 1970 by James Lamb, who, using the planktonic zonation developed in *Bulletin 215*, turned the conventional interpretation on its head in demonstrating that the deep subsurface structure of the field is an overturned fold, thus crucially redirecting exploration and exploitation efforts in Quiriquire (Figure 9).

Gulf of Mexico Exploration – Extension of Trinidad Planktonic Foraminiferal Biostratigraphy

Eventually Trinidad planktonic foraminiferal biostratigraphy spread to the Gulf Coast of the USA on a routine operational basis, driven by the expansion of exploration offshore, where correlations based on traditional benthic foraminiferal biostratigraphy which had worked well previously, began to fail as deeper marine sequences with planktonics were encountered downdip offshore. In 1969, in the first of many working visits with the Amoco Production Company operations paleontology group in New Orleans, the author became closely associated with Dr A.D. 'Buzz' Ellis, who had been mandated to develop the Amoco New Orleans division's planktonic foraminiferal capability – more than 10 years after planktonic biostratigraphy was routine in Trinidad! Efforts of the Amoco Production Research Centre in Tulsa and of the research and operations laboratories of other companies, in particular that of the Exxon Production Research Company under the direction of R.M. Stainforth, the Trinidad-based planktonic foraminiferal zonation of the Cenozoic evolved into the Gulf of Mexico planktonic correlation scheme of today.

Oceanographic Applications in the Caribbean-Atlantic Region

After 1968, the paleoceanographic programme of the JOIDES Deep Sea Drilling Project gave a whole new impetus to Trinidad and Caribbean planktonic foraminiferal studies. John B. Saunders at the Texaco Trinidad Inc (formerly TLL) laboratory at Pointe-a-Pierre was a member of the planning committee for the Caribbean sea floor coring programmes, served as co-scientific chief in the DSDP Leg 15, and collaborated with the shipboard scientists of this and the earlier Leg 4 in the Caribbean – western Atlantic, notably Isabella Premoli-Silva of the University of Milan and Hans M. Bolli, in the analytical work and publication of the results. These included descriptions of the planktonic foraminifera from the cored sequences of the sea floor drill sites, correlations with Trinidad, Cubagua and Margarita islands and western and northern Venezuela, and the development of the Upper Miocene to Pleistocene planktonic foraminiferal biostratigraphy for the Caribbean – northern South American region.

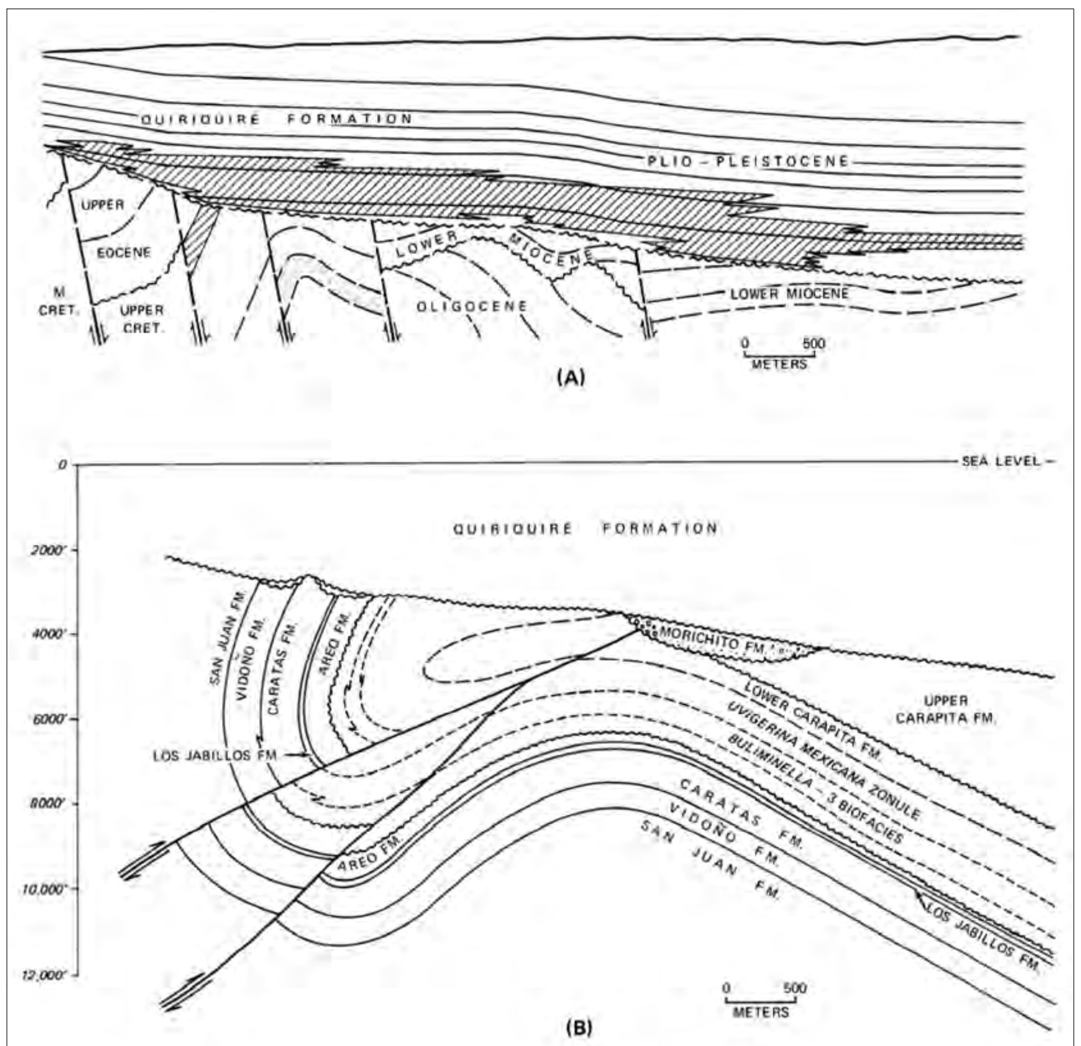


Figure 9: Early conventional interpretation of the structure and stratigraphy of the Quiriquire oilfield (A), and (B) later revised interpretation of its subsurface structure based on planktonic foraminiferal biostratigraphy by J.L. Lamb, 1970 (Article 62, University of Kansas Paleontological Contributions, 1975)

A Global and Regional Synthesis of Planktonic and Benthic Biostratigraphy

In 1975 John B. Saunders resigned from Texaco Trinidad Inc and joined Hans G. Kugler at the Natural History Museum Basel, as Curator of Micropaleontology. While at the NHMB he continued his collaboration on Trinidad and Caribbean micropaleontological research with Hans M. Bolli at the Swiss Federal Institute of Technology (ETH) in Zurich, and co-edited and co-authored with Bolli and former Trinidad TLL laboratory and European and North American colleagues, two definitive books on biostratigraphy. The first, *Plankton Stratigraphy*, published in 1985, is a major work, integrating high and low latitude planktonic foraminiferal biostratigraphy of the Cretaceous and Cenozoic, with the other major planktonic biostratigraphic subdisciplines which developed in paleoceanographic and commercial usage and calibrated the zonations derived for these, using radiometric dates and geomagnetic stratigraphy records. The second, published in 1995, *Benthic Foraminiferal Biostratigraphy of the South Caribbean Region*, co-authored by alumni of the TLL/Texaco Trinidad Pointe-a-Pierre geological laboratory – Hans M. Bolli, Jean-Pierre Beckmann and John B. Saunders – is a comprehensive integration of Cretaceous and Cenozoic benthic foraminiferal micropaleontology of Trinidad, Venezuela and the southern Caribbean, with modern planktonic foraminiferal biostratigraphy, and is the standard reference for the region.

Final Contributions of the Pointe-a-Pierre Laboratory Alumni to Trinidad Geology

John B. Saunders retired from the Natural History Museum Basel in 1994 and settled in Wensleydale, Yorkshire, where he had done mapping as a geological student. Hans M. Bolli died in 2007. Both were elected honorary members of the Geological Society of Trinidad and always maintained a close personal and professional relationship with Hans G. Kugler, who died at age 93 in 1986. They never lost their close professional ties with industry professionals in Trinidad, Venezuela and the Caribbean, embracing every opportunity to be involved with the region's geology and paleontology, and of Trinidad in particular (Figures 10-12).

Hans M. Bolli's last visits to Trinidad were in 1987 to give a professional seminar in Pointe-a-Pierre organised by the author, and in 1993 for a sentimental vacation with his family. His final scientific contribution to this country was Part 4 of Hans G. Kugler's Treatise of the Geology of Trinidad, on the Paleocene to Holocene formations, which he edited, updated and saw to its publication by the Natural History Museum Basel in 2001. This is the standard stratigraphic lexicon for Trinidad geological work.

John B. Saunders was last in Trinidad in 1998 for the official release by the Ministry of Energy and Energy Industries of the Revision of H.G. Kugler's 1:100,000 scale Map of Trinidad, which work he had initiated and in which he invested considerable effort, and edited, inclusive of the new geological map of Tobago by Professor A.W. Snoke of the University of Wyoming, and his graduate students. ❑

Figure 10: From left to right: Felix Wiedenmeyer, Hans M. Bolli, John B. Saunders and Barry Carr-Brown at ETH, Zurich, 1986

Figure 11: From left to right: John B. Saunders, Barry Carr-Brown, Hans G. Kugler and Hans H. Renz at Kugler's vacation spa, the Schönegg Hotel, Switzerland, 1986

Figure 12: Taking a break from resurveying the Late Miocene San Jose River outcrops, Central Range, 1996. From left to right: Barry Carr-Brown (BioSTRAT), Brian Harry (Amoco), John B. Saunders (NHMB), guide, J. Frampton (BioSTRAT)