THE STRATIGRAPHIC DISTRIBUTION OF NEOGENE DINOFLAGELLATE CYSTS FROM A DEEP WATER WELL, OFFSHORE SABAH, NORTHERN BORNEO

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ABSTRACT

A research project was initiated with the objective to establish a dinoflagellate cyst biozonation for deep water wells drilled offshore Sabah and Brunei, Northern Borneo, to complement the biozonations based on nannoplankton, foraminifera and spores-pollen.

Analysis of dinoflagellate cysts in ditch cutting samples from deep water well Kebabangan-1, offshore Sabah, resulted in a list of FDO's, which could be of stratigraphic value: Hystrichokolpoma rigaudiae at 3150', Operculodinium sp. A at 3840', Dapsilidinium pastielsii at 4140' and Lingulodinium pycnospinosum at 4950' within the Pliocene section; Selenopemphix brevispinosa subsp. conspicua at 5760' and consistent occurrence of Achomosphaera sp. B at 5760' within the Upper Miocene section. Samples from appraisal well Kebabangan-2 were examined for calibration.

Dinoflagellate cysts have been recovered from mud-rich shelfal topsets and underlying mud-rich slope fan systems in the interval 2610' to 6495', while the basal sand-rich base-of-slope fans in the interval 6705' to 7905' were barren of palynomorphs. A dinoflagellate biozonation is not yet proposed based on analyses of one well and cursory examination of the appraisal well. The correlation potential of the FDO's reported for this well needs to be confirmed in follow-up wells along the Northern Borneo offshore.

INTRODUCTION

The objective of this study was to establish a dinoflagellate cyst biozonation for deep water wells drilled offshore Sabah and Brunei, Northern Borneo, to complement the routinely used biozonations based on nannoplankton, foraminifera and spores-pollen.

The first phase of this project, palynological analyses of a pilot well, was carried out in 2001-2002, while the author was employed by Curtin University in Perth, Australia, as senior lecturer at the then existing Centre of Excellence in Petroleum Geology. Results were presented at the 34th Annual Meeting of the American Association of Stratigraphic Palynologists in San Antonio, USA (Van den Brink 2002, abstract only), and an abbreviated version was published in Berita Sedimentologi 16 (2001).

Because of the limited amount of publications on dinoflagellate cysts of Neogene age in low latitudes and specifically in SE Asia (e.g. Van Gorsel, 2014), it seems useful to fully document the stratigraphic distribution of dinoflagellate cysts from a deep water well drilled offshore Sabah.

Dinoflagellate cysts are the prime markers in the Mesozoic biozonations of wells drilled in the Australian Margin, including the deep offshore. The main justification to initiate the research project was the expectation that dinoflagellate cysts could play an equally important role in the marine Neogene sediments in SE Asia. For this purpose, the deep water well Kebabangan-1, offshore Sabah, was selected, for palynological analysis, complemented with a scan of samples from appraisal well Kebabangan-2, drilled in the same structure (Figure 1).

A substantial number of deep water wells were drilled offshore Sabah and Brunei. Its objective sequences are Miocene-Pliocene turbiditic reservoirs, deposited in a prodeltaic deep water (bathyal) environment. Major gas and minor oil resources have been identified, i.e. in the Kebabangan Field (Figure 1).

Biostratigraphy plays an important role in the deep water drilling campaign, since correlations based on seismic are hampered by heavy faulting. Calcareous nannoplankton presently provides a high resolution Neogene biozonation for the deep water wells, with foraminifera and pollen as

additional support for age dating. Dinoflagellate cysts are expected to represent an alternative biostratigraphic 'tool' in case nannoplankton markers are absent in future wells, since both microfossil groups are supposed to occur in sediments deposited in the deep water environment, encountered in the deep water wells.

In order to be useful in wells for which only ditch cutting samples are available, the envisaged new dinoflagellate cyst biozonation should mainly be based on F(irst) D(ownhole) O(ccurrence)'s of key dinoflagellate cysts. Acmes of dinoflagellate cysts could be of correlative value at local scale. '

REGIONAL SETTING OF KEBABANGAN-1 WELL

The modern subaerial and submarine morphology of West Sabah is assumed to be an analogue to the Miocene-Pliocene turbidite play (Figure 1). The exceptionally large height differential of about 7 – km, over only 200 km between the mountainous hinterland, (coastal Crocker Ranges and the Mt. Kinabalu plutonic complex; 4101 m) and the base of the continental slope (about 3000 m water depth) is very different from other 'classical' turbidite provinces (e.g. Gulf of Mexico). The submarine morphology comprises a 80-100 km wide shelf, passing into a steep continental slope (2-10°). The sediments were transported from the hinterland into the offshore by multiple rivers, and the succession indicates an overall regressive trend since Late Miocene times.

The studied pilot well Kebabangan-1 is located 80 kilometers offshore and penetrated high energy, sand-rich, base of continental slope fans at the objective interval. These are covered by low energy, mud-rich continental slope fan systems, grading upward into mud-rich shelfal topsets at shallow depth.

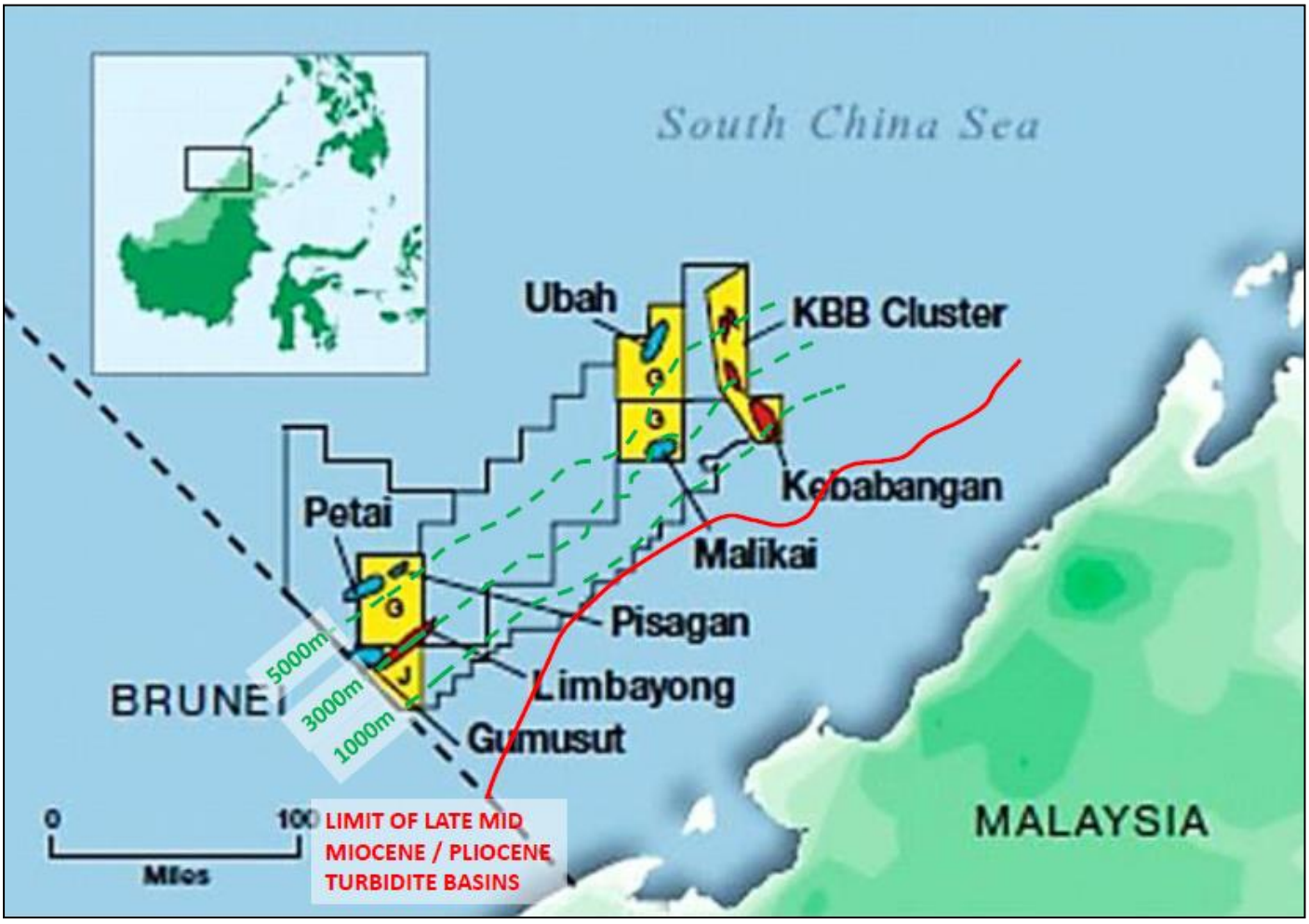


Figure 1: *Location map of Kebabangan gas field (Asia Pacific Oil & Gas News, adapted)*

The Kebabangan-1 well was drilled in 1994 to test the deepwater turbidites in a structural closure created by shale diapirism along a major fault (Figure 2). It was the first discovery drilled in the SB-1 PSC, at a location 12km NE of Kinarut-1 (1972). The bounding fault of the structure has a significant strike-slip component with a very steep thrust fault. The well drilled to a total depth of - about 11,300' and penetrated 4000' of turbidite sands (Chua, 1998).

Dinoflagellate cysts have been recovered from the mud-rich shelfal topsets and underlying mud-rich slope fan systems; the underlying sand-rich base-of-slope fans (Figure 2) were barren.

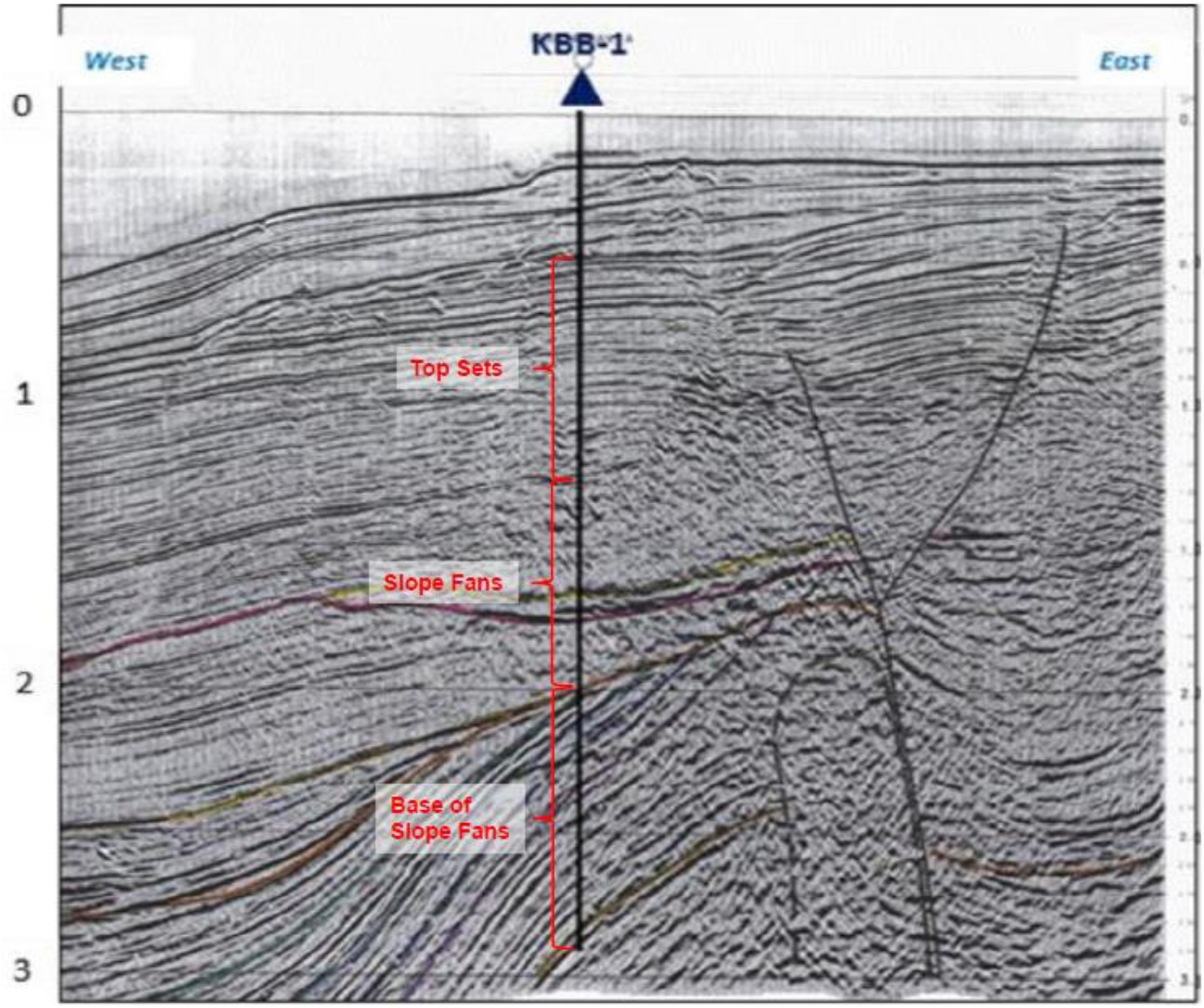


Figure 2: *Seismic Line across Kebabangan-1 (Challis et al, 2015).*

PREVIOUS DINOFLAGELLATE STUDIES IN THE AREA

A limited amount of studies on dinoflagellate cysts of Tertiary age in low latitudes and specifically in SE Asia has been published. Dinoflagellate cysts from the Eocene Nanggulan Formation and the Miocene Sentolo Formation in Central Java were discussed by Matsuoka (1981, 1983a, 1984). Taxa reported from the Sentolo Formation, of relevance to present study, include *Operculodinium sp.* and *Spiniferites sp.*

Besems (1993) listed the dinoflagellate cysts of Tertiary age from Northern Borneo, as compiled and described by Shell palynologists in the last 30 years. Dinoflagellate cysts were recovered from specific thin intervals in about 40 wells, supposedly representing marine incursions in coastal environments. None of these walls penetrated sediments deposited in bathyal/slope environments over the full section, in contrast to the present deep water well. Besems (1993) proposed a range chart of selected dinoflagellate cysts of Tertiary age for Northern Borneo, based on these scattered dinoflagellate cyst occurrences, calibrated with the other palynomorphs, in the above wells. Most of his selected dinoflagellate taxa are long ranging and therefore he proposed a biozonation based on successive dinoflagellate cyst assemblage groups. This biozonation is of little use to the current study, since variations of the three successive dinoflagellate cysts assemblages covering the Neogene interval are not reflected in the palynological analyses of Kebabangan-1. Furthermore, Protoperidiniacean dinoflagellate cysts were not included in his review, since most of these were removed by Shell's sample processing technique that included oxidation. Therefore an important part of the dinoflagellate cyst microflora was not recorded.

Of further relevance to the present study are the Neogene dinoflagellate cysts reviews by McMinn (1992 and 1993), as part of the Ocean Drilling Program, from the Eastern Indian Ocean and the Northeastern Australian Margin, because of the relative proximity in (sub)tropical environment. Sediments from the first location were initially deposited on the outer continental shelf and slope and have been redeposited at their present location on the Argo Abyssal Plain by density currents. Sediments from the second location were deposited at outer neritic to bathyal water depths on submerged margin plateaus off the northern Queensland coast.

PALYNOLOGICAL ANALYSES OF KEBABANGAN-1

Thirty three ditch cutting samples from well Kebabangan-1 were provided by Sarawak Shell Berhad and prepared by Laola Pty Ltd in Perth. Palynological analyses of dinoflagellate cysts only have been carried out.

Dinoflagellate cysts are restricted to the interval from 2610' to 6495' (Figure 3). A set of slides prepared from the oxidized fraction of the samples was fully analyzed, with counts of dinoflagellate cysts. In addition, the un-oxidized fractions were screened for thin walled Protoperidiniacean dinoflagellate cysts, like *Selenopemhix spp., Brigantedinium* spp. and *Lejeunecysta* spp., the bulk of which had been removed by oxidation. Protoperidiniacean dinoflagellate cysts are illustrated in Plate 3. The palynological assemblages are overwhelmingly dominated by land plant material, i.e. pollen, spores, fungi and macerals. Marine elements (dinoflagellate cysts, acritarchs and algae) overall contribute just 2 to 5 % of the microflora in the interval from 2610' to 6495'. From 6705' to 7905' the ditch cutting samples are virtually barren of marine palynomorphs. They still contain some (caved?) pollen and spores, but are dominated by dark brown debris.

Biostratigraphy

The interval from 2610' to 4020' has been assigned to the Upper Pliocene, the interval from 4140' to 5430' to the Lower Pliocene and the interval from 5640' to 6495' to the Upper Miocene, based on the distribution of calcareous nannoplankton with support from foraminifera and pollen, as reported by the operator.

The dinoflagellate cyst assemblages are dominated by (cf.) *Brigantedinium* spp., *Spiniferites* spp. and *Operculodinium* spp. The adjective cf. applies to *Brigantedinium* spp. without a clearly visible archeopyle. The *Spiniferites* spp. have been subdivided into three morphogroups: (1); *Spiniferites ramosus* group, (2) group with *Spiniferites hyperacantha* and *Spiniferites mirabilis* and (3) group with smaller forms including *Spiniferites bulloideus*. Most of the *Operculodinium* spp. can be allocated to *Operculodinium centrocarpum* sensu Wall 1967. Large size varieties of *Operculodinium israelianum* and *Operculodinium wallii* (Matsuoka 1983) are common, similar to those described in the tropical

Neogene environment in the Bahamas (Head and Westphal, 1999). *Impagidinium* spp. (incl. *I. paradoxum, I. aculeatum* and *I. patulum), Selenopemphix nephroides, Selenopemphix quanta, Tuberculodinium vancampoae, Polysphaeridium zoharyi* and *Lingulodinium machaerophorum* are consistently present over the full interval.

A suite of FDO's (and acmes) of dinoflagellate cysts in descending order is presented over the study interval. The FDO's of dinoflagellate cysts marker species are referred to the published stratigraphic ranges. However, since these mainly originate from North American and European dinoflagellate cysts reviews at higher latitudes, their applicability in low-latitude SE Asia has yet to be established.

Interval 2610'- 4020': Upper Pliocene

The FDO of *Hystrichokolpoma rigaudiae* at 3150' could be of stratigraphic value. However, highest occurrences have been reported within the Pleistocene in the Western and Northern Pacific (Bujak and Matsuoka 1986), the Gulf of Mexico (Wrenn and Kokinos 1986) and the Mediterranean (Londeix et al. 1999).

A very distinctive FDO in this interval belongs to the informal species *Operculodinium* sp. A*.,* a large size (80-90 microns) proximochorate dinoflagellate cyst with a precingular archeopyle, densely covered with fibrous processes. It has been allocated to *Operculodinium* spp., as advised by Head and Norris independently (pers. comm. 2001). It could be of considerable stratigraphic importance with a consistent range from 3840' downwards.

Interval 4140'- 5430': Lower Pliocene

The FDO of *Dapsilidinium pastielsii* at 4140' is considered to coincide with the top of the Lower Pliocene interval, as established by calcareous nannoplankton. Also Besems (1993) reported a FDO of *Dapsilidinium pastielsii* at the top of the Early Pliocene for NW Borneo. Its highest occurrence has been reported in the Late Pliocene in the Eastern Indian Ocean and the Northeastern Australian Margin (McMinn 1992, 1993).

Also the FDO of *Lingulodinium pycnospinosum* at 4950' is considered to be of stratigraphic value. The highest occurrence to date was reported in the Late Oligocene in Germany (Benedek and Sarjeant 1981).

Several rare occurrences have been detected in this interval which could have stratigraphic potential; *Homotryblium tenuispinosum* with FDO at 4290' (reworked?), *Lejeunecysta* cf. sp. *2* (Biffi and Grignani 1983) with FDO at 4950', *Spiniferites* sp. A (Duffield and Stein 1986) with FDO at 4950' and *Trinovantidinium ferugnomatum* at 5115'. *Lejeunecysta* sp. 2, nearest resembling *Lejeunecysta* cf. sp. 2, has been recorded in the Oligocene sediments of the Niger Delta (Biffi and Grignani 1983). *Spiniferites* sp. A has been detected in sediments of Middle to Late Miocene age in the Gulf of Mexico, but the analyzed interval did not extend into the Pliocene (Duffield and Stein 1986). The highest occurrence of *Trinovantidinium ferugnomatum* has been reported from the Late Pliocene in the eastern United States (De Verteuil and Norris 1992).

The acritarch species *Comasphaeridium* sp., present over the full analyzed section, shows an acme at 5115'. From 5430' to 6270' (Upper Miocene) *Spiniferites* spp. and *Brigantidinium* spp. are relatively rich. Both events could be of local stratigraphic value.

Analysis of ditch cutting samples invalidates the use of LDO's. However, it should be noted that (in ditch cutting samples) thin walled dinoflagellate cyst species *Barssidinium* cf. *graminosum* and *Barssidinium evangelineae* (Head 1993; Lentin et al. 1994) and *Achomosphaera granulata* are restricted to the Pliocene interval. The published occurrence of *Barssidinium evangelineae* ranges from Late Miocene to Pleistocene in eastern Canada (Williams et al. 1998). The irregularly shaped *Barssidinium* cf. *gramisosum* shows similarities to the Miocene species *Barssidinium graminosum. Achomosphaera granulata* with very distinct granular surface has been reported from the Quaternary in the South China Sea (Mao and Harland 1993).

Interval 5640'- 6495': Upper Miocene

The Late Miocene age assignment by calcareous nannoplankton and foraminifera is supported by the FDO at 5760', and consistent presence underneath this depth, of *Selenopemphix brevispinosa* Head et al. 1989 subsp. *conspicua*, which has a published highest occurrence in the Late Miocene in the eastern United States (De Verteuil and Norris 1992, 1996). The scattered occurrences in the Pliocene interval have been interpreted as reworking, although it should be mentioned that it locally occurs in Pliocene sediments in the Mediterranean as well (Londeix et al 1999).

A further support for the Miocene age assignment for this interval could be provided by the top of -

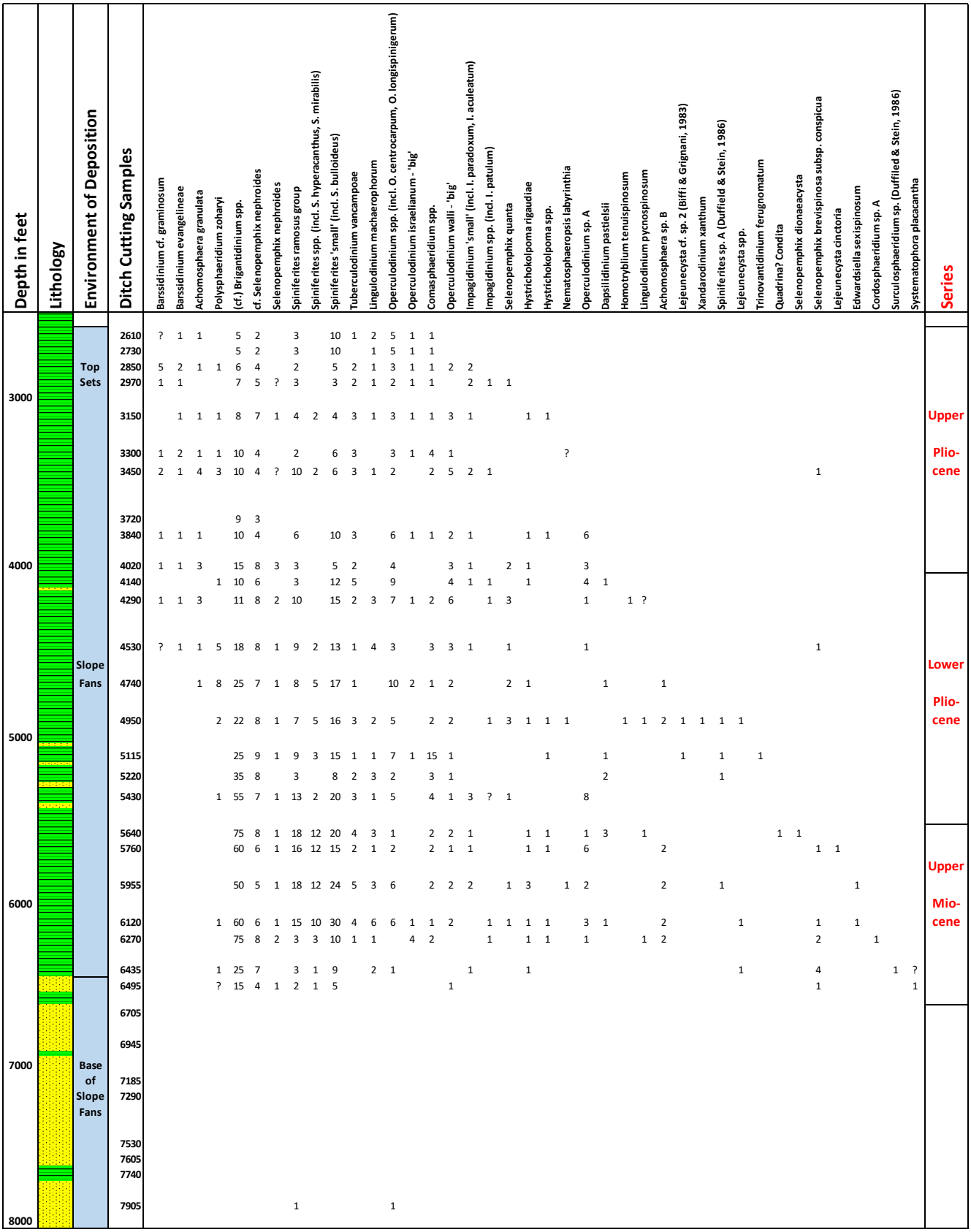


Figure 3: *Kebabangan-1 Dinoflagellate cyst distribution chart*

the consistent occurrence of informal species *Achomosphaera* sp. B at 5760', occasionally also present in the Lower Pliocene interval of the well. It has a thick-walled spherical shaped central body and is covered by thin processes. These distinctive features point into the direction of an undescribed species, although allocation to an *Achomosphaera* spp. morphogroup cannot be excluded.

Over the Upper Miocene interval in the well several single occurrences of diagnostic dinoflagellate cysts have been recorded to be discussed next. It should be realized that their stratigraphic value could be doubtful (reworking, contamination?).

An established marker species for the top of the Late Miocene is *Systematophora placacantha.* Its highest occurrence has been reported in the Late Miocene in Italy (Powell 1986). A single presence has been recorded at 6495'.

Of stratigraphic importance in this interval could also be the single presence of *Quadrina? condita* at 5640', *Lejeunecysta cinctoria* at 5760' and *Surculosphaeridium* sp. (Duffield and Stein 1986) at 6435'. *Quadrina? condita* (= Gen. et sp. indet. A of Duffield and Stein 1986) has been reported from the Middle to Late Miocene in the eastern United States (De Verteuil and Norris 1992, 1996). The youngest occurrence of *Lejeunecysta cinctoria* has been recorded from the Oligocene sediments of the Niger Delta (Biffi and Grignani 1983). *Surculosphaeridium* sp. has been reported from the Early to Middle Miocene in the Gulf of Mexico (Duffield and Stein 1986).

The single presence of *Selenopemphix dionaeacysta* at 5640', *Edwardsiella sexipsinosum* at 5995' and informal species *Cordosphaeridium* sp. A at 6270' could also be of significance. However, the highest occurrence of *Selenopemphix dionaeacysta* has been reported in the Late Pliocene in the eastern United States (De Verteuil and Norris 1992) and *Edwardsiella sexipsinosum* in the Late Pliocene in Italy (Versteegh and Zevenboom 1995). *Cordosphaeridium sp. A* shows similarities to *Operculodinium* sp. A. The fibrous processes are longer and less densely distributed.

PALYNOLOGICAL ANALYSES OF KEBABANGAN-2

Palynological analyses of twenty five ditch cutting samples (interval 4132'to 7000') from nearby well Kebabangan-2 (2001) were carried out in order to calibrate the results of Kebabangan-1. Dinoflagellate cysts are restricted to the interval from 4245'to 6165'. The organic content of the slides and resulting palynomorph density is about four times lower than in Kebabangan-1, resulting in Kebabangan-2 dinoflagellate cyst assemblages to be a diluted copy of Kebabangan-1.

The interval from 4245' to 4485' has been assigned to the Upper Pliocene, the interval from 4605' to 5325' to the Lower Pliocene and the interval from 5445' to 6165' to the Upper Miocene, based on correlation with Kebabangan-1, supported by the distribution of nannoplankton in both wells.

FDO's in the top section of Kebabangan-1, like *Hystrichokolpoma rigaudiae and Operculodinium sp. A,* are not recognized in Kebabangan-2, since the top of the interval of investigation is deeper in the section (4245'vs. 2610'). The top of the Lower Pliocene interval in Kebabangan-2 at 4605'is based on the FDO of *Dapsilidinium pastielsii* in correlation with Kebabangan-1, followed by the single occurrence of *Lingulodinium pycnospinosum* at 4725'. The top of the Upper Miocene interval in Kebabangan-2 at 5445' is based on correlation with Kebabangan-1. It is supported by the top consistent occurrence of *Selenopemphix brevispinosa* subsp. *conspicua* in the next downhole samples in both wells. Overall, the diluted dinoflagellate cyst microfloras of Kebabangan-2 confirm the stratigraphic events established in Kebabangan-1.

ENVIRONMENTS OF DEPOSITION

From regional geological studies and seismic data it has been established that the environment of deposition penetrated in the interval from 2610' to 6495' in Kebabangan-1 ranges from outer shelfal (outer neritic) at the top (mud-rich shelfal topsets), to lower continental slope (lower bathyal) at the base of the section (low energy mud-rich continental slope fan system). Below 6495' the Kebabangan-1 well penetrated high energy, sand-rich, base of the continental slope fans (the objective interval).

In a deep marine environment of deposition (outer shelf to lower continental slope), rich dinoflagellate cyst microfloras are expected, with dinoflagellate percentages of 50% or more of total palynomorphs (including landplant pollen, spores, fungi and macerals) and a species diversity of 25 or higher, analogous to the scheme applied to the Mesozoic sediments of the Australian margin. It is obvious that this scheme is not applicable to the Neogene sediments in Kebabangan-1. In the interval from 2610'to 6495' the dinoflagellate cyst

content ranges from 2 to 5% of total palynomorphs, and diversity is between 10 and 20 species. The low percentage of dinoflagellate cysts and moderate species diversity is explained by severe dilution by land plant material, discharged by major rivers, and transported across the continental shelf into the low energy, mud-rich outer shelf and slope fan systems at a distance of 100-150 km from the coastline.

The dinoflagellate cysts assemblages, encountered in Kebabangan-1 between 2610' and 6495', are dominated by *Brigantedinium* spp., *Spiniferites* spp. and *Operculodinium* spp., while *Polysphaeridium zoharyi, Selenopemphix nephroides, Tuberculodinium vancampoae* and *Lingulodinium machaerophorum* are commonly present. These assemblages are supposed to be characteristic for tropical inner to outer neritic shelfal environments (Harland 1983; Wrenn and Kokinos 1986; Brinkhuis 1992a; in: Jansonius and McGregor 1996). Genera indicative of oceanic environments like *Impagidinium* spp. and *Nematosphaeropsis* spp. are rare. The dinoflagellate cyst assemblages show similarities to the Neogene (sub)tropical assemblages from the Eastern Indian Ocean and the Northeastern Australian Margin (McMinn 1992, 1993). However, assemblages of the ODP wells show a higher species diversity with e.g. *Impagidinium* spp., *Batiacasphaera* spp. and *Melitasphaeridium choanophorum* commonly present as well.

From regional geological studies and seismic data it is clear, that the dinoflagellate cysts assemblages encountered in Kebabangan-1 in the interval 2610' to 6495', are not derived from inner to outer neritic shelfal environments, but from a more distal zone (outer neritic/shelfal to upper bathyal/slope environment). This zone is characterised by upwelling of oceanic waters, rich in nutrients, responsible for high organic productivity. Upwelling of deep, cold ocean currents is common, especially at low latitudes. From this zone, only short distance transport of dinoflagellate cysts into the mud-rich slope fan sediments occurred.

The influx of fresh water from multiple river mouths onto the shelf probably causes dinoflagellate assemblages to predominantly occur in outer neritic to upper bathyal environments, as reduced salinities have an adverse impact on the inner shelfal dinoflagellate microfloras. High discharge of fresh water is indicated by the long distance offshore transport of land plant material across the shelf. The lower species diversity of dinoflagellate cysts in the Borneo deep water well compared to the ODP wells in the Eastern Indian Ocean and the NE Australian Margin, also deposited in outer shelf to slope environments (McMinn 1992, 1993), could also be due to influx of less saline water (slightly higher numbers of *Impagidinium* spp. in the ODP wells could indicate stronger oceanic influence).

The decrease in numbers of *Brigantedinium* spp. and *Spiniferites* spp. going upwards in the section in the interval from 2610' to 6495' in Kebabangan-1 could be due to shallowing of the environment of deposition, moving away from the zone of nutrient-rich upwelling. This confirms the overall regressive trend from the Late Miocene to present day.

The interval from 6705' to 7905' in the deep water well represents the top of the high energy, sand-rich, base-of-slope fan reservoir section of the well. The sands lack palynomorphs.

CONCLUSIONS AND RECOMMENDATIONS

This research project with the objective to establish a dinoflagellate cyst biozonation for deep water wells drilled offshore Sabah and Brunei was envisaged to complement the biozonations based on nannoplankton, foraminifera and pollen. The palynological analysis of deep water well Kebabangan-1, offshore Sabah, was complemented with a quick analysis of well Kebabangan-2, drilled in the same structure.

Low percentages of dinoflagellate cysts relative to landplant material and moderate species diversities were encountered in Kebabangan-1. However, dinoflagellate cyst recovery is sufficient to produce a stratigraphic useful distribution. A list of FDO's is presented, which could contain stratigraphic value: *Hystrichokolpoma rigaudiae* at 3150', *Operculodinium* sp. A at 3840', *Dapsilidinium pastielsii* at 4140' and *Lingulodinium pycnospinosum* at 4950' within the Pliocene section; *Selenopemphix brevispinosa* subsp. *conspicua* at 5760', and consistent occurrence of *Achomosphaera* sp. B at 5760' within the Upper Miocene section.

Dinoflagellate cysts were recovered from mud-rich shelfal topsets and underlying mud-rich slope fan systems from 2610' to 6495'. The underlying sand-rich base-of-slope fans in the interval 6705' to 7905' were barren of palynomorphs.

A dinoflagellate cyst biozonation cannot yet be proposed based on results of one well, complemented with a scan of the appraisal well. The correlation potential of the FDO's reported for this well needs to be confirmed in additional wells,

both along the Northern Borneo offshore and from other parts of SE Asia.

There is still the potential for dinoflagellate cysts to become a powerful tool in Neogene biostratigraphy of SE Asia, as they are in the Paleogene of the North Sea and in the Mesozoic of the Australian margins. However, additional analytical studies are needed, preferably in conjunction with a re-evaluation of palynological processing techniques. Dinoflagellate cysts are generally less robust and more delicate than the associated spores and pollen and many of them may not be preserved in standard palynology slides. Un-oxidized slides should be prepared for the determination of the thin walled Protoperidiniacean dinoflagellate cysts, which are removed by the standard preparation.

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REFERENCES

Benedek, P.N. and Sarjeant, W.A.S., 1981. Dinoflagellate cysts from the middle and upper Oligocene of Tonisberg (Niederrheingebiet): a morphological and taxonomic restudy. Nova Hedwigia 35, p. 313-356.

Besems, R. E., 1993. Dinoflagellate cyst biostratigraphy of Tertiary and Quaternary deposits of offshore NW Borneo. Geological Society of Malaysia, Bulletin 33, p. 65-93.

Bujak, J. P., and Matsuoka, K., 1986. Late Cenozoic dinoflagellate cyst zonation in the western and northern Pacific. In: Wrenn, J. H., Duffield, S. L., and Stein, J. A. Eds., Papers from the first Symposium on Neogene dinoflagellate cyst biostratigraphy, American Association of Stratigraphic Palynologists Contribution Series 17, p 7-25.

Biffi, U. and Grignani, D., 1983. Peridinoid dinoflagellate cysts from the Oligocene of the Niger Delta, Nigeria. Micropaleontology 29, 2, p. 163-212.

Challis, M., Curtis, C., Mahadzir, N.L., Mennie, J. and Zainal, S.B., 2015. The Kebabangan Gas Field, Malaysia: a 20 year journey continues. SEAPEX Exploration Conference.

Chua Beng Yap, 1998. A decade of (1987-1997) of exploration in Malaysia under the 1985 Production Sharing Contract. SEAPEX Exploration Conference.

De Verteuil, L and Norris, G., 1992a. Miocene Protoperidiniacean dinoflagellate cysts from the Maryland and Virginia coastal plain. In: Head, M. J., and Wrenn, J. H., Eds., Neogene and Quarternary dinoflagellate cysts and acritarchs. Dallas, American Association of Stratigraphic Palynologists Foundation, p. 391-430.
.

De Verteuil, L and Norris, G., 1996. Miocene dinoflagellate stratigraphy and systematics of Maryland and Virginia, Micropaleontology 42, supplement, p. 1-172.

Duffield, S.L., and Stein, J.A., 1986. Peridiniacean-dominated dinoflagellate cyst assemblages from the Miocene of the Gulf of Mexico shelf, offshore Louisiana. In: Wrenn, J.H. et al. (eds.), Papers from the first Symposium on Neogene dinoflagellate cyst biostratigraphy, American Association of Stratigraphic Palynologists Contribution Series 17, p. 27-45.

Head, M.J., Norris, G., and Mudie, P.J., 1989. Palynology and dinocyst stratigraphy of the Miocene in ODP leg 105, Hole 645E, Baffin Bay. In: Srivastava, S.P. et al. (eds.), Proc. Ocean Drilling Program, Scientific Results, 105, p. 467-514.

Head, M.J., 1993. Dinoflagellates, sporomorphs, and other palynomorphs from the upper Pliocene St. Erth Beds of Cornwall, southwestern England. The Paleontological Society Memoir 31 (J. Paleontology 67; supplement to No. 3), The Paleontological Society, 63p.

Head, M.J. and Westphal, H. 1999. Palynology and paleoenvironments of a Pliocene carbonate platform: the Clino Core, Bahamas. J. of Paleontology 73, 1, p. 1-25.

Jansonius, J. and McGregor. D.C., 1996. Palynology: Principles and Applications. American Association of Stratigraphic Palynologists Foundation.

Lentin, J. K., Fensome, R.A., and Williams, G.L., 1994. The stratigraphic importance of species of *Sumatradinium, Barssidinium and Erymnodinium*, Neogene dinoflagellate genera from the offshore eastern Canada. Canadian J. Earth Sciences 31, p. 567-582.

Londeix, L. et al. 1999. Late Neogene dinoflagellate cyst assemblages from the Strait of Sicily, Central Mediterranean Sea: paleoecological

and biostratigraphical implications; In: Wrenn, J.H. et al. (eds.), The Pliocene: Time of change, American Association of Stratigraphic Palynologists Foundation, p. 65- 91.

Mao, S. and Harland, R. 1993. Quarternary organic walled dinoflagellate cysts from the South China Sea and their paleoclimatic significance. Palynology 17, p. 47-65.

Matsuoka, K., 1981. Dinoflagellate cysts and *Pediastrum* from the Nanggulan and Sentolo Formations in the Middle Java Island, Indonesia. In: T. Saito (Ed.), Micropalaeontology, petrology and lithostratigraphy of Cenozoic rocks of the Yogjakarta region Central Java. Dept. of Earth Sciences, Yamagata Univ., Special Publication, p. 48-52.

Matsuoka, K., 1983a. A new dinoflagellate cyst (*Danea heterospinosa*) from the Eocene of Central Java, Indonesia. Review of Palaeobotany Palynology 40, p. 115-126.

Matsuoka, K., 1983b. Late Cenozoic dinoflagellates and acritarchs in the Niigata District, central Japan. Palaeontographica Abt. B. Palaeophytologie 187, p. 89-154.

Matsuoka, K., 1984. Some dinoflagellate cysts from the Nanggulan Formation in Central Java, Indonesia. Trans. Proc. Palaeontology Society of Japan, N.S., 134, p. 374-387.

McMinn, A., 1992. Neogene dinoflagellate distribution in the Eastern Indian Ocean from Leg 123, Site 765. Proc. Ocean Drilling Program, Scientific Results, 123.

McMinn, A., 1993. Neogene dinoflagellate cyst biostratigraphy from Sites 815 and 823, Leg 133, Northeastern Australian Margin. Proc. Ocean Drilling Program, Scientific Results, 133.

Powell, A.J., 1986. The stratigraphic distribution of Late Miocene dinoflagellate cysts from the Castellanian Superstage stratotype, Northwest Italy. In: Wrenn, J.H., Duffield, S.L., and Stein, J.A. Eds., Papers First Symposium on Neogene dinoflagellate cyst biostratigraphy, American Association of Stratigraphic Palynologists Contribution Series 17, p. 129-149.

Van den Brink, H.A., 2002. Neogene dinoflagellate cysts from a deep water well, offshore Sabah, Northern Borneo. Abstract in Proceedings Annual Meeting AASP, San Antonio, 2001, Palynology 26, p. 278-279.

Van Gorsel, J.T., 2014. Annotated bibliography of biostratigraphy and paleontology of Indonesia- SE Asia. Berita Sedimentologi, 29, Supplement.

Versteegh, G.J.M., and Zevenboom, D., 1995. New genera and species of dinoflagellate cysts from the Mediterranean Neogene. Review of Palaeobotany and Palynology 85, p. 213-229.

Williams, G.L., Lentin, J.K., and Fensome, R.A., 1998. The Lentin and Williams Index of Fossil Dinoflagellates, 1998 edition. American Association of Stratigraphic Palynologists Foundation.

Wrenn, J.H. and Kokinos, J.P., 1986. Preliminary comments on Miocene through Pleistocene dinoflagellate cysts from the Soto Canyon, Gulf of Mexico. In: Wrenn, J.H.et al. (eds.), Papers First Symposium on Neogene dinoflagellate cyst biostratigraphy, American Association of Stratigraphic Palynologists Contribution Series 17, p. 169-225.

PLATE 1 – Gonyaulacales Dinoflagellate Cysts

All figures X 600, KBB-1 unless otherwise indicated

1 *Achomosphaera granulata* Mao Shaozhi, 1989
2610': Upper Pliocene
2, 3 *Achomosphaera* sp. B
5955' and 6270': Upper Miocene
4 *Spiniferites hyperacanthus* (Deflandre and Cookson, 1955) Cookson and Eisenack, 1974
5640': Upper Miocene
5, 6 *Dapsilidinium pastielsii* (Davey and Williams, 1966) Bujak et al., 1980
5640' (2x): Upper Miocene
7 *Hystrichokolpoma rigaudiae* Deflandre and Cookson, 1955
5640': Upper Miocene
8 *Polysphaeridium zoharyi* (Rossignol, 1962) Bujak et al., 1980
4740': Lower Pliocene
9 *Lingulodinium pycnospinosum* (Benedek, 1972) Stover and Evitt, 1978
5640': Upper Miocene
10 *Lingulodinium machaerophorum* (Deflandre and Cookson, 1955) Wall, 1967
2970': Upper Pliocene

PLATE 2 – Gonyaulacales Dinoflagellate Cysts

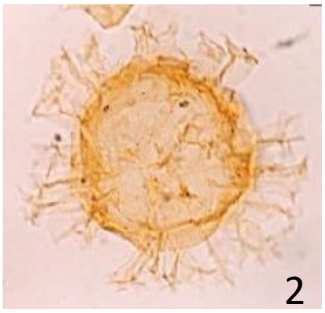
1 *Operculodinium israelianum* (Rossignol, 1962) Wall, 1967
Large size specimen (see text).
3150': Upper Pliocene
2 *Operculodinium wallii* (Matsuoka, 1983)
Large size specimen. Some authors allocate it to *O. centrocarpum* s. l.
4290': Lower Pliocene
3, 4 *Operculodinium* sp. A
4140' and 4290': Upper and Lower Pliocene
5 *Tuberculodinium vancampoae* (Rossignol, 1962) Wall, 1967
2850': Upper Pliocene
6 *Impagidinium patulum* (Wall, 1967) Stover and Evitt, 1978
4290': Lower Pliocene

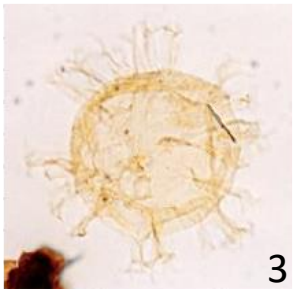
PLATE 3 – Protoperidiniacean Dinoflagellate Cysts

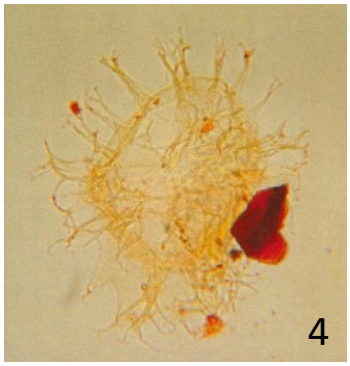
1, 2 *Selenopemphix nephroides* Benedek, 1972
4290': Lower Pliocene, KBB-2, 4845': Lower Pliocene
3, 4 *Selenopemphix brevispinosa* subsp. *conspicua* de Verteuil and Norris, 1992
3450': Upper Pliocene, KBB-2, 4365': Upper Pliocene
5, 6 *Selenopemphix quanta* (Bradford, 1975) Matsuoka, 1985
4290': Lower Pliocene, KBB-2, 5565': Upper Miocene
7 *Leneunecysta sp*.
KBB-2, 4845': Lowe Pliocene
8 *Lejeunecysta* cf. *sp. 2* (Biffi and Grignani, 1983)
4950': Lower Pliocene
9 *Lejeunecysta cinctoria* (Bujak, 1980) Lentin and Williams, 1981
5760': Upper Miocene
10 *Lejeunacysta sp.* 'small'
KBB-2, 5565': Upper Miocene
11 *Brigantidinium simplex* Wall 1965
6270': Upper Miocene
12 *Quadrina ?condita* de Verteuil and Norris, 1992
5640': Upper Miocene
13 *Barssidinium* cf. *graminosum* Lentin et al. 1994
2850': Upper Pliocene
14 *Barssidinium evangelineae* Lentin et al. 1994
4020': Upper Pliocene

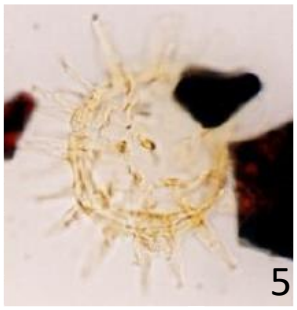
Plate 1

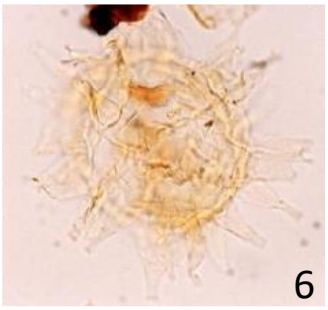




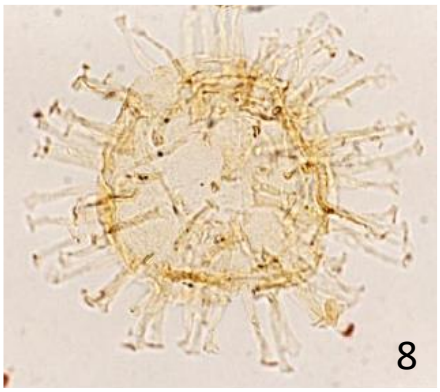












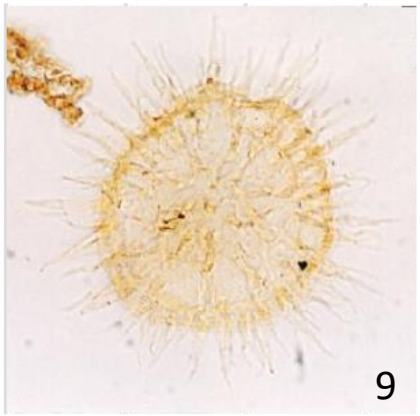
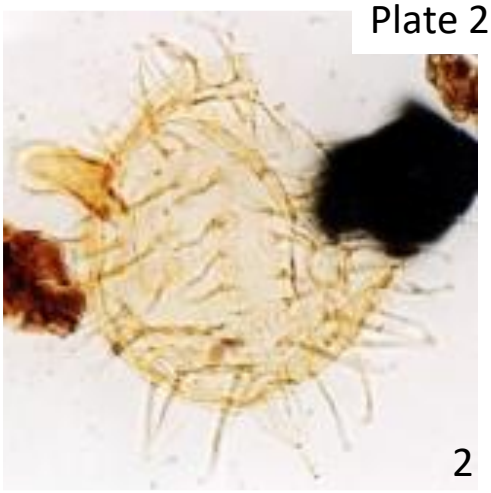
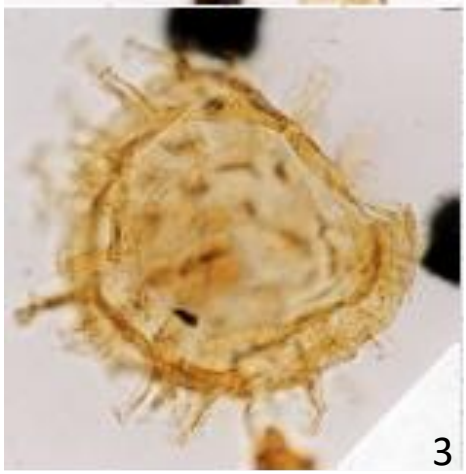


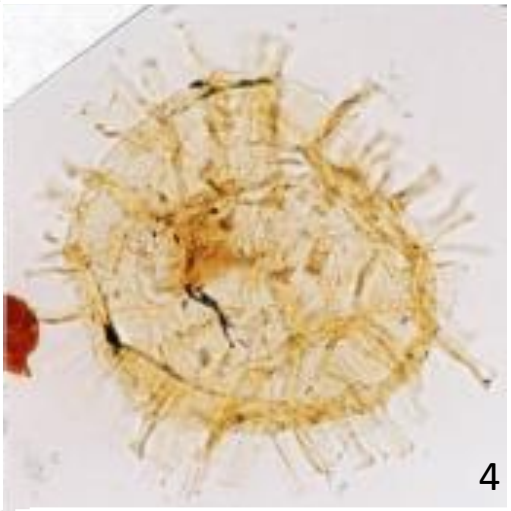


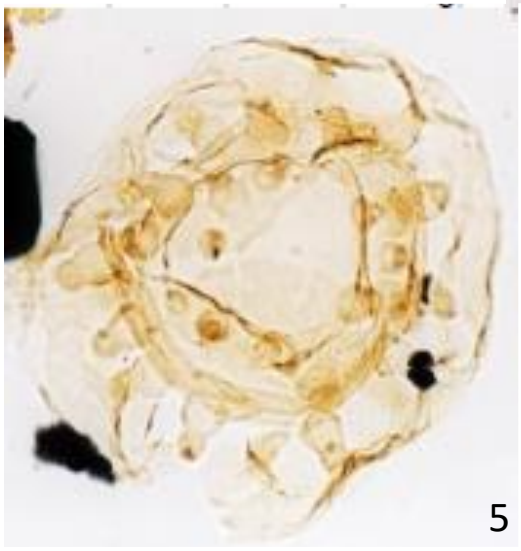
Plate 2

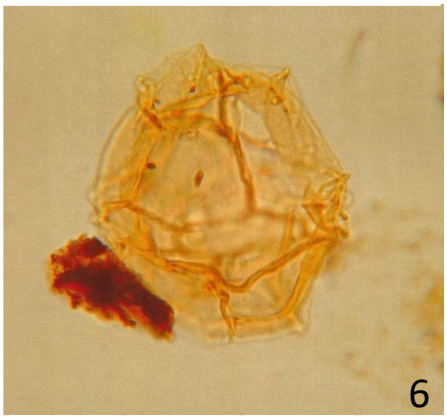

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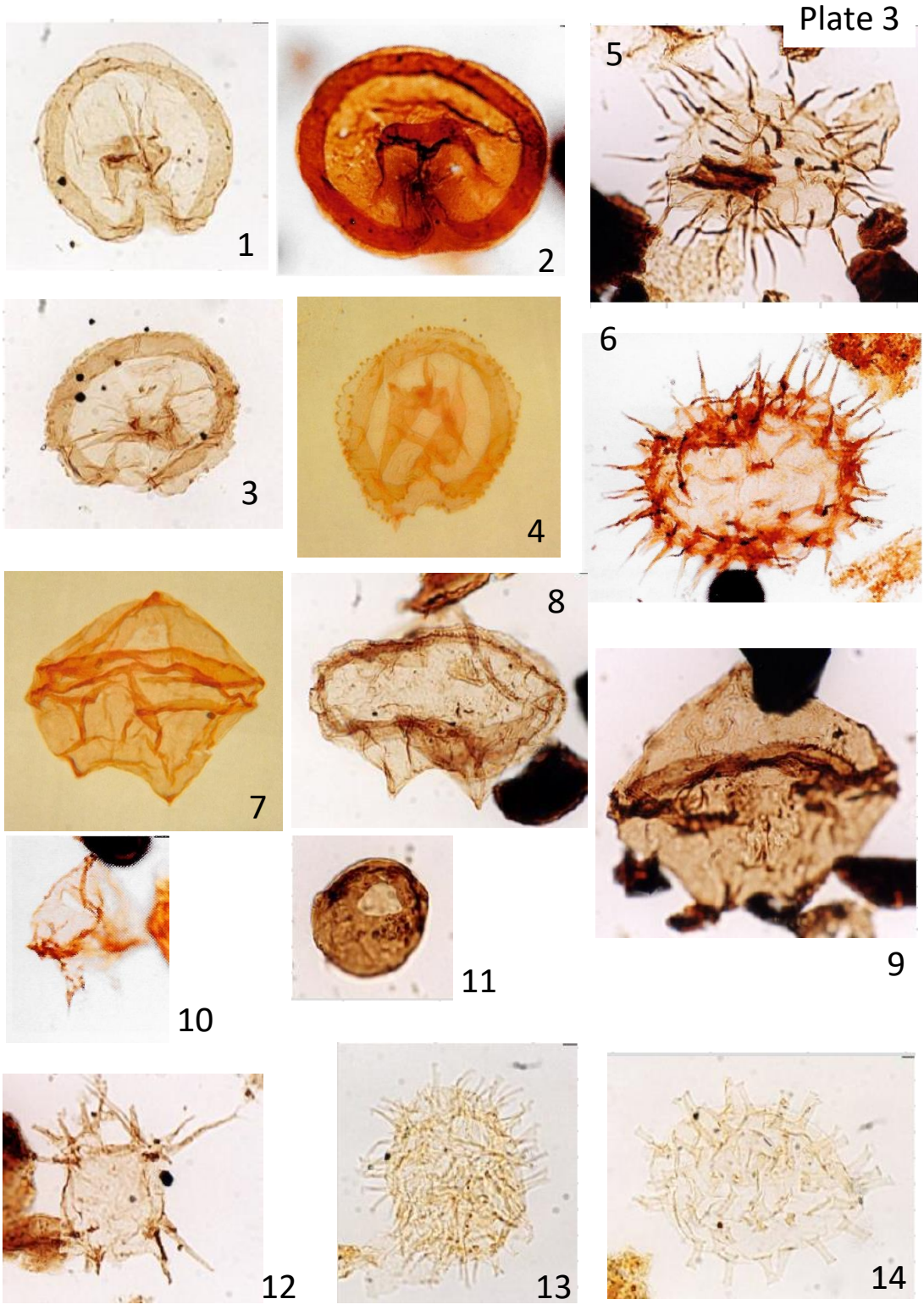

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Plate 3
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