Origins of coral diversity in Southeast Asia

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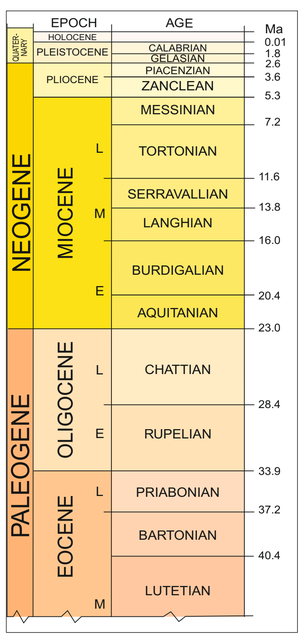
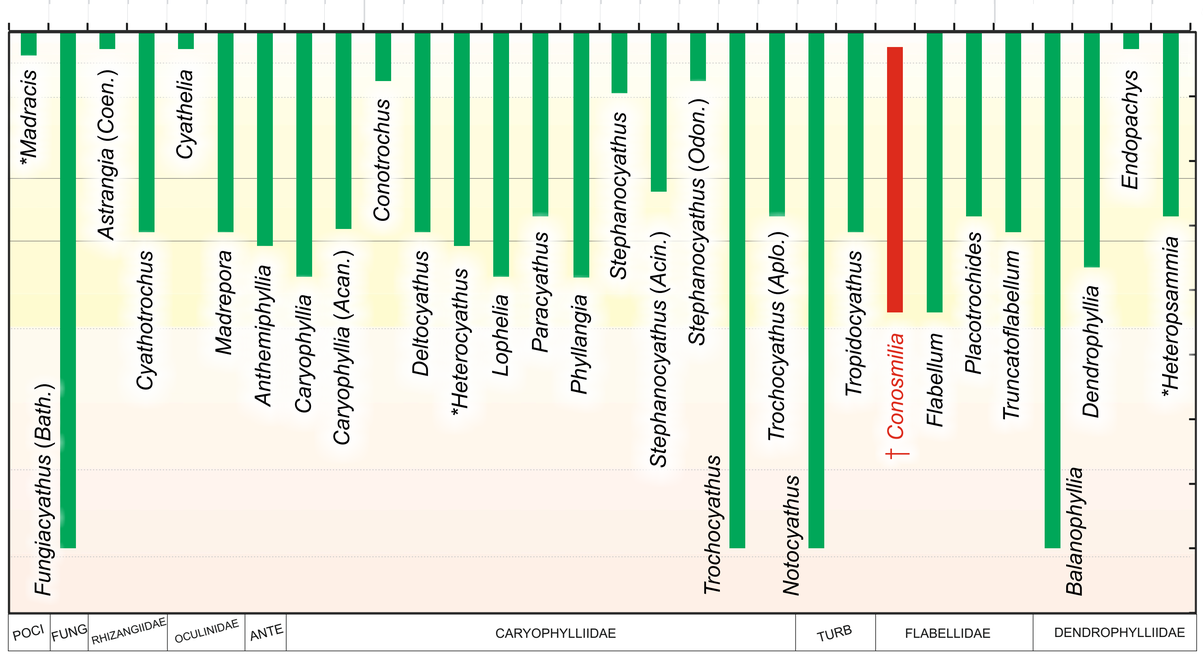
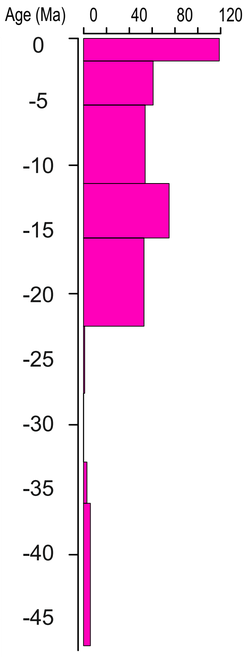
Fossil AZ-coral genera and first occurrences

This table shows the current knowledge of AZ-coral taxa, based on inventories of recent species (Cairns and Zibrowius, 1997) and fossil coral collections at NCB Naturalis and the Natural History Museum. A total of 51 fossil AZ-coral species have been recognised, from which 30 are extinct and 21 are present in modern fauna. The genus *Conosmilia* is the only one extinct.
The first occurrences of the different AZ-coral genera are illustrated in the graph below.

Modern species: 212 spp.		3	5		1	1	3	2	14	6	2	7	4*	1	3	1	2	1	1	11	2	2	2		13	1	15	18	6	2	2*
Fossil record	**Extant: 21 spp.**	1				1			1	1	1		2	1	1			1		1	1				2	1	4			1	1
	Extinct: 30 spp.		1	1	2		1	1	2	1		2			3	2	1		1	2		1	1	1	2			3	2		





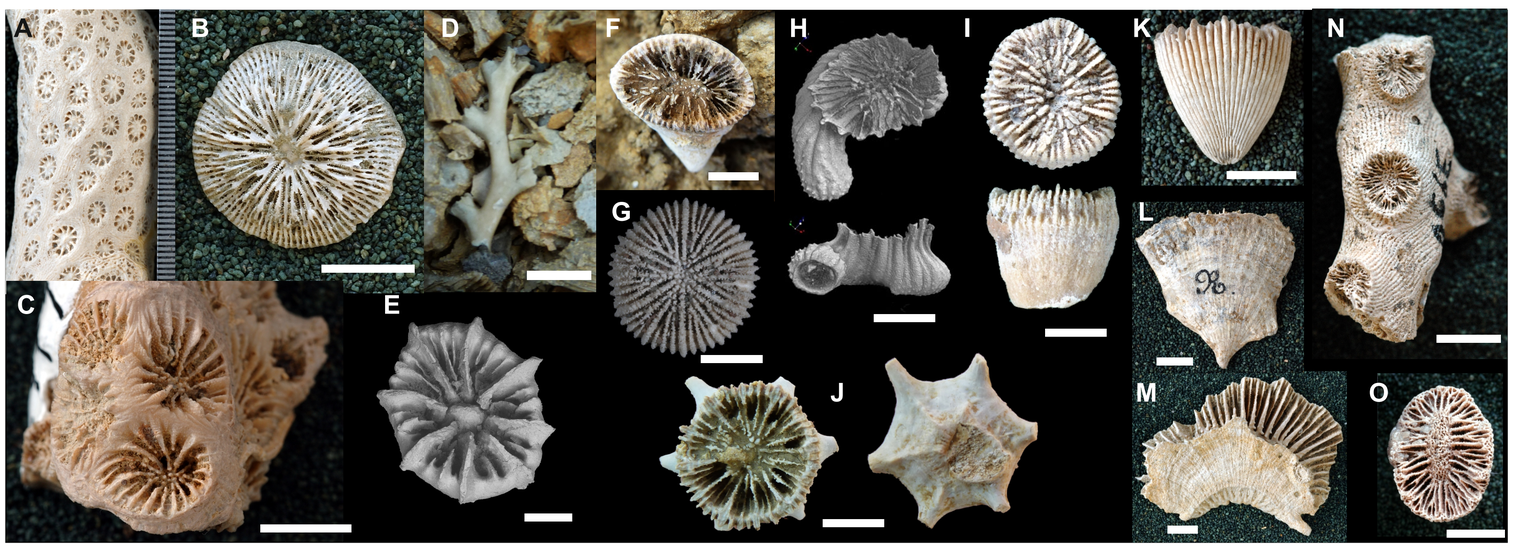


Late occurrence of common genera (e.g. *Madracis*, *Astrangia*) that are known from earlier records in adjacent areas.

Most first occurrences of AZ-coral genera are from the Early to Middle Miocene.

Paucity of AZ-corals or "Oligocene gap"? Some recent studies in the area include earlier records of *Lophelia* and few other species.

The Eocene is represented by a single locality in Java, containing 4 species.



A. *Madracis myriaster*, B. *Fungiacyathus* (*Bathyactis*) *eocaenica*, C. *Astrangia* (*Coenangia*) *polygonalis*, D-E. *Madrepora* sp., F. *Caryophyllia* sp. G. *Deltocyathus* sp., H. *Heterocyathus aequicostatus*, ct-scan reconstruction, I. *Paracyathus* cf. *javana*,, J. *Stephanocyathus* (*Odontocyathus*) sp., K. *Notocyathus viola*, L. *Truncatoflabellum variabile*, M. *Flabellum patens*, N. *Dendrophyllia rutteni*, O. *Balanophyllia javaensis* (?).
Scale bar= 5mm in B-D,F,H-O; scale bar= 1mm in E; scale bar= 2.5 mm. Images: A-C, K-O from Leloux and Renema, 2007.

AZ-corals show the same pattern as shallow Z-corals: most first occurrences are from the Early to Middle Miocene. This supports the idea that plate tectonics and other regional processes (climatic events) are the main factors involved in the diversification of this area.

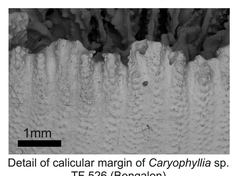
No fossil record is known for the basal clades of Scleractinians in this region (Fam. Micrabaciidae).

More than half of known fossil AZ-coral species became extinct, suggesting high rates of origination.

In combination with parallel studies on shallow water ecosystems, these new data provide insights to the origins of the high diversity in this region.

Beyond the palaeontology

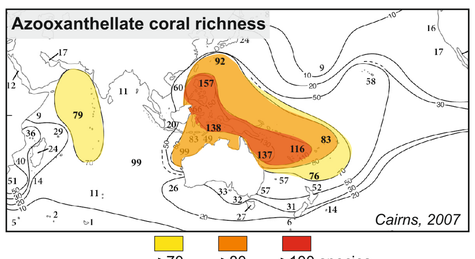
Evolution: First occurrences of fossil corals can be used for the calibration of molecular clocks in phylogenetic analysis.
Climate archivals: Preservation can be excellent allowing geochemical analysis to understand the palaeoenviroments.

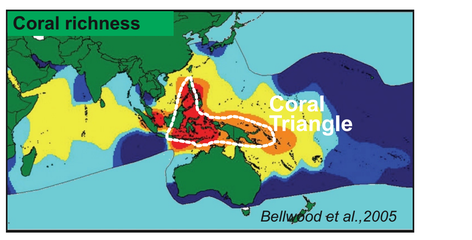


Detail of calicular margin of *Caryophyllia* sp. TF 526 (Bengalon)

Biological and Geological context

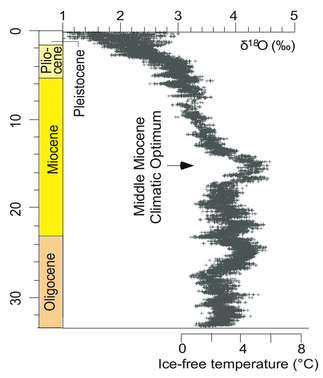
Southeast Asia hosts the maximum centre of marine diversity for both azooxanthellate (AZ-) and zooxanthellate (Z-) corals. Various hypotheses have been proposed to explain this pattern (centre of originiation, accumulation, survival), for which fossils could offer key information. However, the fossil record is still markedly undersampled.





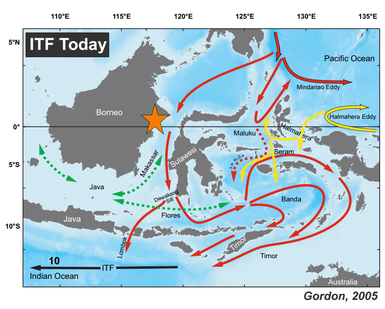
Evidence from palaeontological and molecular studies suggests that the Miocene was an important period for diversification in the region. Reef development during the Cenozoic has been linked to major global climatic changes, such as the Middle Miocene Climatic Optimum, when corals reached its acme, followed by their decrease during the gradual ocean cooling after this period.

This global pattern is mainly based on studies of the Mediterranean and Caribbean fossil fauna. They present different trajectories suggesting that regional factors might also play an important control on the coral development. Plate tectonic dynamics and consequent constraint of the Indonesian Throughflow Current (ITF) during the Miocene could have favoured the diversification in the region.



Zachos et al., 2008

★ Study area



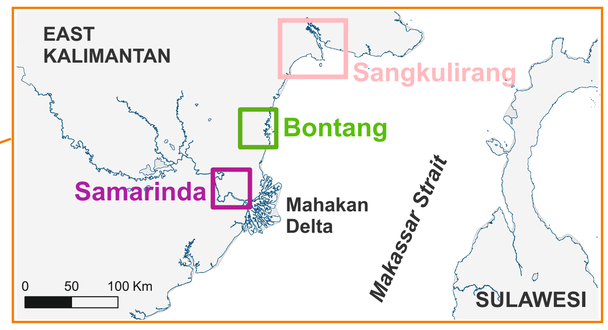
Gordon, 2005

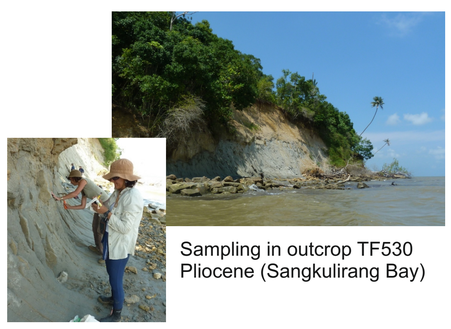
Historical collections

Most fossil corals were collected by geologist employed by the Dutch Government, during their explorations of mineral resources in Indonesia (Netherlands East Indies). First collections were made by Junghuhn (1809-1864) and J.K.L. Martin (1851-1942), followed by Wanner, Gerth, Verbeek, Rutten, Leupold and Umbgrove, with last expeditions by the end of the 40's. Monographies of this fossil coral fauna include Martin (1880, 1917), Felix (1913,1921), Gerth (1921-1933) and Umbgrove (1926-1950).
We are currently examining the identifications and taxonomic status of these collections.

The Throughflow Expeditions

The Throughflow network includes five major topics: palaeoceanography, palaeoecology, stratigraphy, geochemistry and biodiversity. Researchers of seven European institutions work in close collaboration with the Geological Survey in Indonesia.




Sampling in outcrop TF530 Pliocene (Sangkulirang Bay)

Two expeditions were carried out in Nov-Dec 2010 and Jun-Jul 2011 resulting in the collection of about 3 tons of coral specimens of Million years old). Although this extensive sampling was focussed on shallow marine ecosystems, some deep-water facies were also studied. AZ-corals have been found in 8 of the 49 outcrops so far.

Caryophyllia sp.
TF 530 (Sangkuliran Bay)

Acknowledgements

Thanks to all the members of the Throughflow team. To Brian Rosen, Jill Darrell, Lindsey Douglas, and the V-factor Team (NHM). To Alex Ball and Thomasz Goral (SEM at NHM)