

Mitt. österr. geol. Ges.	82 1989	S. 119 — 133 1 Fig., 3 Tab.	Vienna, December 1990
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On the Plate-Tectonic Setting of the Coal Deposits of Indonesia and the Philippines

By Alexander Horkel*)

With 1 figure and 3 tables

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Zusammenfassung

Die plattentektonische Entwicklung von Indonesien und den Philippinen kontrollierte auch die Entwicklung der tertiären Kohlebecken dieser Länder. Der plattentektonische Rahmen der jeweiligen Lagerstätten ist für Qualität und Inkohlungsgrad der Kohlelagerstätten wesentlich bedeutender als deren Alter.

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Summary

The geodynamic evolution of the south-east Asian archipelagoes controls the development of the Tertiary sedimentary basins which contain the coal deposits of Indonesia and the Philippines. The plate-tectonic setting of these basins and the associated geothermal gradients and tectonic stress are more relevant for the quality and rank of these Tertiary coals than the age.

1. Introduction and Economic Background

The Cenozoic crustal evolution of the Indonesian and Philippine archipelagoes created an intricate pattern of subduction zones, island arcs, microcontinental fragments, and oceanic ridges. The structures have not yet reached the complexity and maturity of the young Eurasian orogenic belts, and small intervening oceanic basins still separate several structural elements.

The plate-tectonic process controls also the distribution of the coal resources of the region. Their economic potential consists at present mainly in the partial substitution of imported fuels or the conservation of domestic oil and gas for export markets. Despite the relatively small current coal production (Tab. 1), a substantial in-situ resource potential of several hundred million tons is available for further development.

Tab. 1: Selected data on the coal industry (1988)

	INDONESIA	PHILIPPINES
PRODUCTION ('000 t)	4,500	1,330
MINES ('000 t)	560 Ombilin 1,860 Bukit Assam 2,080 other mines	670 Unong (SCC) 660 other mines
PLANNED CAPACITY (in mill. tpy)	2.40 Bukit Assam 0.65 Ombilin Ia 0.60 Ombilin Ib 0.75 Ombilin II	1.30 Unong (SCC) 1.50 Panian "
EXPLORATION AREAS	Kalimantan, Sumatra	Luzon, Mindanao

Source of production figures: Mining Annual Review 1989

Remark: Production figure of Unong mine (Semirara Coal Corp.) refers to direct shipping coal

The Tertiary SE-Asian coals, which rank from lignite and subbituminous coal to anthracite, differ fundamentally from Permian Gondwana coals or Carboniferous Laurasian coals. The various coal basins are frequently not known in sufficient detail for a comprehensive geological review. This paper describes therefore major and better documented coal deposits, or other deposits known to the author as typical for each plate-tectonic environment.

2. Data Basis

The data on the geology of the SE-Asian archipelagoes are of variable quality and partly fragmentary. Unpublished data from the colonial era still form a considerable and crucial part of the material. Even recent papers contain several assumptions and ambiguities on details of lithostratigraphy or facies correlation. V. BEMMELEN (1949), HAMILTON (1979), and BARBER & WIRYOSUJONO (1981) provide comprehensive reviews of the regional geology. The coal resources are described by BOMASANG & al. (1987) and the Indonesian Directorate of Coal (1986).

3. Geological Framework

3. 1. *Plate-tectonic Framework*

Rapidly changing subduction systems dominate the geodynamic evolution of the SE-Asian archipelagoes. They result from the northward drift and eventual collision of fragments of Gondwana with the Tethyan margin of Eurasia, and in addition from the relative westward convergence of the Philippine and Caroline plates of the Western Pacific (Fig. 1).

The pre-Tertiary tectogenesis is characterized by the accretion of arc-subduction systems onto Permo-Carboniferous cratonic nuclei (e. g. the Jurassic-Cretaceous mobile belts of the "Malaya" and "Sunda" orogene of v. BEMMELEN 1949). The modern subduction system, which did already exist during the middle Cenozoic, has the following main units:

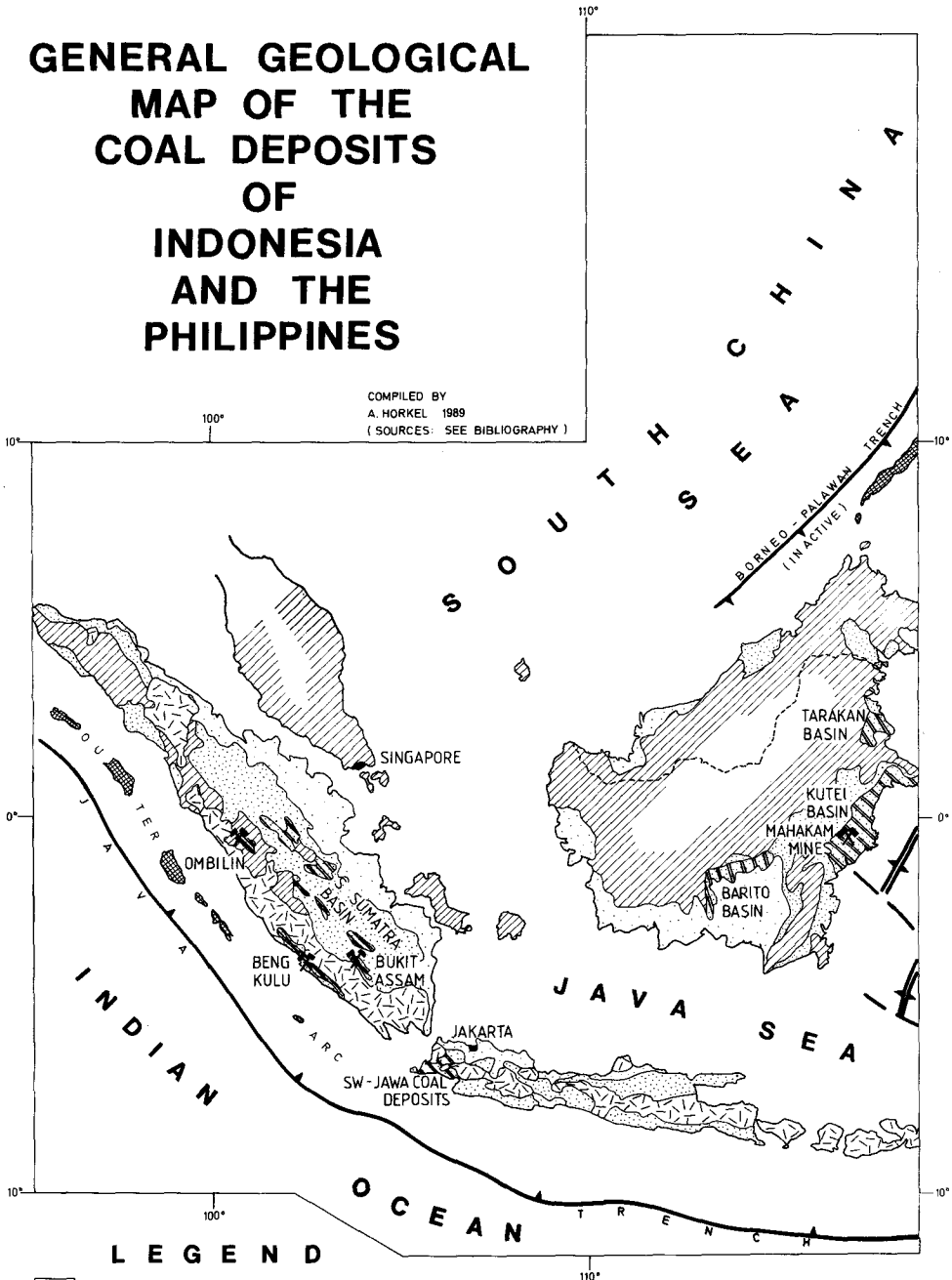
- The continental crust of the Sunda shelf, incl. the pre-Cenozoic ensialic basement of Borneo, peninsular Malaya, and eastern Sumatra.
- The Indonesian arc systems, which extends from western Sumatra to Celebes (Sulawesi) and the Moluccas, and comprises in principle the main arc with predominantly andesitic volcanism and the non-volcanic outer arc.
- The composite island arcs of the Philippines between the North Borneo and Palawan micro-plates and the subduction zone of the Philippine trench.
- The Precambrian-Paleozoic Australian platform, with the Australian fragment of Gondwana, and the Paleozoic mobile belts of E-Australia and central New Guinea. The coal deposits in this unit exceed the scope of this paper.

The following structural elements result from this middle to late Cenozoic convergence process:








- oceanic trenches, where oceanic crust is subducted;
- outer arcs with subduction melanges and ophiolites;
- elongate sedimentary troughs of the inter-arc basins;
- volcanic arcs with acidic plutonism and predominantly andesitic volcanism;
- molasse-type foreland basins (with the major oil deposits of Sumatra and the Java Sea);
- continental margin basins (with the oil fields of Eastern Kalimantan); and

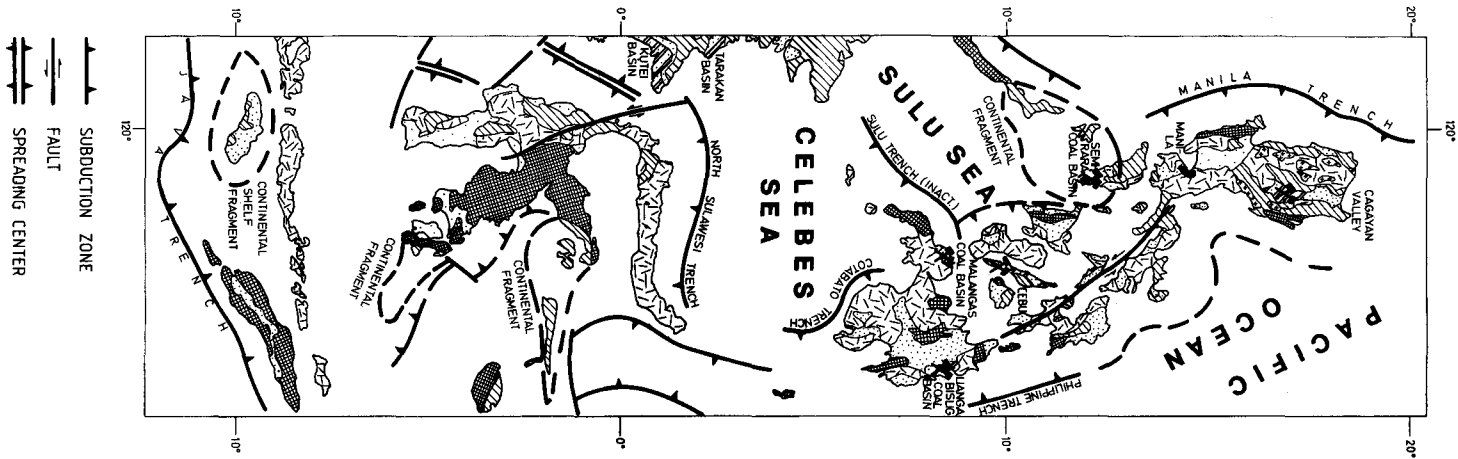
GENERAL GEOLOGICAL MAP OF THE COAL DEPOSITS OF INDONESIA AND THE PHILIPPINES

COMPILED BY
A. HORKEL 1989
(SOURCES: SEE BIBLIOGRAPHY)

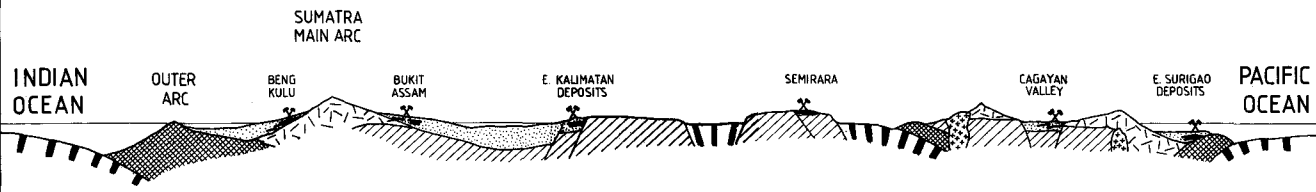


LEGEND

- | | | | | |
|---|--|-----------------------------|---|---------------------------------|
|  | QUATERNARY | |  | PALEOGENE AND PRE-TERTIARY |
|  | MELANGE, SUBDUCTION COMPLEXES OF OUTER ARC | } NEOGENE SUBDUCTION SYSTEM |  | COAL MEASURES WITH COAL DEPOSIT |
|  | ARC VOLCANICS AND VOLCANICLASTICS | |  | TERTIARY ACID INTRUSIVES |
|  | SEDIMENTARY BASINS | | | |



**SCHEMATIC GEOLOGICAL SECTION
WITH TYPICAL LOCATION OF COAL BASINS
(PRIOR TO MAIN DEFORMATION)**



— consolidated continental blocks with Neogene platform cover, rift systems, and continental shelf.

Numerous subsequent and diachronous subduction cycles (HAMILTON 1979 and BARBER & WIRYOSUJONO 1981) complicate the detailed relationship of these elements in time and space.

3. 2. *Sedimentary Basins*

The thick paralic sequences favourable for coal deposits developed mostly in inter-arc basins, foreland basins, continental margin basins, and continental rifts.

The **inter-arc basins** between the non-volcanic outer arcs (mostly subduction melanges and ophiolites) and the volcanic arc contain mainly flysch and molasse-type sediments. Fluvial deltaic-shoreline complexes with paralic coal deposits lap onto the volcanics and basement of the main arc. Coal deposits in transgressive series in this tectonically active zones tend to be lenticular and impersistent, and show rapid lateral and vertical facies changes. Reserves are therefore usually rather limited. The active arc volcanism causes contamination by volcanic or sedimentary detritus; marine influences result in elevated sulphur contents. The subduction-related tectonics create complex structures, such as upthrusts and overthrusts. Thermal effects of volcanic intrusions and tectonic stress improve the coal rank in basins close to the main arc (W Sumatra and SW Java). The Surigao basin (SE-Mindanao), is partly located on the inner slope of the outer-arc melanges, and has a comparatively weak corresponding volcanism with geothermal gradients insufficient for coal rank levels comparable with Sumatra and Java.

The sedimentary environments of the **foreland basins** are more favourable for larger coal deposits (e. g. Bukit Assam in southern Sumatra). The margins adjacent to volcanic arcs or structural highs constitute slowly subsiding sheltered environments. As the trench system migrates seaward, molasse-type sediments with coal measures develop during regressions. Ash and sulfur contents of the coal deposits depend on the amount of recycled volcanoclastic detritus and the proximity of marine facies.

Continental margin basins (or platform edge basins — BEN AVRAHAM & EMERY 1973) on the foreland margins adjacent to continents are favourable for coal deposits during transgression phases, as evidenced by the Semirara deposits in estuarine basins with thick sandstone-shale sequences. Emerging high-energy erosion environments during regressions are bordered by basins with coal seams in prograding delta sequences (e. g. East Kalimantan).

Thick coal measures occur also in **continental rifts** (e. g. Cagayan Valley, Luzon), while **platform cover sequences** on relatively stable shelves with thin sedimentary sequences have no economic coal potential.

3. 3. *Stratigraphy of the Coal Deposits*

The limited scope of this paper permits only a general outline of the stratigraphic correlations.

Despite the importance of pre-Tertiary sequences for the geodynamic evolution of the archipelagoes, their areal extent is rather restricted compared to the Cenozoic for-

mations, which are separated from the pre-Tertiary through the archipelagoes by a major unconformity. Marine transgressive-regressive cycles with a transgression maximum during the middle Miocene, and a regional marine regression during the upper Miocene to Pliocene characterize most of the Tertiary sedimentation. Minor cycles, locally superposed on this general trend, caused the local development of restricted basins.

The coal measures are essentially paralic freshwater sequences with little or no diagnostic marine fauna. Correlations are mainly on a lithological basis, since palynological subdivisions are not yet established in sufficient detail. Some coal deposits in the commonly diachronous basal transgressive series, which were regarded in the past as Paleogene on account of their proximity to the basal unconformity and high rank, could be of Lower Miocene age, since marine Miocene overlies these basal transgressive coal measures. The Upper Miocene regression created a more uniform environment for coal formation.

3. 4. Coal Petrology

The sub-bituminous to bituminous Tertiary coals of SE-Asia differ fundamentally from the geographically close Permian Gondwana coals (Australia, India or S. Africa) or from the Carboniferous coals of Laurasia. The Tertiary SE-Asian coals are usually non-banded clean vitrainous, or clarainous coals with resins, and have monotonous seam profiles; ash occurs in intercalated clay and sandstone partings. There are thus distinct contrasts to the usually conspicuously banded durainitic Gondwana coals with high inherent ash contents.

The widely variable microlithotypes of Gondwana coals differ significantly from the uniform SE-Asian coals, which consist almost exclusively of vitrite + clarite with almost no durite + inertinite or intermediates, and have thus characterical high reactive components. Vitrinite, the principal maceral (in low-RANK coals huminite and humodetrinite), is accompanied by minor amounts of exinite and inertinite. The more variable macerals of Gondwana and Laurasian coals differ mainly in regard to exinite and inertinite components (MACKOWSKY 1968, ROBERTSON RESEARCH 1977). Three characteristic types of the relatively uniform SE-Asian coals can be discerned in the field:

- vitrain: massive bright coal, mainly vitrite with more than 95% vitrinite;
- vitroclarain: dominant type; finely laminated bright coal, consisting mainly of vitrite with some clarite/hydrate and clarovitrinite; main macerals — vitrinite with moderate exinite;
- (duro)clarain — durain: occurs subordinately; finely laminated coal with dull lustre, includes vitrite + clarite/hydrate with duroclarite and vitrinertinite.

The characteristic maceral analysis and the low inertinite contents (mainly fungal remains) indicate a tropical flora in a humid climate and relatively high water levels during the decay of the vegetation. The intensive gelification of the plant tissue points to relatively acid ground water, possibly with brackish or marine influences (in higher sulphur coals). Detrital vitrinite may indicate the decay of plant material in limnetic and open-marsh environments (ROBERTSON RESEARCH 1977).

4. Geology of the Coal Deposits

4. 1. Coal Deposits in Inter-arc Basins

4. 1. 1. The Coal Deposits of Bengkulu (Sumatra)

MARSDEN (1811) mentions already the coal deposits of Bengkulu on the SW coast of Sumatra, which were “not esteemed very good“. Mine development started in 1984 after the construction of a deep water harbour.

The Miocene paralic coal deposits of Bengkulu formed in a transgressive fluvial-deltaic-shoreline complex on the seaward side of the main volcanic arc of Sumatra. They are characterized by relatively rapid lateral facies changes, lenticular nonpersistent seams, and a complex tectonic pattern with thrust faulting and compressive polycyclic deformation. The general stratigraphy of the area is summarized in Tab. 2.

Tab. 2: Summarized Stratigraphy of the Bengkulu Area

Lower Miocene (?) — Pliocene	Younger Volcanics
Lower — Middle Miocene	Marine facies — reef limestones, shales — sandstones, conglomerates
Lower Miocene	Deltaic facies — coal measures
	Transgression
Paleogene (to Lower Miocene?)	Older Volcanics

The **Older Volcanics** are usually poorly exposed andesitic flows with subordinate trachytes and dacites. Their conjectural age is based on general lithological correlations.

The **Miocene sediments** rest on the eroded surface of the older volcanics or directly on the pre-Tertiary basement. They comprise an upper marine facies with limestones, marls, and sandstones and a lower deltaic sequence which is again subdivided into the coal measures and a facies without coal and carbonaceous shales.

Volcaniclastic sediments of rapidly changing high- and low energy environments dominate the general lithology of the **coal measures**. The basal seams of Bukit Sunur are associated with deltaic crossbedded, arkosic, lower Miocene sandstones (palynological age by T. WAYNE, pers. comm. 1989). A wealth of sedimentary structures indicates as facies delta fronts or plains with rapidly changing and varying currents. The main seams, which are up to 10–12 m thick, overlie this facies and are part of a low-energy facies which reflects periods of quiescence during which coal swamps could form. This unit comprises gray siltstones with bioturbation structures and coalified plant detritus, finely bedded carbonaceous claystones, or shales. Tuff horizons or clay partings in coal seams with kaolinitic volcanoclastic detritus indicate contemporary volcanic activity.

The **marine Miocene** is better exposed in SE Bengkulu, and comprises mainly fossiliferous shallow-marine marls, shales and limestones; beach sands contain reworked coalified detritus.

The **Younger Volcanics** are partly contemporary with the Miocene sediments and comprise porphyritic compact andesite (incl. subordinate dacites, and trachytes); they form intrusive dykes, vents, and sills. Non-chilled hanging wall contacts with the Miocene indicate sub-aeric lava flows. Pyroclastics include welded tuffs, ignimbritic ash flows, and agglomerates, which are frequently of rhyolitic composition.

The rank of the usually low-sulfur, vitritic Bengkulu coals ranges from sub-bituminous in areas with limited volcanic activity, to high-volatile bituminous coal (ASTM D388 – 77) near volcanic diatremes. Natural coke, anthracite or low-volatile coal occur in thermal alteration haloes around igneous intrusives.

4. 1. 2. The Piedra Negra Deposit (Mindanao)

The coal deposits of Surigao on the eastern side of Mindanao occur in an inter-arc basin of the Philippine arc systems. The Neogene of the Lianga-Bislig-Lingig basin in Surigao comprises mainly sandstones and shales with subordinate conglomerates, limestones and coal seams. Small-scale coal mining takes place in this coal basin at Bislig.

The coal-bearing sequence of the Piedra Negra deposit north of Bislig rests unconformably on Paleogene subduction complexes and related younger sediments or volcanics of the Philippine-Halmahera arc. It is part of the early Miocene Pampayan formation which contains also the Bislig coal deposits (VERGARA & SPENCER 1952). Thick basal conglomerates of reworked andesites are overlain by sandstones and shales. Inter-calations of calcareous sandstones and limestones increase towards the top. The coal seams occur mainly with shales and sandstones, or volcaniclastic graywackes, although coals are also associated with marine fossiliferous mudstones or calcareous sandstones.

The Piedra Negra deposit and the other coal deposits in this area form multi-seam deposits with several thin coal seams (thickness about 2 to 3 m) in shale-sandstone sequences. Intensive tectonics create a complex structural pattern. The coal seams contain relatively hard and brittle duritic, claritic and vitritic coal. The rank is usually not above sub-bituminous C.

4. 1. 3. The Ombilin Coal Field (Sumatra)

The Ombilin coal field in West Sumatra, mined since 1891, forms the transition between coal deposits in inter-arc and foreland basins. The Tertiary intramontane Ombilin basin occurs apparently immediately north of an island range of the Barisan volcanic arc. The coal seams are part of a delta system near the coast line.

The stratigraphic sequence is summarized below:

- Marls and shales, resp. corraline and algal limestones (marine Miocene)
- Sandstones, shales and conglomerates
- Coal measures with three mineable coal seams
- Sandstone, shale, marls and conglomerates.

The basal series and the coal measures were traditionally considered as Eocene because of the high coal rank. However, recent work indicates considerably younger and even possible lower Miocene ages (similar to the Bengkulu coals).

Two major coal seams occur in a sequence of carbonaceous shales and sandstones along strike over approx. 12 km. Their thickness varies (seam A: 1.5–2.5 m, seam C: 4.5–9 m). The coal is a low sulfur high-volatile coal with low ash contents. Clarite with subordinate vitrite constitutes the prevailing macerals (AUSTROMINERAL 1977). Fusinite or pyrite are scarce.

4. 2. *Deposits in Foreland Basins (Sumatra-Bukit Assam)*

The South Sumatra basin between the tin granites of the Sunda shelf and the volcanic arc of Sumatra contains mainly Paleogene paralic and tuffaceous non-marine clastic sediments, overlain by transgressive marine Neogene and a subsequent regression series with major coal deposits. The stratigraphy is summarized below:

- Upper Palembang formation (Plio-Pleistocene): tuffaceous clays, sands and gravels;
- Middle Palembang formation (Mio-Pliocene): brackish-fresh water facies with sandstones, mudstones and coal measures;
- Lower Palembang formation (U. Miocene): early stage of the regressive cycle with a shallow neritic to delta plain facies with shales and glauconitic sandstones;
- Telisa/Batu Raja formation (L. Miocene): maximum extent of the transgressive facies with limestones, calcareous fossiliferous shales, glauconitic sandstones, and tuffs;
- Talang Akar formation (Oligo-Miocene): initial transgression with deltaic sandstones, siltstones, shales, grading in the basin into marine sandstones and shales with local euxinic environments;
- Eo-Oligocene: coarse clastics, tuffaceous sandstones and variegated clays; tuffaceous shales with thin limestones;
- Pre-Tertiary: Mesozoic metamorphics, interlayered sediments and mafics, limestones, and Jurassic to Cretaceous granites.

The coal measures in the middle Palembang formation developed between the Asian landmass and the rising Barisan range after the closing of channels through the Barisan volcanic arc. They extend from central Sumatra over more than 700 km to south Sumatra, and are exploited since decades at Bukit Assam, where the three main coal seams have an average aggregate thickness of about 30 to 40 m. Several minor seams, lenticular shales, sandstones, carbonaceous mudstones, and tuffitic marker horizons are interbedded. The coal rank depends mainly on the proximity to igneous intrusives. In general, the usually claritic coals with distinct resins are lignite to sub-bituminous coal, although the coal rank improves even to anthracite in thermal alteration haloes.

4. 3. Coal Deposits on Continental Margins

4. 3. 1. The Coal Deposits of East Kalimantan

The Tertiary sequence of East Kalimantan starts with an Eocene — Oligocene transgression on the rifted continental edge of the Sunda shelf, followed by a Late Oligocene — Miocene regression associated with an orogenic phase, and a Mio-Pliocene transgression. The development of the large coal potential in the following tectonic units has just started.

The **Barito basin** between the pre-Tertiary Barito platform and the ultrabasics, acid intrusives and metamorphic Cretaceous of the Meratus High probably started with block faulting during the late Mesozoic or early Tertiary. It contains virtually no coal concessions.

The **Kutai basin**, at present the center of coal development, formed in the early Tertiary between the pre-Tertiary of the Meratus High and the Mangkalibat Ridge. Local unconformities are known at the base of the Miocene and in the Upper Miocene, and orogenic phases during the younger Miocene.

The **Tarakan basin** with few coal concessions is bound by the Mangkalihat peninsula and by the volcanics and pre-Tertiary of Sabah. The eastward migrating sedimentation axis, a regressive Miocene sequence, and the Mio-Pliocene coal measures resemble the geology of the Kutei basin.

The Mahakam coal deposits of the Kutai basin which are typical for this setting, have the following general stratigraphy:

- Pliocene deltaic-estuarine sandstones and mudstones with carbonaceous shales and minor lignites.
- Middle and Upper Miocene (Balikpapan formation): The Lower Miocene marine facies is succeeded during a major regression by inner shelf, deltaic and lagoonal deposits with major coal deposits in prograding delta complexes.
- Oligocene and Lower Miocene: Marine open shelf deposits, incl. shales, marls, and subordinate limestones.
- Late Eocene: widespread transgression over Mesozoic basement with basal conglomerates, sandstones, marls, and calcareous sediments. Local development of freshwater environments with limited coal swamps.

Several private mines exploit the multi-seam Mahakam deposits. The geological correlation between the various 1.5 m to approx. 9 m thick main seams is not yet established in detail. The deposits contain in general sub-bituminous to high volatile bituminous, low-sulfur vitritic to claritic coals.

4. 3. 2. The Coal Deposits of Semirara (Central Philippines)

The isolated Semirara coal basin on the eastern margin of the North Palawan micro-continent covers the southern tip of Mindoro and Semirara island. The geological contacts of the following stratigraphic sequence with the micro-continent are obscured by the sea.

- The **Buenavista formation** (Pliocene) overlies the Semirara formation unconformably; basal calcareous arenites grade upward into massive coralline limestone.
- The **Semirara formation** (M.–U. Miocene) comprises:
 - Upper member: near-shore neritic facies with non-persistent argillaceous limestones;
 - Middle Member: estuarine sandstones with minor intercalations of shales and thin coal seams;
 - Basal Member: **Coal measures** — four cyclical sequences of friable, weakly consolidated sandstones, siltstones and carbonaceous shales, terminated on top by major coal seams; underlain by basal monotonous sandstone-shale-coal cycles with tuffaceous shales, thin impure sandstones and minor coal seams.

The cyclical fining upward sequences of the coal seams indicate that the accumulation of peat in alluvial swamps was interrupted by the sudden deposition of sands of higher-energy environments, followed by the return of the low-energy swamp facies.

The mine development of the Unong deposit on Semirara started in 1982 (production 1988: 0.95 mill t run-of-mine coal, of which approx. 0.6 mill t were direct shipping grade). The Panian and Himalian deposits still await development. The main seams at Semirara are up to 20 m thick and consist mainly of claritic subbituminous C coals with relatively high resin contents.

4. 4. *Deposits in Continental Rifts (N. Luzon)*

Few published data exist on the Pliocene lignite deposits of Cagayan Valley, northern Luzon, which occur in a transgressive series in the rift valley between the Sierra Madre and the Cordillera Central. The deposits are multi-seam deposits; the main “base seam” has a maximum thickness of over 6 m.

The deposits in the Cagayan rift valley were apparently not exposed to significant volcanism or compressive tectonic stress. Their relatively low quality is therefore more comparable with European deposits in post-tectonics basins, than with the comparatively high-rank coals in the tectonically active young basins.

5. **Conclusions and Economic Perspectives**

The tectonic and stratigraphic position of the various coal deposits of Indonesia and the Philippines is summarized in Tab. 3. Sedimentological conditions which depend on the plate-tectonic setting of each basin, control crucial economic parameters of the coals, such as seam thickness, lateral extent and quality (mainly ash and sulfur contents); tectonic stress and geothermal gradients related to each plate-tectonic regime determine the coal rank.

Regardless of the problematics of the definition of relevant economic parameters for semi-quantitative estimates of the coal potential of various basins, such estimates

indicate for the Philippines (BOMASANG & al. 1987) the following order-of-magnitude resources:

Semirara (continental margin type): 550 mill t
 Cagayan valley (rift type): 330 mill t
 Surigao-Davao (inter-arc type): 300 mill t

The estimates of the resource potientiale of the other Philippine coal basins are significantly lower.

Tab. 3: Summary of tectonic and stratigraphic Position of coal Deposits

AGE DEPOSIT		PLIOCENE	MIOCENE			OLIGOCENE	
			U	M	L		
A R C T R E N C H G A P	BENGKULU	Younger Volcanics	Marine facies		Delta sequ. w. coal meas.	Older volcanics	
	SURIGAO		Marine facies		Pampaya fm. w. Bislig + P. Negra deposits		
	OMBILIN		Marine facies		Coal measures (age uncert.)		
FORELAND		U	M	L			
BUKIT ASSAM		delta- estuar.	regress w. coal	initial regress.	Marine facies	Delta sequence	Marine Paleog.
CONTINENTAL MARGIN							
MAHAKAM R.		Delta-estuar.	regression w. coal deposits		Marine facies		
SEMIRARA		Buenavista Fm. (marine)	Semirara fm. w. basal coal deps.				

The major coal potential of Indonesia and apparently the largest resources potential of the entire region is located in the continental margin basins of Kalimantan. Another major potential exists in the foreland basin of South Sumatra.

The coal deposits with the best economic potential and quality require slowly subsiding paralic environments without excessive erosion or high-energy facies. Marine influences should be sufficiently remote to avoid elevated sulfur contents. Post depositional volcanism and compressive tectonics are required for higher coal ranks. Accordingly, the structural units with the best potential are:

- subsiding shelves of the inter-arc basins;
- regressive sequences on outer margins and structural highs of the foreland basins;
- transgressive and regressive series in foreland and continental margin basins;
- transgressive series in rifted graben systems.

The arc-trench gap, as a tectonically active zone exposed to open seas, is characterized by lenticular coal seams with rapid lateral facies changes, complex structures and intensive faulting. Coal rank and quality depend on volcanic or sedimentary detritus and marine facies influences during coal deposition, and on postdepositional tectonics and volcanic activity. Deposits are usually rather small and have complex tectonic structures.

Continental margin and foreland basins constitute the major resources potential. Multi-seam deposits with thick seams and wide lateral extent characterize this type of deposit. The quality is usually lower than in inter-arc basins, unless thermal alteration improved the coal rank in halos around igneous intrusions related to the main arc magmatism.

Post-orogenic coal deposits in rifted basins have the lowest qualities and rank, owing to the absence of post-depositional volcanism and compressional stress.

Acknowledgements

The author wishes to acknowledge the data and assistance provided for the completion of this paper by Alpine Mineral and Austromineral, Vienna, ODECO Mining & Engineering Ltd., London and Mulheim, P. T. Bukit Sunur, Jakarta, Semirara Coal Corp., Manila, Piedra Negra Mining Corp., Manila, and Indocoal Resources Pte Ltd. Singapore.

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Appendix

Coal Quality Data (on air-dry basis) (Typical Quality Ranges for Run-of-mine Coal)

Deposit	Rank	T.M.%	I.M.%	ASH%	VCM%	C-FIX%	S%	KCAL/KG
Bengkulu	sb, a	15-20	5-7	12-16	15-40	40-70	.3-.7	6200-7500
Piedra N.	sb		15-18	4-14	37-43	32-40	.5-2.6	3900-5500
Ombilin	sb	10	6-7	5	37	46	.5	6900
Bukit Ass.	sb	24	12-15	4	32	40	.5	5400
	a	4-6	2	1.5-6	8-17	75-85	.7-1.2	7900-8200
Kalimantan	sb		5-15	5-12	35-50	30-49	.1-1.5	4300-6400
Semirara	sb		14	20	37	28	1-2	4300-5150
Cagayan v.	1	40-50	20	20	35	25	-1.0	3650

Note:	T. M.	Total moisture	RANK	1	lignite
	I. M.	Inherent moisture		sb	sub-bituminous
	VCM	Volatile matter		b	bituminous
	C-FIX	Fixed carbon		a	anthracite
	S	Sulphur			
	KCAL/KG	Calorific value in kcal/kg			