

## Tectonics and Oil Prospects of the Moluccas, Eastern Indonesia

EDWARD A. GRIBI, JR.<sup>1</sup>

**Abstract:** The greater Moluccas are bounded by the Pacific and Indian oceanic plates and the greater Australian and Sunda continental crustal plates or shelves. The effect of their opposing movement is a giant counterclockwise swirl. The island arcs within this pattern are parts of subduction zones between the opposing plates. The Sorong transform left lateral fault resulted from these forces and offset remnants of the West Irian shelf terrane at least 700 kilometers westerly to the Sula Islands. Fossil subduction zones are present in the form of melanges including a persistent zone extending in an "S" pattern from Timor through Ceram, Buru, and Sulawesi. The age of emplacement of this zone in part is post-Lower Miocene pre-Middle Pliocene.

Sedimentary rocks of pre-Pliocene to Permian age occur notably in Timor and the Sula Islands. In most localities they are deformed and indurated to the extent of making them economic basement. Plio-Pleistocene linear sedimentary basins follow the "S" trend and reach a maximum of 3,000 meters in thickness in northeast Ceram and Timor. Rocks include deep water claystones, shelf and lagoonal clays, bar and beach sands, and barrier coral reefs. Oil seeps occur on Ceram, Timor, and Buton (asphalt) mostly from Plio-Pleistocene rocks. Oil is produced at Bula, Ceram, from Pleistocene bar and shoreline sands in stratigraphic traps. A recent development at Bula has established prolific production from an extremely permeable Pleistocene reef. The data suggest that oil accumulation per unit volume of sediments is abnormally high in the Plio-Pleistocene. Reasonable extrapolation indicates that major oil fields may be found in prospecting the "S" trend. Most likely traps will be stratigraphic with accumulations in beach, bar, and turbidite sands and reef limestones. Prospects also exist in other than Plio-Pleistocene in other portions of the Moluccas. Prospecting for these subtle, elusive traps may be rewarding if geologists exchange certain negative prejudices for a positive optimistic approach in combination with good imaginative geology.

### INTRODUCTION

This paper will describe the tectonics of the Moluccas Island group of the Indonesian Archipelago and vicinity and relate this to the prospects for oil. The approach is to stick with the structural facts as presently known relating these to the development of sedimentary basins.

The Moluccas (see Fig. 1) lie between the Sulawesi group and West Irian. The main subdivisions are the Halmahera Islands to the north; the Sula Islands to the northwest; Ceram and adjacent islands (including the provincial capital, Ambon); and the smaller more scattered Kai, Tanimbar, and Banda Arc islands to the south. The lesser Sunda Islands, Timor, and eastern Sulawesi are not part of the political province but are discussed here because they constitute part of a natural geological province. The islands range from the relatively large Ceram with a 3000-meter peak in its mountainous core to countless islets and atolls. Most are hilly to mountainous with flat coastal plains the exception. The northern portion has well-distributed tropical rainfall with resultant rain forests. The lesser Sundas and Timor have a short rainy season and approach semi-arid conditions and vegetation. Several deep oceanic trenches parallel the major island arcs. Waters deepen rapidly away from nearly all the islands leaving little area of shallow shelves.

Published geological work in the Moluccas largely consists of the results of early traverses and sampling. (van Bemmelen, 1970. Germeraad, 1946. van der Sluis, 1950.

<sup>1</sup> Holland Park D-1, Singapore 10.

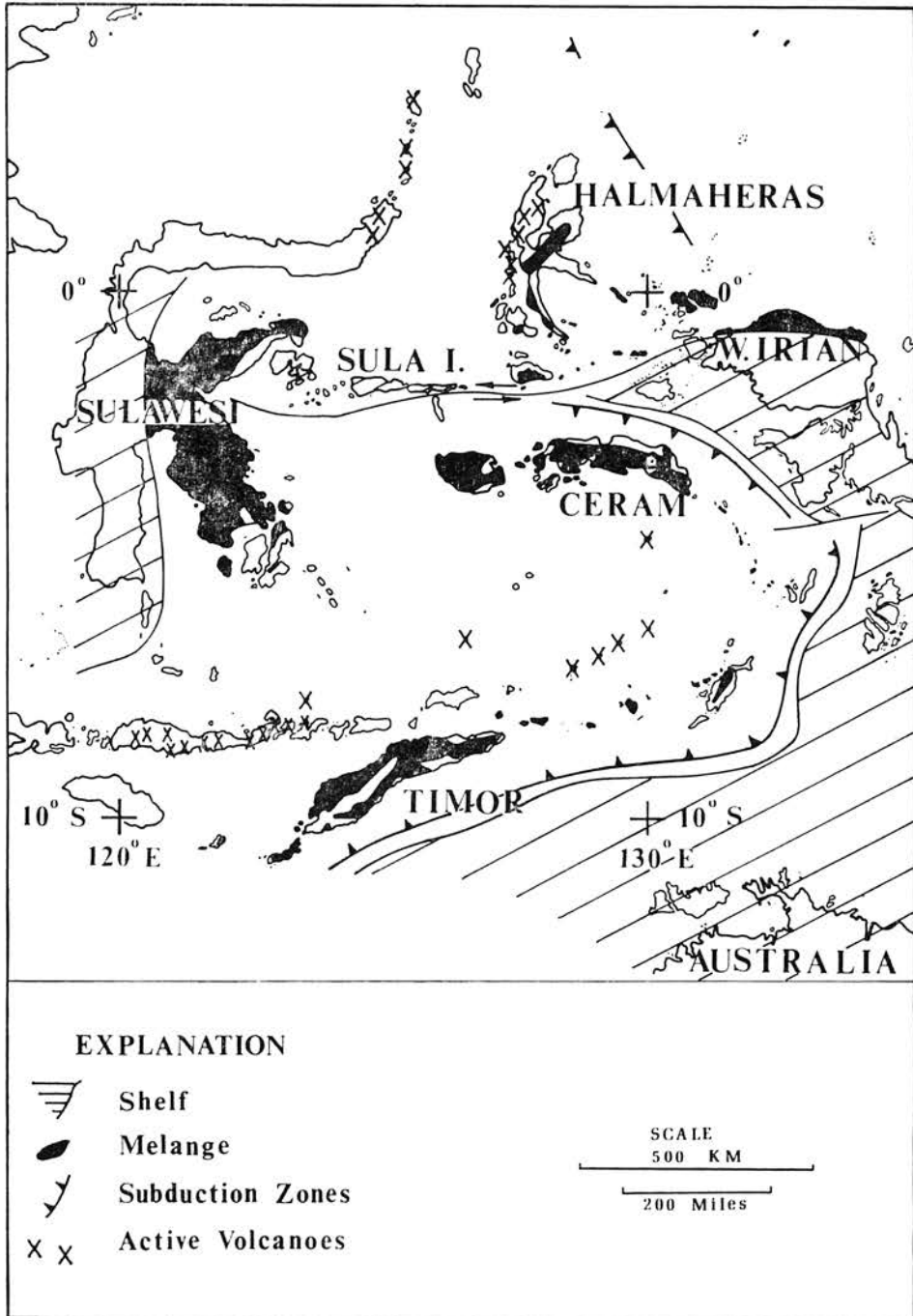


Fig. 1. Generalised Tectonic Map of the Moluccas.

Valk, 1945.) A comprehensive geological study of Portuguese Timor was published by Audley-Charles in 1968. Unpublished geological studies were made throughout the Moluccas during the pre-World War II oil search, including several detailed maps of local areas in northeast Ceram. Gulf & Western Indonesia, Inc., contractor to P.N. Pertamina, has been conducting exploration including reconnaissance mapping, geophysics, and drilling centered on northeast Ceram for the last two years. Most recently a group from the Indonesian Geological Survey has conducted a geological reconnaissance of the Sula Islands (personal communications, 1972, Sukamto and Wolcott).

### REGIONAL GEOLOGY

The Moluccas are more or less involved in the meeting between four crustal plates. The Pacific plate on the northeast is obviously expanding to the southwest. The Indian Ocean plate to the southwest is providing a northeasterly push. The Australian shield and its stable and unstable shelf components provide a relatively stable eastern buttress. To the west of the Moluccas the edge of the Sunda shelf within Sulawesi constitutes a western limit to this complex mobile area. The result of the collision of these moving crustal plates is a pattern appearing in plan as a gigantic counterclockwise swirl. The island arcs obviously are part of subduction zones involving portions of the oceanic plates. Speculation as to which portion is Indian Ocean or which is Pacific is beyond the scope of this paper.

Another result of this plate movement is the development of at least one major transform left lateral fault, the Sorong zone. This fault crosses the north side of West Irian and is believed to continue along the south side of the Sula Islands almost to the Sulawesi Coast. It appears to have dragged remnants of shelf and basin sediments and igneous rocks of West Irian at least 700 kilometers westerly to the Halmahera and Sula Islands. Other similar faults with less movement are suspected in the region. In detail the few local faults mapped in northeast Ceram exhibit left lateral offset. It should be noted that no Alpine-type nappe features have been observed in Ceram during recent mapping, previous publications to the contrary notwithstanding.

Besides the presently active subduction zones, evidence exists for the presence of at least one and probably several fossil subduction zones. A persistent zone of deformed sedimentary rocks containing exotic blocks of different ages and occasionally exhibiting varying degrees of metamorphism exists through the core of Ceram, Buru, and Timor. A similar zone in the southeast arm of Sulawesi may be correlative. The age of emplacement of the melange, based on Ceram and Timor occurrences, appears to be at least post-Lower Miocene and may be as late as early Pliocene. Due to the counterclockwise couple between the plates, the occurrence of this melange describes a large "S" pattern with east Sulawesi and Timor being the two extremities joined by the Ceram-Buru trend. It is suggested that the Sulawesi portion of the trend may have been broken off from the original trend and rotated 45° and displaced to the southwest.

### SEDIMENTARY BASINS

Pre-Pliocene sediments down to Permian in age exist, notably in Timor and the Sula Islands. Although there are some large areas where these older rocks are undeformed, they generally exhibit strong deformation and occasional mild metamorphism, thus effectively making them economic oil basement over most of the area. A general exception to this is north of the Sorong fault zone where a displaced mildly deformed pre-Pliocene section exists in the Sula and possibly the Halmahera Islands.

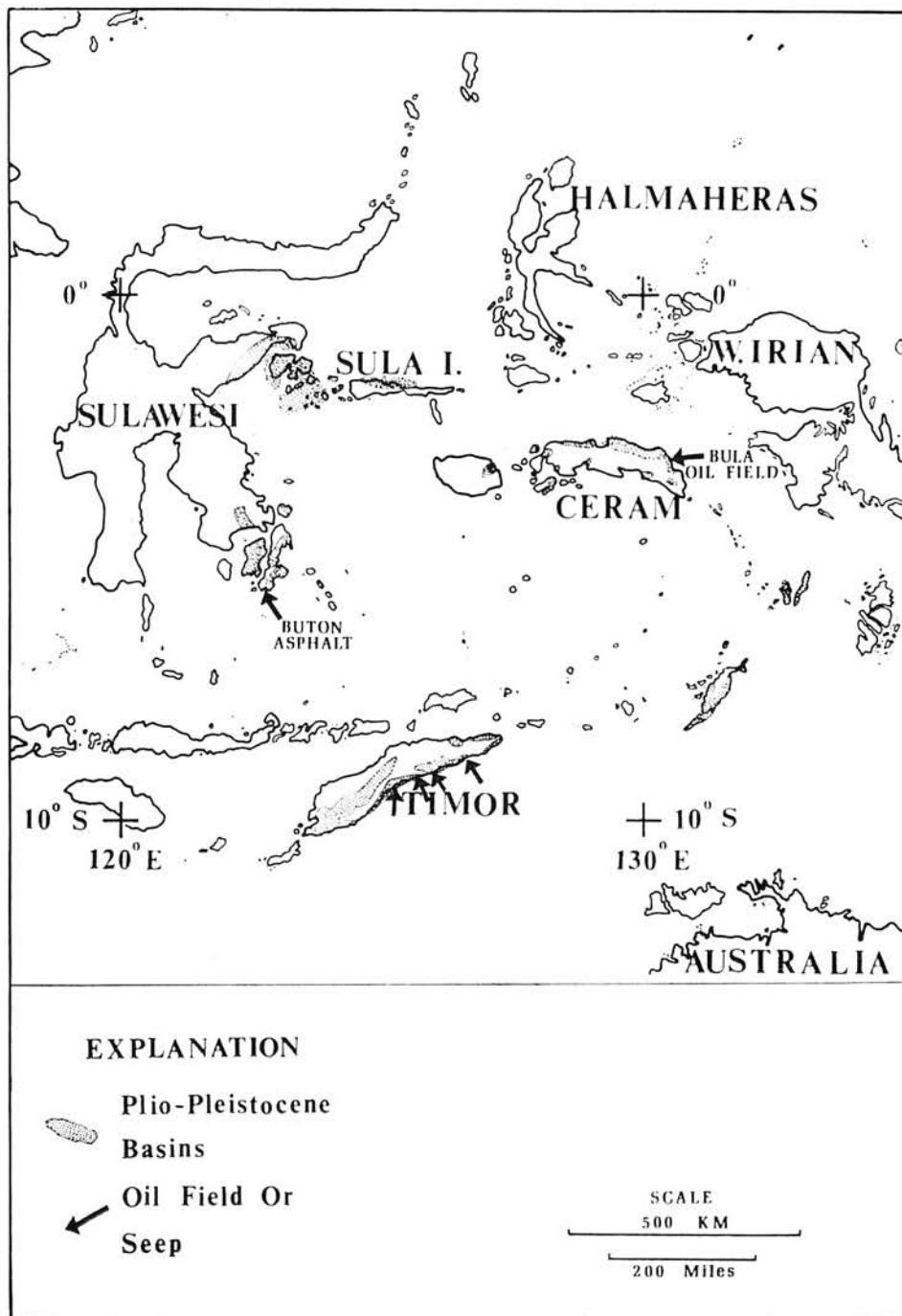


Fig. 2. Map of the Moluccas showing the Plio-Pleistocene Basins and oil occurrences.

Otherwise the section of interest to oil finders is Plio-Pleistocene, in fact mostly Pleistocene in age (see Fig. 2). It unconformably overlies the deformed rocks. The larger basins are linear features lying on the outer sides of the fossil subduction zones. Much smaller structural basins are downfaulted or downfolded at several localities within the melange belt. The Plio-Pleistocene reaches a maximum thickness of 3000 meters in northeast Ceram but it commonly averages between 500 and 1000 meters. Similar thicknesses are present in Timor. A section of probably correlative rocks on Buton measured 800 meters. Depositional environments are mostly open marine with deep water claystones constituting the major rock type. Shallow water shelf facies are typically developed along the westerly and southwesterly onlapping shoreline edges on Ceram. Permeable beach and bar sands and barrier coral reefs occur at and parallel to these ancient shorelines. Actual and potential reservoir beds in the shelf facies range from 20 to 150 meters in total thickness within sedimentary sections ranging from 300 to 800 meters in thickness. In addition turbidite sands have been encountered in the deep water facies. They can be expected to be an important target locally.

#### EVIDENCES OF OIL

Oil seeps occur widely along the basin trend. Two major seeps at the Plio-Pleistocene outcrop edge at Bula and Nief, Ceram, were first mentioned in the literature in 1865. Oil seeps are known over most of the eastern part of Timor distributed throughout the section. The most notably are associated with Plio-Pleistocene rocks or adjacent areas in older rocks. Large quantities of asphalt outcrop in Buton in the Plio-Pleistocene section. They are still being commercially quarried.

The first drilling commenced at Bula, Ceram, in 1897. A well was completed that same year with a reported initial production of 200 barrels per day with a total depth of 200 meters. Development reached a peak in the late thirties when some 70 wells were producing a total of 2000 barrels daily of 21° to 25° oil. Production has been mostly from individual Pleistocene bar sands averaging 10 to 20 meters thick and aggregating up to 50 meters of net pay. Production ranges from 100 to 300 meters in depth and the field is a 160 acre stratigraphic trap with localization due to structural nosing. Production was also developed in association with the Nief seeps in the twenties and thirties, but daily production never exceeded 10 barrels per day. Bula Field lay dormant from 1944 until Gulf & Western Indonesia, Inc., contractor to Pertamina, commenced operations in late 1970. G & W completed 18 wells within the original field and reached a maximum total daily production of 2000 barrels of oil per day in mid-1971. Cumulative production for the 70 odd years is estimated at around nine million barrels.

In early 1972 a northwest stepout at Bula was completed from an extremely porous Pleistocene calcarina reef for 700 barrels of oil per day. Depth is 130 to 150 meters. Additional stepouts in the same zone have been completed with similar productivity.

#### OIL PROSPECTS

Preliminary indications from Ceram experience suggest that oil accumulation per unit volume of sediments is abnormally high in the Plio-Pleistocene. Certainly the Bula accumulation is this way, though small by absolute standards. Extrapolation of this set of conditions to areas with several times thicker sedimentary section and potential pay horizons is both reasonable and warranted on the basis of existing facts. It then falls within the realm of possibility to expect that several 50 to 100 million barrel fields might be found in this type of basin with diligent and intelligent prospecting. Prospects

will most likely be in stratigraphic traps in beach, bar, and turbidite sands and reef limestones. The similarity of Plio-Pleistocene basin development and environment in the other areas of the Ceram group, Timor, and perhaps Buton-Sulawesi suggest that such prospects also exist in these other basins along the "S" trend. Outside the "S" trend prospects could exist in the Sula Islands and the Halmahera group if a sedimentary section can be found.

Geologists involved in prospecting for these subtle elusive traps will have to discard some "geological masks and prejudices" if they wish to reap the rewards. The first is the "square mileage syndrome." If this standard had been applied to the 700 square miles (1800 square kilometers) of the Los Angeles Basin of California, many geologists would have rejected the area outright as too small thus losing the chance of locating the six billion barrels already recovered. The second is the "Pleistocene syndrome." A widely held prejudice says that oil can not have had time to generate and accumulate since Pleistocene deposition. These who ignore this fable are now having notable success prospecting for Pleistocene oil in offshore Louisiana. Third is the "shoot it out syndrome." Many geologists (and companies) seem congenitally unable to conduct exploration if they can not see a computer processed 1200% stack CDP seismic section. This type of stratigraphy does not lend itself readily to reflection seismic evaluation because of the nature of the Plio-Pleistocene and the shallow depths involved. Therefore, other techniques will be required to locate what may well be subtle stratigraphic traps—gravity, exploratory drilling, and—do I really have to mention geology applied with imagination and common sense?

#### ACKNOWLEDGEMENTS

I would like to thank P.N. Pertamina and Gulf & Western Indonesia Inc. for permission to publish this paper. Drafting of the figures was done by courtesy of Sun Eastern Exploration Co.

#### REFERENCES

- AUDLEY-CHARLES, M.G. "The Geology of Portuguese Timor." *Memoirs of the Geological Society of London*, No. 4, 1968.
- VAN BEMMELEN, R.W. *The Geology of Indonesia*, second edition, Nijhoff, The Hague, 1970.
- GERMERAAD, J.H. *Geology of Central Seran*—Utrecht, 1946.
- VAN DER SLUIS, J.O. *Geology of East Seran*, Utrecht, 1950.
- VALK, W. *Contributions to the Geology of West Seran*, Utrecht, 1945.
- VISSER & HERMES. Geological results of the Exploration for Oil in Netherlands New Guinea. *Transactions, Koninklijk Nederlands geologisch*, Geological Series, Vol. XX, 1962.

#### NOTE ADDED IN PROOF

"Further more intensive review of the entire area has indicated to me that some revision is necessary in the interpretation of Timor geology. I am now convinced that a Miocene melange unit does not exist on Timor as described and shown on the map. The only true melange on Timor is at least early Eocene or older and of limited occurrence. The widespread unit that I had previously considered melange is the Bobonaro scaly clay of Plio-Pleistocene age (age from T. Rothwell, personal communication, 1971). Instead this mysterious unit apparently is truly a sedimentary unit. It has been derived from a rapidly eroding uplifted subduction zone which is now not in evidence anyplace on Timor. In detail, then, revision are needed but overall regional considerations are unchanged. The story is still unfolding."