Sulawesi Sedimentology Literature
A BRIEF REVIEW

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Sulawesi is well known for its complex Cretaceous-Tertiary collisional tectonic history, with a succession of volcanic arc deposits. Numerous publications have appeared on these topics. Also quite a few papers discuss general stratigraphy of areas, but very few papers can be characterized as 'sedimentology papers', i.e. papers documenting and interpreting sedimentary structures, measured sections, current directions, provenance, depositional environments, paleogeography, etc.

The Sulawesi region may be divided into four broad provinces with different Mesozoic- Cenozoic stratigraphic successions:

1. West / SW Sulawesi

Fraser and Ichram (1999) proposed to call this 'Sundawesi', due to the similarities of its Mesozoic- Paleogene stratigraphy with that of East Kalimantan/ Sundaland. This was part of the SE Sundaland margin before is was disconnected by the opening of Makassar Straits in the Eocene, and the likely provenance of much of the pre-Late Eocene sediment was from Kalimantan. Late Cretaceous and younger sediments were deposited over Early Cretaceous accretionary complexes. They are locally rich in volcanic detritus, were locally affected by contact metamorphism around Eocene, Miocene and younger igneous intrusions associated with volcanic episodes, and were involved in Late Miocene-Pliocene folding-thrusting, strike-slip faulting and uplift.

2. East Sulawesi and Buton

As argued by Milsom et al. (2000), Villeneuve et al. (2001) and others there are no compelling arguments to consider East Sulawesi and Buton as separate terranes, as is commonly accepted. Together with Seram and Buru they formed part of the 'Banda assemblage' or 'Banda Block' or 'Kolonodale Block', a plate of North

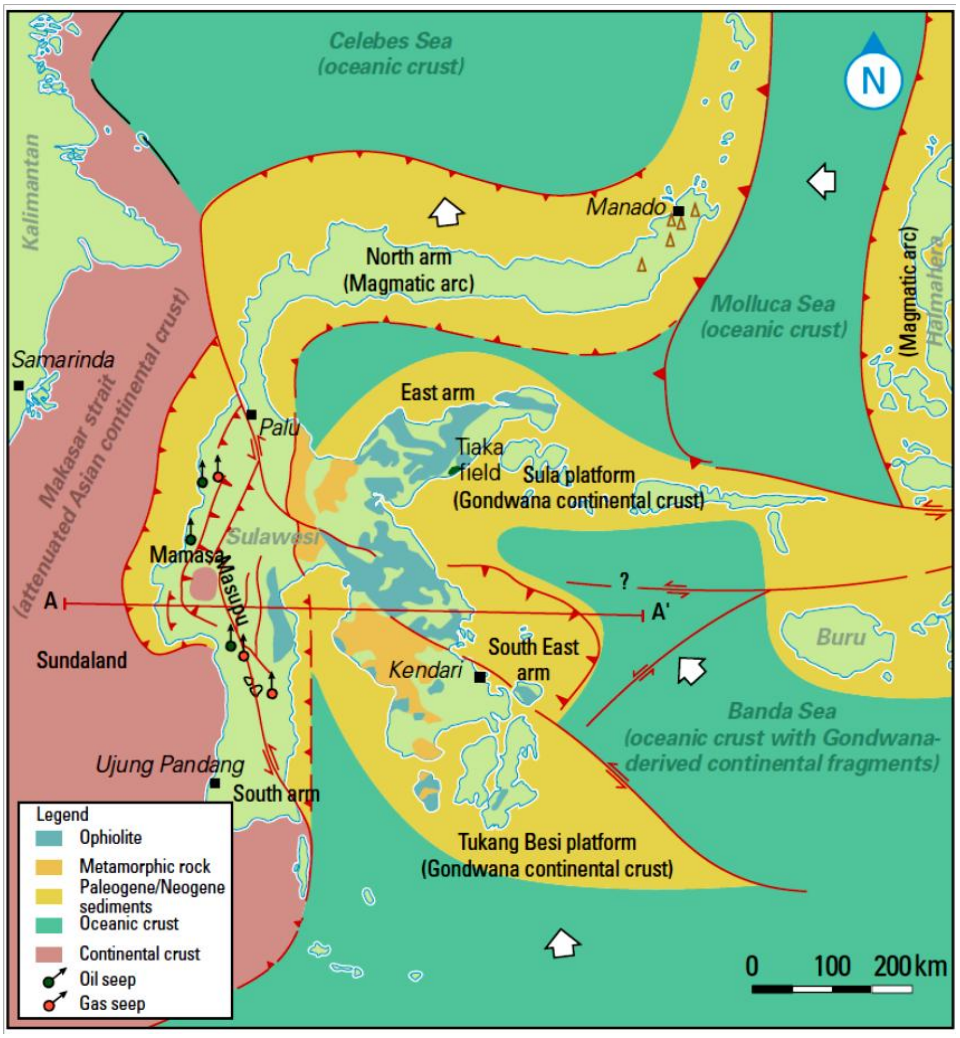


Figure 1: Main tectonic provinces of Sulawesi (from Netherwood, 2000, after Guritno et al., 1996)

Australian origin that that rifted off the Australian northen margin in the Triassic and collided with the West Sulawesi microcontinent/ volcanic arc system, probably in Oligocene time (also related the obduction of the East Sulawesi ophiolite). Buru Seram and Banda Ridges were dismembered from E Sulawesi-Buton in the Miocene, with the Banda Sea opening.

East and SE Sulawesi (incl. Buton) contain the oldest sediments of Sulawesi: generally highly deformed Late Triassic fluvial and marine clastics (including bituminous shales), Late Triassic- Early Jurassic shallow marine carbonates and Jurassic, Cretaceous and Paleogene pelagic calcareous sediments.

Late Paleozoic sediments may also be present in East Sulawesi here. Late Devonian and Permian brachiopods and a Permian ammonite have been reported by several pre WW-II authors (Brouwer, Von Loczy), but the origins of these fossils have been questioned. Their presence can, in my opinion, not be discarded completely and should be expected if this is a terrane of North Australian-origin.

3. North Sulawesi

Most of the North arm of Sulawesi is a Lower Miocene and younger volcanic arc, built on Eocene-Oligocene submarine volcanics and limestones,

probably on oceanic crust, with one or more micro-continental fragments. There are no significant onshore sedimentary basins.

4. Banggai Sula block
This fourth province is a New Guinea affinity terrane with a Mesozoic stratigraphy that is different from East Sulawesi- Buton. It collided with East Sulawesi in Late Miocene or Early Pliocene time. Since it does not outcrop on Sulawesi it is not included in the listing below.

Below is a listing of these papers, crudely arranged in stratigraphic order from young to old. Many of these are general geology papers, but contain significant observations on sedimentology, stratigraphy or paleogeography of Sulawesi sediments. The listing is confined to relatively 'modern' papers; useful observations on stratigraphy, petrography, provenance, etc., have been recorded in colonial-era publications, but are not included here. For most of these papers brief summaries can be found in the Indonesia geology bibliography on *www.vangorselslist.com*.

Many thanks to Herman Darman, Robert Hall and Theo van Leeuwen for suggestions and checking the list for omissions.

Modern environments

Papers on modern clastic sedimentation on Sulawesi are rare, probably because it lacks spectacular large depositional systems like a Mahakam Delta. One paper of note on modern deep water depositional systems is:

Decker, J., P.A. Teas, R.D. Schneider, A.H. Saller & D.L. Orange (2004)- Modern deep sea sedimentation in the Makassar Strait: insights from high-resolution multibeam bathymetry and backscatter, sub-bottom profiles, and USBL-navigated cores. In: R.A. Noble et al. (eds.) Proc. Deepwater and Frontier Exploration in Asia & Australia Symposium, Jakarta, Indon. Petrol. Assoc., p. 377-387.

Modern carbonates have been studied mainly on the Spermonde/ Sangkarang Platform off SW Sulawesi, and also on the Tukang Besi islands atolls.

De Neve, G.A. (1981)- Development and origin of the Sangkarang reef archipelago (South Sulawesi, Indonesia). Proc. 10th Ann. Conv. Indon. Geol. Assoc. (IAGI), Bandung, p. 102-108.

Lanaru, M. & R. Fitri (2008)- Sediment deposition in a South Sulawesi seagrass bed. Marine Res. Indonesia 33, 2, p. 221-224.

Renema, W. & S.R. Troelstra (2001)- Larger foraminifera distribution on a mesotrophic carbonate shelf in SW Sulawesi (Indonesia). Palaeogeogr., Palaeoclim., Palaeoecol. 175, p. 125-146.

Wilson, M.E.J. (2008)- Reservoir quality of Cenozoic carbonate buildups and coral reef terraces. Proc. 32nd Ann. Conv. Indon. Petrol. Assoc., IPA08-G-155, 8p.

Middle Miocene- Pliocene clastics (incl. 'Celebes Molasse', Walanae Fm, etc.)

Major Middle Miocene- Pliocene uplift(s) on Sulawesi are documented by the presence of locally thick, dominantly non-marine clastics, with erosional products of all pre-Middle Miocene formations. In older reports these 'syn-orogenic' deposits were grouped as 'Celebes Molasse'. More recent formation names include the Walanae Formation. On Buton these are called Tondo and Sampolakosa Formations.

Bartstra, G.J. (1977)- Walanae Formation and the Walanae terraces in the stratigraphy of South Sulawesi, (Celebes, Indonesia). Quartar 27, p. 21-30.

Rochmanto, B. & L.M. Adam (2007)- Sedimentary environment of Sampolakosa Formation at Gonda baru subdistrict Sorawolio, Bau-Bau, Southeast Sulawesi. Proc. Joint Conv. 32nd HAGI, 36th IAGI, and 29th IATMI, Bali, p.

Rochmanto, B. & Darwin (2007)- Depositional environment of the Tondo Formation at Wakoko River Pasar Wajo Area, District of Buton, Southeast Sulawesi. Proc. 31st Ann. Conv. Indon. Petrol. Assoc. IPA07-G-101, 6p.

Smith, R.B. (1983)- Sedimentology and tectonics of a Miocene collision complex and overlying late orogenic clastic strata, Buton Island, Eastern Indonesia. Ph.D. Thesis Univ. California, Santa Cruz, 254 p.

Simandjuntak, T.O. (1986)- Sedimentology and tectonics of the collision complex of the East arm of Sulawesi, Indonesia. Ph.D. Thesis, Royal Holloway and Bedford New College, London University, 374 p.

Surono (1989)- Molasa di lengan Timur Sulawesi. Bull. Geol. Res. Dev. Centre, Bandung 13, p. 39-45.

Surono (1995)- Sedimentology of the Tolitoli Conglomerate Member of the Langkowala Formation, Southeast Sulawesi, Indonesia. J. Geol. Sumberdaya Min. 5, 46, p. 1-7.

Surono & D. Sukarna (1996)- Sedimentology of the Sulawesi molasse in relation to Neogene tectonics, Kendari area, Eastern Indonesia. Proc. 6th Int. Congr. Pacific Neogene Stratigraphy, IGCP355, Serpong 1995, p. 57-72.

Suyono & Kusnama (2010)- Stratigraphy and tectonics of the Sengkang Basin, South Sulawesi. Jurnal Geol. Indonesia 5, 1, p. 1-11.

Van den Bergh, G.D., U.M. Lumbanbalu, P.L. de Boer & F. Aziz (1995)- Lithostratigraphy of the West Sengkang Basin. In: The geology and stratigraphy of the vertebrate-bearing deposits in the Sengkang Basin: the terrestrial faunal evolution of South Sulawesi during the Late Pliocene and Quaternary. Geol. Res. Dev. Centre, Spec. Publ. 18, p. 14-27.

Late Miocene carbonates, SW Sulawesi (Tacipi Fm)

The Late Middle Miocene- earliest Pliocene of the up to 300m thick Tacipi Limestone with small gas-bearing reefal buildups in the Bone/ East Sengkang Basin of S Sulawesi were discussed in a series of papers below.

Ascaria, N.A. (1997)- Carbonate facies development and sediment evolution of the Miocene Tacipi Formation, South Sulawesi, Indonesia. Ph.D. Thesis, University of London, 397p.

Ascaria, N.A. (1999)- Control on carbonate sedimentation of Tacipi Formation, South Sulawesi, Indonesia. Berita Sediment. 10, p.

Ascaria, N.A. & N.A. Harbury (1997)- Tacipi Limestone facies distribution and sequence development, Mio- Pliocene, South Sulawesi, Indonesia. Berita Sediment. 5, p.

Ascaria, N.A., N.A. Harbury & M.E.J. Wilson (1997)- Hydrocarbon potential and development of Miocene knoll-reefs, South Sulawesi. In: J.V.C. Howes & R.A. Noble (eds.) Proc. Conf. Petroleum Systems of SE Asia and Australasia, Indon. Petrol. Assoc., p. 569-584.

Boudagher-Fadel, M.K. (2002)- The stratigraphical relationship between planktonic and larger benthic foraminifera in Middle Miocene to Lower Pliocene carbonate facies of Sulawesi, Indonesia. Micropaleontology 48, 2, p. 153-176.

Grainge, A.M. & K.G. Davies (1985)- Reef exploration in the East Sengkang Basin, Sulawesi, Indonesia. Marine Petrol. Geol. 2, p. 142-155.

Imran, A.M. & R. Koch (2006)- Microfacies development of the Selayar Limestone, South Sulawesi. Proc. 35th Conv. Indon. Assoc. Geol. (IAGI), Pekanbaru 2006, p. PITIAGI2006-028, 8p.

Imran, A.M. & R. Koch (2008)- Marine diagenetic history of the Selayar Limestone, South Sulawesi. Jurnal Inform. Tekn. 14, 2, p. 109-117.

Mayall, M.J. & M. Cox (1988)- Deposition and diagenesis of Miocene limestones, Sengkang Basin, Sulawesi, Indonesia. Sedim. Geol. 59, p. 77-92.

Subandrio, A.S. (2006)- Diagenetic alteration in Late Miocene carbonate of Tacipi area, South Celebes. Proc. 35th Ann. Conv. Indon. Assoc. Geol. (IAGI), Pekanbaru 2006, 10 p.

Suyono & Kusnama (2010)- Stratigraphy and tectonics of the Sengkang Basin, South Sulawesi. Jurnal Geol. Indonesia 5, 1, p. 1-11.

'Post-rift' Late Eocene- Early Miocene carbonates, SW Sulawesi (Tonasa Fm, Makale Fm)

Carbonate sedimentology of the large Latest Eocene- Early Miocene Tonasa platform in SW Sulawesi has been described mainly in a series of papers by Moyra Wilson.

Sudijono (2005)- Biostratigraphy and the depositional environment of the Toraja Limestone at the Nanggala river section, Toraja, South Sulawesi. J. Sumber Daya Geol. (GRDC) 15, 1, p.

Sulistyani, L. & Surono (2006)- Facies analysis on the Limestone Member, the Tondo Formation, based on samples taken from Kaisapu Area, Buton, Southeast Sulawesi Province. Proc. Jakarta 2006 Int. Geosciences Conf. and Exhib., Indon. Petrol. Assoc., Jakarta, 06-SPG-04, 5 p.

Surono (1995)- A petrographic study of an oolitic limestone succession of the Eocene-Oligocene Tampakura Formation, South-East Sulawesi, Indonesia. J. Geol. Sumberdaya Min.5, 40, p. 2-11.

Surono (1998)- A sedimentological study of the oolitic limestone succession of the Paleogene Tampakura Formation in Southeastern Sulawesi, Indonesia. In: J.L. Rau (ed.) Proc. 33rd Sess. Co-ord. Comm. Coastal Offshore Geosc. Progr. E and SE Asia (CCOP), Shanghai 1996, 2, p. 10-41.

Wilson, M.E.J. (1995)- The Tonasa Limestone Formation, Sulawesi, Indonesia: development of a Tertiary carbonate platform. Ph.D. Thesis University of London, 520 p.

Wilson, M.E.J. (1996)- Evolution and hydrocarbon potential of the Tertiary Tonasa Limestone Formation, Sulawesi, Indonesia. Proc. 25th Ann. Conv. Indon. Petrol. Assoc., 1, p. 227-240.

Wilson, M.E.J. (2000)- Tectonic and volcanic influences on the development and diachronous termination of a Tertiary tropical carbonate platform. J. Sed. Res. 70, p. 310-324.

Wilson, M.E.J. & D.W.J. Bosence (1996)- The Tertiary evolution of South Sulawesi: a record in redeposited carbonates of the Tonasa Limestone Formation. In: R. Hall & D.J. Blundell (eds.) Tectonic evolution of Southeast Asia. Geol. Soc., London, Spec. Publ. 106, p. 365- 389.

Wilson, M.E.J. & D.W.J. Bosence (1997)- Platform-top and ramp deposits of the Tonasa carbonate platform, Sulawesi, Indonesia. In: A.J. Fraser, S.J. Matthews & R.W. Murphy (eds.) Petroleum geology of Southeast Asia. Geol. Soc. London Spec. Publ. 126, p. 247-279.

Wilson, M.E.J., D.W.J. Bosence & A. Limbong (2000)- Tertiary syntectonic carbonate platform development in Indonesia. Sedimentology 47, p. 395-419.

Eocene- Early Oligocene rift-fill clastics (Toraja Fm, Malawa Fm, Budungbudung Fm)

The presence of sediments of Paleocene age on Sulawesi has never been documented conclusively, but because dating of non-marine deposits at the base of the Paleogene rift-fill section is very difficult, their presence can not be excluded either. Middle and Late Eocene transgressive rift-fill sediments are relatively widespread and usually 1000- 3000m thick in rift basins in West and SW Sulawesi. These deposits include generally non-commercial Eocene coals and local limestones rich in *Nummulites*.

Calvert, S.J. (2000)- The Cenozoic geology of the Lariang and Karama regions. Western Sulawesi, Indonesia. Ph.D. Thesis, University of London, 353 p.

Calvert, S.J. & R. Hall (2003)- The Cenozoic geology of the Lariang and Karama regions, Western Sulawesi: new insight into the evolution of the Makassar Straits region. Proc. 29th

Ann. Conv. Indon. Petr. Assoc., p. 501-517.

Calvert, S.J. & R. Hall (2007)- Cenozoic evolution of the Lariang and Karama regions, North Makassar Basin, western Sulawesi, Indonesia. Petroleum Geosc. 13, p. 353-358.

Hasibuan, F. (2009)- Lingkungan pengendapan Formasi Malawa, Sulawesi Selatan berdasarkan kandungan makro fosil. J. Sumber Daya Geol. (GRDC) 19, 2, p. 95-106.

Kusnama & S. Andi Mangga (2007)- Hubungan lingkunan pengendapan Formasi Malawa dan keterdapatan batubara di daerah Soppeng, Sulawesi Selatan. J. Sumber Daya Geol. 17, 4, p. 218-232.

Maryanto, S. (1999)- Proses diagenesis batugamping eosen di lintasan S. Nanggala, Tana Toraja, Sulawesi Selatan. J. Geol. Sumberdaya Min. (GRDC Bandung) 9, 94, p.

Maryanto, S. (2002)- Stratigrafi Tersier daerah Torajah, Sulawesi Selatan. Proc. 31st Ann. Conv. Indon. Assoc. Geol. (IAGI), p. 734-768.

Maryanto, S. (2002)- Lingkungan pengendapan Formasi Toraja di daerah Sekitat Rantepao, Sulawesi Selatan. Bull. Geol. Res. Dev. Centre 22, p. 63-84.

Maryanto, S., E.E. Susanto & Sudijono (2004)- Sedimentologi Formasi Salokupang di daerah Bone, Sulawesi Selatan. J. Sumber Daya Geol. (GRDC Bandung) 1, 1, p. 69-83.

Paju, J.A., Y.S. Purnama, B.Nugroho, A. Bachtiar & F. Peera (2006)- Sedimentology of Malawa clastics and its implication to hydrocarbon occurrences in western part of West arm Sulawesi. Proc. 35th Ann. Conv. Indon. Assoc. Geol. (IAGI), Pekanbaru 2006, PITIAGI2006-012, p. 1-18.

Upper Cretaceous flysch, W Sulawesi (Balangbaru Fm, Latimojong Fm, etc.)

In West Sulawesi Late Cretaceous marine sediments are present, unconformably on Early- 'Mid'-Cretaceous metamorphic- accretionary complexes. This Late Mesozoic stratigraphy is very similar to that of SE Kalimantan. The key work on the sedimentology of the Upper Cretaceous 'flysch' of SW Sulawesi is by Hasan (1990, 1991), demonstrating provenance of the Balangbaru Formation turbidites from the W/ NW, presumably from Kalimantan before opening of Makassar Straits.

Hasan, K. (1990)- The Upper Cretaceous flysch succession of the Balangbaru Formation, Southwest Sulawesi, Indonesia. Ph.D. Thesis, University of London, 336 p.

Hasan, K. (1991)- The Upper Cretaceous flysch succession of the Balangbaru Formation, Southwest Sulawesi. Proc. 20th Ann. Conv. Indon. Petrol. Assoc., p. 183-208.

Hasan, K., R. Garrard & P. Mahodim (1991)- SW Sulawesi, Post-convention field trip guidebook. Indonesian Petroleum Association, p. 1-61.

Simandjuntak, T.O. (1981)- Some sedimentological aspects of Mesozoic rocks in eastern Sulawesi, Indonesia. Proc. 9th Ann. Conv. Indon. Assoc. Geol. (IAGI), Yogyakarta, p.

Jurassic- Cretaceous pelagic deposits, East Sulawesi

Rocks of Jurassic age appear to be very rare on Sulawesi, and reported only from East Sulawesi (and Buton). Relatively thin and highly deformed successions of Early Jurassic, Middle Jurassic, Early and Late Cretaceous pelagic limestones and marls were described by French groups.

Cornee, J.J., R. Martini, M. Villeneuve, L. Zaninetti et al. (1999)- Mise en evidence du Jurassique inferieur et moyen dans la ceinture ophiolitique de Sulawesi (Indonesie). Consequences geodynamiques. Geobios 32, 3, p. 385-394.

Cornee, J.J., G. Tronchetti, M. Villeneuve, B. Lathuiliere, M.C. Janin, P. Saint-Marc, W. Gunawan & H. Samodra (1995)- Cretaceous of eastern and southeastern Sulawesi (Indonesia): new micropaleontological and biostratigraphical data. J. Southeast Asian Earth Sci. 12, p. 41-52.

Late Triassic clastics, SE and E Sulawesi (Meluhu Fm)

The key publications on Late Triassic clastic sediments are by Surono and collaborators (1992-2002). A proximal source from poorly dated metamorphic rocks could be demonstrated.

Surono (1994)- Sedimentologic investigation of the Southeast Arm of Sulawesi with special reference to the Kendari area. Ph.D. Thesis Wollongong University, Australia, 211 p.

Surono (1997)- A provenance study of sandstones from the Meluhu Formation, Southeast Sulawesi, Eastern Indonesia. J. Geol. Sumberdaya Miner. 7, 73, p. 2-16.

Surono & S. Bachri (2002)- Stratigraphy, sedimentation and palaeogeographic significance of the Triassic Meluhu Formation, Southeast arm of Sulawesi, Eastern Indonesia. J. Asian Earth Sci. 20, p. 177-192.

Surono, M. Endharto, A. Azis & D.M. Ali (1992)- Sedimentology of the Meluhu Formation, Southeast Arm Of Sulawesi, Indonesia. Proc. 21st Ann. Conv. Indon. Assoc. Geol. (IAGI), 2, p. 833-852.

Relatively few studies were done on the Late Triassic reefal carbonates of East Sulawesi. The distal deep water facies of these are probably the Winto Formation bituminous limestones/ shales of Buton. Despite their obvious economic significance little or no sedimentological work was done on these organic-rich mudrocks. Key papers include:

Cornee, J.J., M. Villeneuve, R. Martini, L. Zaninetti, D. Vachard, B. Vrielynck. W. Gunawan, H. Samodra & L. Sarmili (1994)- Une plate-forme carbonatee d'age rhetien au centre-est de Sulawesi (region de Kolonodale, Celebes, Indonesie). C.R. Acad. Sci., Paris 318, Ser. II, p. 809-814.

Martini, R., D. Vachard, L. Zaninetti, S. Cirilli, J.J. Cornee, B. Lathuiliere &

M.Villeneuve (1997)- Sedimentology, stratigraphy, and micropalaeontology of the Upper Triassic reefal series in Eastern Sulawesi (Indonesia). Palaeogeogr., Palaeoclim., Palaeoecol. 128, p. 157-174.

PALEOGEOGRAPHY

Below is a selection of papers with some useful paleogeographic maps of parts of Sulawesi.

Fraser, T.H., B.A. Jackson, P.M. Barber, P. Baillie & K. Myers (2003)- The West Sulawesi foldbelt and other new plays within the North Makassar Straits- a prospectivity review. Proc. 29th Ann. Conv. Indon. Petrol. Assoc. G-171, p. 429-450.

Hornaday, W.T., R.A. de Boer, J.N. Grant, N. Nastiti & P. Astono (1996)- Sengkang Basin (SW Sulawesi). In: Pertamina/BKKA (eds.) Petroleum Geology of Indonesian basins, VII, Jakarta, p. 1-34.

Moss, S.J. & M.E.J. Wilson (1998)- Biogeographic implications of the Tertiary palaeogeographic evolution of Sulawesi and Borneo. In: R. Hall & J.D. Holloway (eds.) Biogeography and geological evolution of SE Asia, Backhuys, Leiden, p. 133-163.

Wilson, M.E.J. & S.J. Moss (1999)- Cenozoic palaeogeographicl evolution of Sulawesi and Borneo. Palaeogeogr., Palaeoclim., Palaeoecol. 145, p. 303-337.

Yulihanto, B. (2004)- Hydrocarbon play analysis of the Bone Basin, South Sulawesi. In: R.A. Noble et al. (eds.) Proc. Deepwater and frontier exploration in Asia & Australasia Symposium, Jakarta, Indon. Petrol. Assoc., p. 333-348.

OTHER KEY PAPERS ON SULAWESI- BUTON STRATIGRAPHY- GEOLOGY

Davidson, J.W. (1991)- The geology and prospectivity of Buton island, southeast Sulawesi, Indonesia. Proc. 20th Ann. Conv. Indon. Petrol. Assoc., p. 209-234.

Milsom, J., J. Thurow & D. Roques (2000)- Sulawesi dispersal and the evolution of the northern Banda Arc. Proc. 27th Ann. Conv. Indon. Petrol. Assoc., p. 495-504.

Van Leeuwen, T. (1981)- The geology of southwest Sulawesi with special reference to the Biru area. In: A.J. Barber & S. Wiryosayono (eds.) The geology and tectonics of Eastern Indonesia. Geol. Res. Dev. Centre, Bandung, Spec. Publ. 2, p. 277-304.

Van Leeuwen, T.M. & Muhardjo (2005)- Stratigraphy and tectonic setting of the Cretaceous and Paleogene volcanic-sedimentary successions in Northwest Sulawesi, Indonesia: implications for the Cenozoic evolution of Western and Northern Sulawesi. J. Asian Earth Sci. 25, p. 481-511.

Villeneuve, M., J.J. Cornee, W. Gunawan, R. Martini, G. Tronchetti. M.C. Janin, P. Saint-Marc & L. Zaninetti (2001)- La succession lithostratigraphique du bloc de Banda dans la region de Kolonodale (Sulawesi central, Indonesie). Bull. Soc. Geol. France 172, 1, p. 59-68.

Villeneuve, M., W. Gunawan, J.J. Cornee & O. Vidal (2002)- Geology of the Central Sulawesi belt (eastern Indonesia): constraints for geodynamic models. Int. J. Earth. Sci. (Geol. Rundschau) 91, 3, p. 524-537.

Wakita, K., Munasri, J. Sopaheluwakan, I. Zulkarnain & K. Miyazaki (1994)- Early Cretaceous tectonic events implied in the time-lag between the age of radiolarian chert and its metamorphic basement in Bantimala area, South Sulawesi, Indonesia. The Island Arc 3, p. 90-102.