SOUTH SUMATRA BASIN PROVINCE, INDONESIA: THE LAHAT/TALANG AKAR-CENOZOIC TOTAL PETROLEUM SYSTEM

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FOREWORD

This report was prepared as part of the World Energy Project of the U.S. Geological Survey. For this project, the world was divided into 8 regions and 937 geologic provinces, which were then ranked according to the discovered oil and gas volumes within each (Klett and others, 2000). Then, 76 "priority" provinces (exclusive of the U.S. and chosen for their high ranking) and 26 "boutique" provinces (exclusive of the U.S. and chosen for their anticipated petroleum richness or special regional economic importance) were selected for appraisal of oil and gas resources. The petroleum geology of these priority and boutique provinces is described in this series of reports.

The purpose of the World Energy Project is to assess the quantities of oil, gas, and natural gas liquids that have the potential to be added to reserves within the next 30 years. These volumes either reside in undiscovered fields whose sizes exceed the stated minimum-field-size cutoff value for the assessment unit (variable, but must be at least 1 million barrels of oil equivalent) or occur as reserve growth of fields already discovered.

The total petroleum system constitutes the basic geologic unit of the oil and gas assessment. The total petroleum system includes all genetically related petroleum that occurs in shows and accumulations (discovered and undiscovered) that (1) has been generated by a pod or by closely related pods of mature source rock, and (2) exists within a limited mappable geologic space, along with the other essential mappable geologic elements (reservoir, seal, and overburden rocks) that control the fundamental processes of generation, expulsion, migration, entrapment, and preservation of petroleum. The minimum petroleum system is that part of a total petroleum system encompassing discovered shows and accumulations along with the geologic space in which the various essential elements have been proved by these discoveries.

An assessment unit is a mappable part of a total petroleum system in which discovered and undiscovered fields constitute a single relatively homogenous population such that the chosen methodology of resource assessment based on estimation of the number and sizes of undiscovered fields is applicable. A total petroleum system might equate to a single assessment unit, or it may be subdivided into two or more assessment units if each assessment unit is sufficiently homogeneous in terms of geology, exploration considerations, and risk to assess individually.

A graphical depiction of the elements of a total petroleum system is provided in the form of an event chart that shows the times of (1) deposition of essential rock units; (2) trap formation; (3) generation, migration, and accumulation of hydrocarbons; and (4) preservation of hydrocarbons.

A numeric code identifies each region, province, total petroleum system, and assessment unit; these codes are uniform throughout the project and will identify the same type of entity in any of the publications. The code is as follows:

	Example
Region, single digit	**3**
Province, three digits to the right of region code	3**162**
Total Petroleum System, two digits to the right of province code	3162**05**
Assessment unit, two digits to the right of petroleum system code	316205**04**

The codes for the regions and provinces are listed in Klett and others, 2000.

Oil and gas reserves quoted in this report are derived from Petroconsultants' Petroleum Exploration and Production database (Petroconsultants, 1996) and other area reports from Petroconsultants, Inc., unless otherwise noted.

Fields, for the purpose of this report, include producing fields, discoveries (suspended and abandoned) and shows as defined by Petroconsultants (1996) and may consist of a single well with no production.

Figure(s) in this report that show boundaries of the total petroleum system(s), assessment units, and pods of active source rocks were compiled using geographic information system (GIS) software. Political boundaries and cartographic representations were taken, with permission, from Environmental Systems Research Institute's ArcWorld 1:3 million digital coverage (1992), have no political significance, and are displayed for general reference only. Oil and gas field centerpoints, shown on this (these) figure(s), are reproduced, with permission, from Petroconsultants, 1996.

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Petroconsultants, 1996, Petroleum Exploration and Production Database: Petroconsultants, Inc., P.O. Box 740619, 6600 Sands Point Drive, Houston TX 77274-0619, USA or Petroconsultants, Inc., P.O. Box 152, 24 Chemin de la Mairie, 1258 Perly, Geneva, Switzerland.

ABSTRACT

Oil and gas are produced from the onshore South Sumatra Basin Province. The province consists of Tertiary half-graben basins infilled with carbonate and clastic sedimentary rocks unconformably overlying pre-Tertiary metamorphic and igneous rocks. Eocene through lower Oligocene lacustrine shales and Oligocene through lower Miocene lacustrine and deltaic coaly shales are the mature source rocks. Reserves of 4.3 billion barrels of oil equivalent have been discovered in reservoirs that range from pre-Tertiary basement through upper Miocene sandstones and carbonates deposited as synrift strata and as marine shoreline, deltaic-fluvial, and deep-water strata. Carbonate and sandstone reservoirs produce oil and gas primarily from anticlinal traps of Plio-Pleistocene age. Stratigraphic trapping and faulting are important locally. Production is compartmentalized due to numerous intraformational seals. The regional marine shale seal, deposited by a maximum sea level highstand in early middle Miocene time, was faulted during post-depositional folding allowing migration of hydrocarbons to reservoirs above the seal. The province contains the Lahat/Talang Akar-Cenozoic total petroleum system with one assessment unit, South Sumatra.

INTRODUCTION

The South Sumatra Basin Province 3828 consists of several structural sub-basins with Tertiary sedimentary section lying unconformably on the eroded and faulted topography of pre-Tertiary metamorphic and igneous rocks. The province ranks number 60 in known reserves exclusive of the United States (Klett and others, 1997, 2000). Known petroleum is estimated at 4.3 billion barrels of oil equivalent (BBOE) (Klett and others, 1997, 2000). Late Tertiary anticlinal traps account for more than 75% of the known oil and gas reserves in the province with sandstone being the dominant reservoir (Petroconsultants, 1996).

One total petroleum system (TPS) was identified, Lahat/Talang Akar-Cenozoic (382801) (Fig. 1), that is composed of Lahat lacustrine shale and Talang Akar lacustrine and coaly shales as source rocks along with Cenozoic clastic and carbonate reservoir rocks. This total petroleum system contains one assessment unit, South Sumatra (38280101). The U.S. Geological Survey assessment of the estimated quantities of conventional oil, gas and condensate that have the potential to be added to reserves by the year 2025 for this province is 469 million barrels of oil (MMBO), 18,250 billion cubic feet of gas (BCFG), and 239 million barrels of natural gas liquids (MMBNGL) in the South Sumatra assessment unit or 3.7 BBOE (U. S. Geological Survey World Energy Assessment Team, 2000). The assessment suggests that this is and will continue to be a gas-rich province.

PROVINCE GEOLOGY

The province covers an area of approximately 117,000 km^2 primarily onshore Sumatra, Indonesia (Fig. 1). Exploration efforts have been concentrated onshore with only a few dry holes drilled in offshore areas (Petroconsultants, 1996). The Palembang or Lampung High or arch separates the South Sumatra basin from the Sunda Basin of the Northwest Java Province 3824 (Fig. 2). This high served both as a barrier to sediment dispersal and as a sediment source terrain from Mesozoic through most of the Tertiary (de Coster, 1974). The South and Central Sumatra Basin Provinces (3828, 3808) are divided at the Tigapuluh Mountains (Fig. 2). The western margin is the Plio-Pleistocene Barisan Mountains (Fig. 2). South Sumatra is divided into sub-basins: Jambi, North Palembang, Central Palembang, South Palembang, and Bandar Jaya Basin (Fig. 2) (Williams and others, 1995; Suseno and others, 1992). Most of the published data is from the South Palembang sub-basin.

Tectonics

In the center of the South Sumatra Basin Province, are Permian to Carboniferous metamorphic and igneous rocks crop out in a northwest to southeast trend. These consist of phyllites, slates, argillites, quartzites, gneisses and granites (Adiwidjaja and de Coster, 1973). In the northwest, and south of the Permo-Carboniferous trend, are areas of Mesozoic metamorphic rocks with local granite intrusions (Adiwidjaja and de Coster, 1973). In a broad trend south of the Permo-Carboniferous and Mesozoic rocks are Mesozoic metasediments and limestones, which have been dated as Jurassic or Cretaceous, together with mafic igneous rocks (Adiwidjaja and de Coster, 1973). To the north of the Permo-Carboniferous trend near the city of Palembang, is a northwest to southeast trending area described as micritic limestone of Cretaceous age (Adiwidjaja and de Coster, 1973).

The South Sumatra basin was formed by three major tectonic phases: 1) extension during late Paleocene to early Miocene forming north-trending grabens that were filled with Eocene to early Miocene deposits; 2) relative quiescence with late normal faulting from early Miocene to early Pliocene; and 3) basement-involved compression, basin inversion, and reversal of normal faults in the Pliocene to Recent forming the anticlines that are the major traps in the area (Suhendan, 1984). Many of the normal faults that formed the depositional basins in South Sumatra have been reactivated and some have been reversed during Miocene to Plio-Pleistocene compression and basin inversion (Sudarmono and others, 1997; Zeliff and others, 1985; Moulds, 1989). The emergent Sunda Shelf plate (platform, craton, or Malay micro-plate now mostly beneath the Java Sea) was confined on the east by oceanic crust and spreading centers, to the west by continental crust and to the south by Cretaceous oceanic and continental crust (Pulunggono, 1985; Ponto and others, 1988). Sundaland, or the Sunda Shelf Plate, is considered to be composed of a mosaic of continental and oceanic microplates accreted and sutured together in the Late Triassic (Pulunggono, 1985; Cole and Crittenden, 1997). Since the early Tertiary, the Sunda Shelf plate has generally tilted southward and has been subsiding (Ponto and others, 1988). The current subduction system, located offshore west of Sumatra and south of Java, began in the late Oligocene. Uplift of the Barisan Mountains, resulting from the subduction, began in late Miocene but primarily occurred in the Plio-Pleistocene (Hamilton, 1979; Sudarmono and others, 1997). In the Eocene to Oligocene, tectonic stress and extension, resulting from northward movement of both the Australian tectonic plate to the east and the India plate to the west, and rotation of Borneo, formed rifts or half-graben complexes along much of the southern margin of the Sunda Shelf plate (now Sumatra and Northwest Java) (Hall, 1997a, b; Longley, 1997; Sudarmono and others, 1997). These rift basins overlie an unconformity formed on a variety of pre-Tertiary rocks.

The grabens and major faults of the South Sumatra Basin Province are oriented north-northwest to south-southeast. This is a similar alignment to the grabens of Central Sumatra but they are deeper and larger basins (Fig. 3). The Palembang Basin in South

Sumatra is greater than 4,500 m deep (Hutchinson, 1996). The fault-bounded Benakat Gulley connects the major basin complexes of the Lematang Depression and the Palembang Depression (Fig. 2) (Hutchinson, 1996; Moulds, 1989). The north—south Benakat Gulley is similar in trend to the Bengkalis depression in Central Sumatra, the fault zone that forms the eastern coast of Sumatra, the Sunda and Asri Basins offshore, and the grabens of Northern Sumatra (Hutchinson, 1996; Pulunggono and others, 1992; Moulds, 1989). A fault zone that trends southwest to northeast, the Tembesi Fault, forms the northwestern edge of the Jambi Depression (Fig. 2).

Deposition

The overall Tertiary depositional fill of the South Sumatra Basin began in the Eocene with deposition of continental sediments derived from local erosion (Cole and Crittenden, 1997; Courteney and others, 1990). Characteristic half-graben-style locally derived deposits began to fill these basins in response to the half-graben architectural style and subsidence of the basins (Bishop, 1988; Wicaksono and others, 1992). Additional synrift deposits of tuffaceous sands, conglomerates, breccias and clays were deposited in faulted and topographic lows by alluvial, fluvial, and lacustrine processes (Fig. 4). Marine transgression occurred in some areas possibly as early as the late Eocene (Courteney and others, 1990). Widespread marine transgression from the south and southwest in the late Oligocene to Miocene resulted in onlap of clastic deposits onto basement rocks, development of platform carbonates, and carbonate build-ups on fault-block highs. Carbonate and sands were also deposited around emergent islands (Cole and Crittenden, 1997; Courteney and others, 1990; Sitompul and others, 1992; Hartanto and others, 1991; Hutapea, 1981; Tamtomo and others, 1997; Hamilton, 1979). The overall transgression was punctuated by lowstands. This resulted in development of secondary porosity in some of the carbonates. Lowstands also resulted in submarine fans within the marine shale strata (Cole and Crittenden, 1997; Courteney and others, 1990; Sitompul and others, 1992; Hartanto and others, 1991; Hutapea, 1981; Tamtomo and others, 1997; Hamilton, 1979). Regional sediment sources were generally from the Sunda Plate to the north and Palembang or Lampung High to the east (Sitompul and others, 1992). Maximum transgression in the middle Miocene deposited the marine Gumai Shale Formation seal across the region before uplift and compression resulted in deposition of shallow marine and continental sandstones and shales (Fig. 4) (Courteney and others, 1990; Cole and Crittenden, 1997; de Coster, 1974). Development of the Barisan Mountains, and possible volcanic islands to the south and southeast, further decreased and then cut off and overwhelmed marine influences and added new clastic and volcaniclastic sources from those directions (de Coster, 1974; Cole and Crittenden, 1997; Hamilton, 1979). Erosion of northwest trending anticlines that were formed during compression resulted in local Plio-Pleistocene continental deposits within the intervening synclines (de Coster, 1974). Continued volcanic activity has covered much of the surface of the South Sumatra Basin (van Bemmelen, 1949).

History of Exploration

Early exploration was guided by surface seeps that were associated with anticlines, and led to the discovery of Kampung Minyak Field in South Sumatra in 1886 (Fig. 2) (Macgregor, 1995). This field reportedly contained reserves of 31.3 MMBOE in the deltaic Pliocene Muara Enim Formation (Fig. 4) (Zeliff and others, 1985). Numerous surface anticlines have been mapped in South Sumatra, generally with a northwest to southeast trend, and are more tightly folded in the north than the south (Fig. 2) (van Bemmelen, 1949). Until 1921 the exploration target was sandstone in the Air Benakat Formation and the deepest penetration had been the Gumai Formation (Zeliff and others, 1985). In 1921 Nederlandsche Koloniale Petroleum Maatschappij (NKPM), formed by Standard of New Jersey (SONJ), discovered the Pendopo/Talang Akar Field (Fig. 2) (Zeliff and others, 1985). This discovery in the Talang Akar Formation sandstone is the largest oil field in South Sumatra with estimated reserves of 360 MMBOE (Zeliff and others, 1985; Ford, 1985). More recent estimates have increased these reserves by more than 15 percent (Petroconsultants, 1996). This discovery reportedly occurred due to communication delays, since the drillers were being paid by the foot, they drilled ahead after reaching the target Air Benakat Formation, not having been told to stop (Ford, 1985). Royal Dutch Shell (BPM), Standard of New Jersey, Socony Vacuum (Standard of New York (Mobil)), and Pertamina were all companies involved in the early exploration of South Sumatra (Zeliff and others, 1985). In 1933 SONJ (Exxon) and Socony Vacuum each held 50% interest in Standard Vacuum Oil Company (Stanvac) that took over NKPM's oilfields and refineries and Socony's marketing in the Asia Pacific region (Ford, 1985).

PETROLEUM OCCURRENCE

Numerous oil and gas seeps occur in South Sumatra in the foothills of the Gumai and Barisan mountains and are associated with anticlines (Fig. 2) (Macgregor, 1995; Zeliff and others, 1985). The largest fields, however, are not associated with seeps in South Sumatra and there are no seeps associated with fields in the adjacent and prolific Central Sumatra Basin. However, the occurrence of seeps promoted interest and early exploration for hydrocarbons throughout Sumatra (Macgregor, 1995, Zeliff and others, 1985, Van Bemmelen, 1949; Ford, 1985).

Petroleum exploration in South Sumatra has been primarily guided by surface anticlines, sometimes found by digging trenches (in the absence of outcrop) to map dips (Ford, 1985). Therefore the early distribution of fields follows the trend of the anticlines. The same compression that formed the inverted rift-basin anticlines reversed the motion of many normal faults resulting in monoclines and anticlines over keystone type fault blocks (Moulds, 1989). These structures, as well as stratigraphic pinchouts and onlaps trapped hydrocarbons that migrated from mature source rocks in adjacent lows (Courteney and others, 1990). The earliest fields were discovered in shallow Air Benakat and Muara Enim reservoirs and located near the Gumai and Barisan mountain fronts (Moulds, 1989; Ford, 1985; Zeliff and others, 1985). Later discoveries occurred further away from the mountains in older and deeper reservoirs (Ford, 1985).

Fields in the carbonate reservoirs of the Oligocene to Miocene Batu Raja Limestone (Fig. 4) are also aligned generally northwest to southeast since these buildups are located on basement highs or fault-block relief associated with the rifted basins (Zeliff and others, 1985).

Much of the oil in the basin is paraffinic and low in sulfur content (Petroconsultants, 1996; ten Haven and Schiefelbein, 1995). Both lacustrine and terrigenous facies on the margins of lacustrine environments have been interpreted as sources for the oils in the South Sumatra Basin. An additional carbonate source rock is suggested by one oil sample (ten Haven and Schiefelbein, 1995). Gravity of oil and condensate produced from sandstone reservoirs is reported to range from 21—55° API with gas to oil ratios (GOR) ranging from less than one hundred to more than 55,000 (Petroconsultants, 1996). CO_2 content of the natural gas can be as much as 90 % (Courteney and others, 1990). Batu Raja Limestone reservoirs contain oils and condensates with gravity from 27—58° API and GOR ranging from approximately 200 to more than 88,000 (Petroconsultants, 1996). Oil gravity, from more than 30 Talang Akar sandstone reservoirs in the Raja Field alone, ranges from 15° to 40° API (Hutapea, 1981). Oils analyzed by GeoMark from the South Sumatra Basin are plotted with oils from the Northwest Java area (Fig. 5). Oil samples from the adjoining Northwest Java Basin Province separate into two geochemical clusters, 1) lacustrine, 2) coaly and mixed regions, that agree with the literature on the origins of oils in this region (Bishop, 2000 figure 6). By comparison, South Sumatra Basin oil samples show data points transitional between the terrestrial coal/coaly shale and lacustrine clusters of Northwest Java (Fig. 5).

Hydrocarbon migration occured along carrier beds updip from the deep rift basins, where the source rocks are mature, and then along faults to overlying anticlines that form the majority of traps (Sarjono and Sardjito, 1989). Migration may have begun in late middle Miocene in the South Palembang sub-basin (Fig. 2 and 6) (Sarjono and Sardjito, 1989). Fault breaches in the Gumai Formation regional seal, allowed hydrocarbons to migrate into middle and late Miocene reservoirs (Sarjono and Sardjito, 1989).

SOURCE ROCK

Hydrocarbons in South Sumatra Province, Lahat/Talang Akar-Cenozoic (382801) TPS (Fig. 6), are derived from both lacustrine source rocks of the Lahat Formation and terrestrial coal and coaly shale source rocks of the Talang Akar Formation (Sarjono and Sardjito, 1989; Todd and others, 1997; Katz, 1991; Sladen, 1997; Suseno and others, 1992; Schiefelbein and others, 1997; Schiefelbein and Cameron, 1997; Sosrowidjojo and others, 1994). The lacustrine source rocks were deposited in a complex of half-grabens whereas the subsequent coal and coaly shales were deposited in and extended beyond the limits of the half-grabens (Fig. 3). The Batu Raja Limestone and the Gumai Formation shales may also be mature and have generated hydrocarbons in local areas (Sarjono and Sardjito, 1989).

The middle to late Eocene through early Oligocene Lahat or Lemat Formation, in the south Palembang area, includes the Benakat Shale with oil prone Type I and II kerogen and gas prone Type III kerogen depending on its locale (Suseno and others, 1992). The Benakat Shale Member is found in the deep portions of the basins and consists of grey-brown shales with tuffaceous shale, siltstones, sandstones, and coals (Hutchinson, 1996). The depositional environment is described by Hutchinson (1996) as brackish water. Total organic carbon (TOC) content of the Lahat Formation varies from 1.7—8.5 wt% (Sarjono and Sardjito, 1989) and locally as much as 16.0 wt% (Suseno and others, 1992). Hydrocarbon index (HI) values are 130—290 mg hydrocarbon (HC)/g TOC (Suseno and others, 1992). Thermal maturity of the Lahat Formation ranges from 0.64—1.40% R_o (Suseno and others, 1992). The Lahat Formation generated oil in most locations and oil and gas where more deeply buried (Sarjono and Sardjito, 1989).

Organic material in the late Eocene through middle Miocene Talang Akar Formation contains oil- and gas-prone Type I, II and III kerogen, identical to the Lahat Formation, and very similar to the Talang Akar source rocks of the Northwest Java Ardjuna area (Suseno and others, 1992). The Gritsand Member of the Talang Akar is described by Cole and Crittenden (1997) as deposited in intramontane lacustrine, lowland marine-influenced lacustrine, and fluvial-lacustrine-lagoonal settings and contains oil-prone Type I kerogen with the addition of Type II due to local facies changes. The Talang Akar Formation has good to very good source rock potential with a TOC range of 1.5—8 wt% in areas of the South Palembang sub-basin (Sarjono and Sardjito, 1989) ranging locally up to 50.0 wt% (Suseno and others, 1992). The range of HI is 150—310 mg hydrocarbon (HC)/g TOC (Suseno and others, 1992). Thermal maturity of the upper Talang Akar in the South Palembang sub-basin ranges from 0.54—0.60 R_o and from 0.82—1.30 R_o in the lower Talang Akar (Suseno and others, 1992).

The general temperature gradient in South Sumatra is 49° Ckm^{-1} (Hutchinson, 1996). This gradient is lower than in Central Sumatra and consequently the oil window is deeper (Hutchinson, 1996).

The Oligocene to Miocene Batu Raja Limestone and the Oligocene to Miocene Gumai Formation are mature to early mature for thermal gas generation in some of the deep basins and therefore may contribute gas to the petroleum system (Sarjono and Sardjito, 1989). Gas at MBU-1 field has been attributed to mature Gumai Shale source rocks in the adjacent low (Fig. 2) (Sarjono and Sardjito, 1989).

In the Bandar Jaya Basin area (Fig. 2) several grabens contain rich Lahat source rocks (Williams and others, 1995). The lacustrine source rocks are oil prone Type I and II kerogen and the coaly lake margin and deltaic source rocks contain Type III kerogen (Williams and others, 1995). Several wells have tested reservoirs and source rocks in some of these half-grabens, encountering gas and oil shows but without commercial success (Petroconsultants, 1996). Analyses of these source rocks indicate that they are just entering the oil window (Williams and others, 1995).

OVERBURDEN ROCK

Marine flooding from the south resulted in deposition of the Gumai Formation in the basins while Batu Raja Limestone was deposited on platforms and highs with maximum transgression reached during the early middle Miocene (Sarjono and Sardjito, 1989). Clastic deposition increased during the late middle Miocene regression forming claystone, sandstone, and siltstone in a shallow marine environment (Sarjono and Sardjdito, 1989). Shallow marine and terrestrial depositional settings continued. Between 1000—3000 m of overburden was deposited until a widespread late Pliocene through Pleistocene orogeny caused folding and faulting (Sarjono and Sardjito, 1989).

TRAP TYPES

Northwest to southeast trending anticlines were the first traps explored and remain the most important traps in the South Sumatra basin (van Bemmelen, 1949). Oil and gas reserves found in anticlines total 3.1 BBOE ultimate recoverable reserves (Petroconsultants, 1996). These fields have primarily sandstone reservoirs with some limestones and calcareous sandstones and include every producing formation in the basin (Petroconsultants, 1996). The anticlines formed as a result of compression that began as early as the Miocene but was most pronounced between 2—3 Ma (Fig. 6) (Courteney and others, 1990). Stratigraphic pinch-outs and carbonate buildups locally combine with folds and anticlines to enhance the effectiveness of the primary trap type. Recoverable reserves of 178 MMBOE are found in bioherms and carbonate buildup type traps and 688 MMBOE in fault traps (Petroconsultants, 1996). Drape, facies-change, and stratigraphic traps are also important and may be attractive future targets.

RESERVOIR ROCK

Basement Rocks

Uplifted areas and paleohighs of Mesozoic and Eocene fractured and weathered basement granite and quartzite are effective reservoirs, with up to 7% porosity, in ten fields in South Sumatra with gas reserves totaling 106 MMBOE ultimate recoverable reserves (Sardjito and others, 1991; Petroconsultants, 1996).

Lahat (Lemat, Old Lemat, Young Lemat) Formation

The Eocene to Oligocene Lahat Formation (Fig. 4) is composed of synrift deposits that are as much as 1,070 m thick. Although locally absent, this formation, is in most locations, more than 760 m thick (Hutchinson, 1996). The formation was deposited in continental, lacustrine, and brackish lacustrine depositional settings (Hutchinson, 1996). This reservoir accounts for nearly 88 MMBOE of ultimate recoverable reserves (Petroconsultants, 1996).

The Kikim Tuffs, also known as Old Lemat, are tuffaceous sandstones, conglomerates, breccias, and clays, of locally derived provenance, deposited in faulted and topographic lows (Hutchinson, 1996). The Kikim is interpreted to by Late Cretaceous to Paleocene in age and occurs in outcrop and at depth in the southern region (Hutchinson, 1996).

The oldest facies of the Young Lemat is granite wash overlain by coarse clastic deposits that consist of sandstones and breccias with abundant rock fragments, claystones, coals, and tuffs (Hutchinson, 1996).

The Benakat Member is a grey to brown shale with tuffaceous shale, siltstone, sandstone, coal, carbonate stringers and glauconitic sandstones that occurs in the deep portion of the half-graben basins (Hutchinson, 1996). This member was deposited in fresh to brackish water lakes and conformably overlies the coarse clastics of the lower Lemat Formation (Hutchinson, 1996).

Talang Akar Formation

The late Oligocene lower Talang Akar Formation is also referred to as the Gritsand Member and the Oligocene to early Miocene upper Talang Akar Formation as the Transition Member (Sitompul and others, 1992; Tamtomo and others, 1997). The Talang Akar Formation is as much as 610 m thick (Hutchinson, 1996). It is a late synrift to post-rift formation that is thick where the underlying Lahat Formation is thickest (Fig. 3). The Talang Akar Formation unconformably overlies the Lahat Formation. It onlaps the Lahat and the basement, extending farther outside of the depositional basins than the depositional limits of the Lahat Formation (Hutchinson, 1996). This reservoir consists of quartzose sandstones, siltstones, and shales deposited in a delta plain setting that changed basinward, generally to the south and west, into marginal marine sandstones and shales

(Adiwidjaja and de Coster, 1973; Hutchinson, 1996; Eko Widianto and Nanang Muksin, 1989). Specific depositional environments that have been identified include open marine, nearshore, delta plain, delta, distributary channel, fluvial, and beach (Hutapea, 1981). Talang Akar Formation sandstones, which were deposited during marine transgressions and regressions, form important stratigraphic traps (Tamtomo and others, 1997). These shoreline sands are generally aligned east to west, are supplied with sediment from the Sunda Shelf to the north and the Palembang High (Lampung High) to the east, can be laterally restricted, and thicken and thin in response to topography at the time of deposition (Adiwidjaja and de Coster, 1973; Hamilton, 1979; Hutapea, 1981; Sitompul and others, 1992). Other shoreline sandstones that surround basement highs are productive reservoirs for several fields (Tamtomo and others, 1997). Here the quality of the reservoir depends on the type of basement rock eroded to provide the clastics.

The Talang Akar Formation reservoir accounts for more than 75% of the cumulative oil production in South Sumatra (Tamtomo and others, 1997). Approximately 2 BBOE ultimate recoverable reserves have been found in Talang Akar reservoirs (Petroconsultants, 1996). Porosity of this reservoir rock ranges from 15—30 % and permeability is as much as 5 Darcies (Tamtomo and others, 1997; Petroconsultants, 1996). Porosity of the Gritsand Member is primarily secondary and averages 25% (Sitompul and others, 1992). Porosity of the Transitional Member is also primarily secondary and caused by the dissolution of grains and detrital clays. This cleaner and more mature sandstone has 25% average porosity (Sitompul and others, 1992). Clays in both members include smectite, illite, and abundant kaolinite (Sitompul and others, 1992).

Batu Raja Limestone

The early Miocene Batu Raja Limestone is also known as the Basal Telisa Limestone (Hutchinson, 1996). The formation consists of widespread platform carbonates, 20—75 m thick, with additional carbonate buildups and reefs, from 60—120 m thick (Hutchinson, 1996; Hartanto and others, 1991). The Basal Telisa is shale and calcareous shale deposited in deeper water as the carbonates were being developed on the platforms and highs (Courteney and others 1990). At outcrop the Batu Raja is 520 m thick in the Garba Mountains area of the Barisan Mountains (Fig. 2) (Hutchinson, 1996).

Discoveries in Batu Raja limestone and sandy limestone total over 1 BBOE ultimate recoverable reserves, with gas comprising just over half of that amount (Petroconsultants, 1996). Oil gravity ranges from 26—61° API (Petroconsultants, 1996). Reservoir porosity ranges from 18—38% and reservoir permeability is as much as 1 Darcy (Petroconsultants, 1996). Porosity has been enhanced in the upper parts of the formation due to subaerial exposure late in the early Miocene, at approximately 17.5 Ma, and also because of only partially cemented fractures (Courteney and others, 1990; Hartanto and others, 1991; Sitompul and others, 1992).

Gumai Formation

The Oligocene to middle Miocene Gumai Formation, also known as the Telisa Formation, is composed of fossiliferous marine shales with thin, glauconitic limestones that represent a rapid, widespread maximum transgression (Fig. 4) (Hartanto and others, 1991; Hutchinson, 1996). The transgression was toward the northeast, and water depths were shallow in the northeast and bathyal in the southwest (Hamilton, 1979). Fine-grained sandstones and siltstones occur on the basin margins (Hutchinson, 1996). The thickness of the Gumai Formation varies and is as much as 2,700 m thick in basins. The formation thins at basin margins and across highs (Hartanto and others, 1991; Hutchinson, 1996).

The Gumai Formation is the regional seal for the Batu Raja Limestone in South Sumatra but also contains some reservoir intervals. These carbonates contain 130 MMBOE ultimate recoverable reserves (Petroconsultants, 1996). These reserves average 33—52° API gravity and are found primarily in shoreline and shallow marine sandstones with 20% porosity, however, Hartanto and others (1991) have used well logs to identify turbidites and suggest that these sands could be exploration targets in the basins. Thee turbidites suggest that a rapid drop in sea level occurred at the end of Gumai deposition in middle Miocene time (Hartanto and others, 1991).

Air Benakat Formation

The middle Miocene Air Benakat Formation, also known as the Lower Palembang Formation, was deposited during the regression that ended deposition of the Gumai Shale. The Air Benakat Formation changes upward from deep marine to shallow marine conditions. Marine glauconitic clays decrease in frequency and marine sands increase (Hartanto and others, 1991). The formation ranges from 1,000—1,500 m thick (Hutchinson, 1996). Coal beds mark the upper contact with the overlying Muara Enim Formation (Hutchinson, 1996). Ultimate recoverable reserves discovered in shallow marine and deltaic sandstone reservoirs within the Air Benakat Formation total 647 MMBOE (Petroconsultants, 1996). The average porosity of the sandstone is 25%. The reservoirs contain oil with average 47° API gravity and some gas (Petroconsultants, 1996).

Muara Enim Formation

The late Miocene to Pliocene Muara Enim Formation, also known as the Middle Palembang Formation, was deposited as shallow marine to continental sands, muds, and coals. The formation thins to the north from a maximum of 750 m in the south (Fig. 4) (Hutchinson, 1996). Oil reserves of 179 MMBOE ultimate recoverable are located in Muara Enim sandstone reservoirs with 30% average porosity (Petroconsultants, 1996). Uplift of the Barisan Mountains provided source terrains for clastics from the south and southwest during deposition of the Muara Enim Formation (Hamilton, 1979).

Kasi Tuff

Continental tuffaceous sands, clays, gravels, and thin coal beds of the Kasi Tuff, also known as the Upper Palembang Formation, are found in valleys and synclines formed during deformation of the Barisan Mountains. These sediments are derived primarily from these mountains (Courteney and others, 1990; Hutchinson, 1996).

SEAL ROCK

The Gumai Formation represents the maximum highstand transgression following development of Batu Raja carbonates (Fig. 3 and 4) (Hartanto and others, 1991). Shales of this regional formation seal carbonate reservoirs and locally seal a series of stacked sandstone reservoirs of the Talang Akar Formation (Martadinata and Wright, 1984; Hartanto and others, 1991). Hydrocarbons that are found above the regional seal either have migrated there due to faults that broke the seal during the compression phase or were generated by the Gumai Formation shales in local areas where this formation might be mature. Intraformational seals within the Talang Akar consist of shallow marine and overbank shales that are important seals that compartmentalize the sandstones (Courteney and others, 1990).

UNDISCOVERED PETROLEUM BY ASSESSMENT UNIT

One assessment unit, the South Sumatra assessment unit (38280101), is recognized in the Lahat/Talang Akar-Cenozoic petroleum system (Fig. 1). The primary exploration targets in the South Sumatra Basin have been anticlines and carbonate buildups. This play is fairly mature. Although the basin as a whole has had a similar depositional history, there is a great deal of local variation within and around the half-grabens and half-graben complexes that could yield many targets for exploration. Future exploration targets would include smaller traps associated with more subtitle structures, stratigraphic traps associated with lowstand fan deposits, shoreline onlap onto basement highs, and synrift clastic fluvial, deltaic, and possibly deep-water deposits deeper in the half-grabens. Basin inversion could form traps in some of these synrift deposits. Due to the complex and varied nature of the province numerous prospects may remain to be explored.

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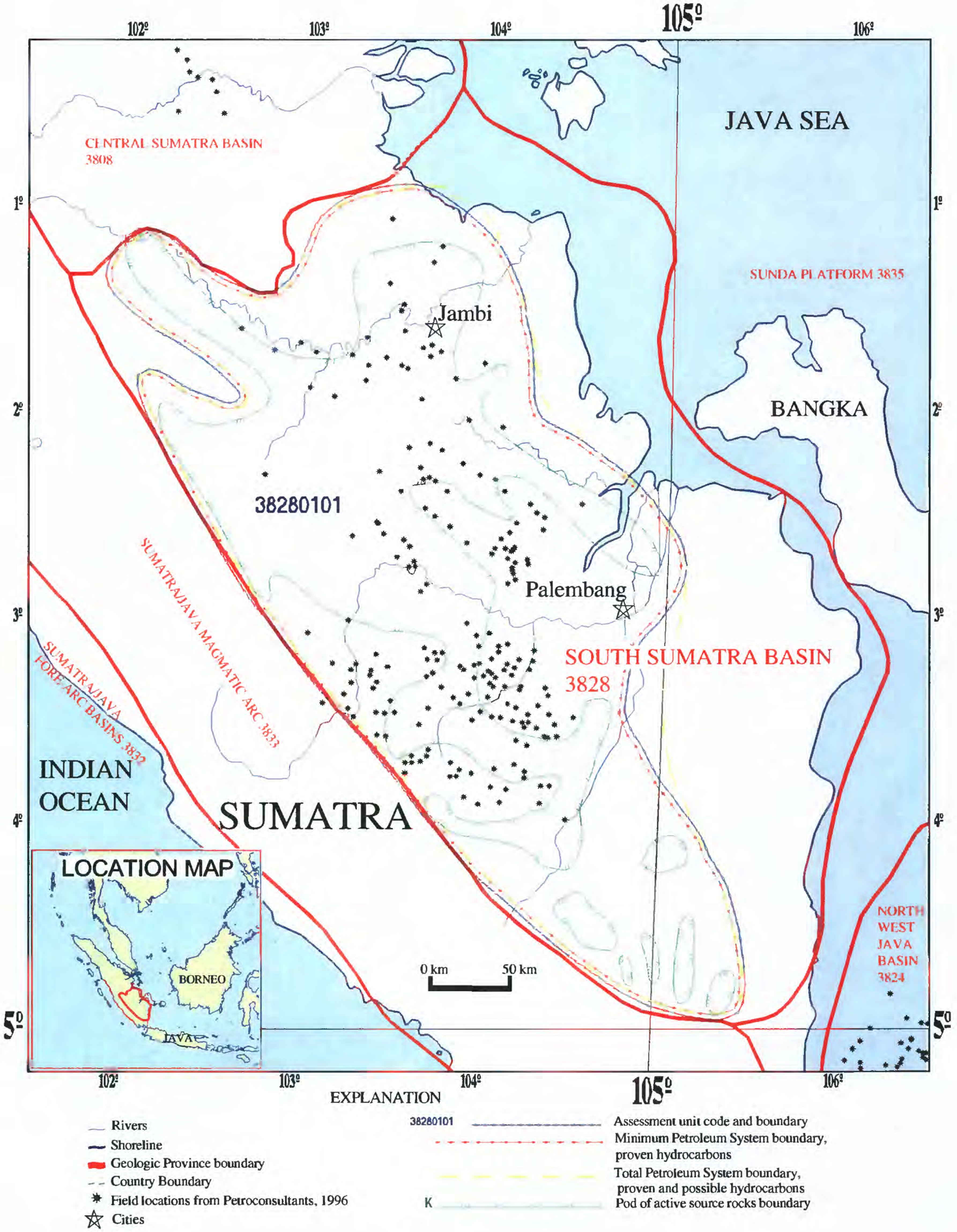

Figure 1. Index map of South Sumatra Basin Province, 3828. This map locates the pods of active source rock and one Total Petroleum System, Lahat/Talang Akar-Cenozoic (382801) with one assessment unit, South Sumatra (38280101).

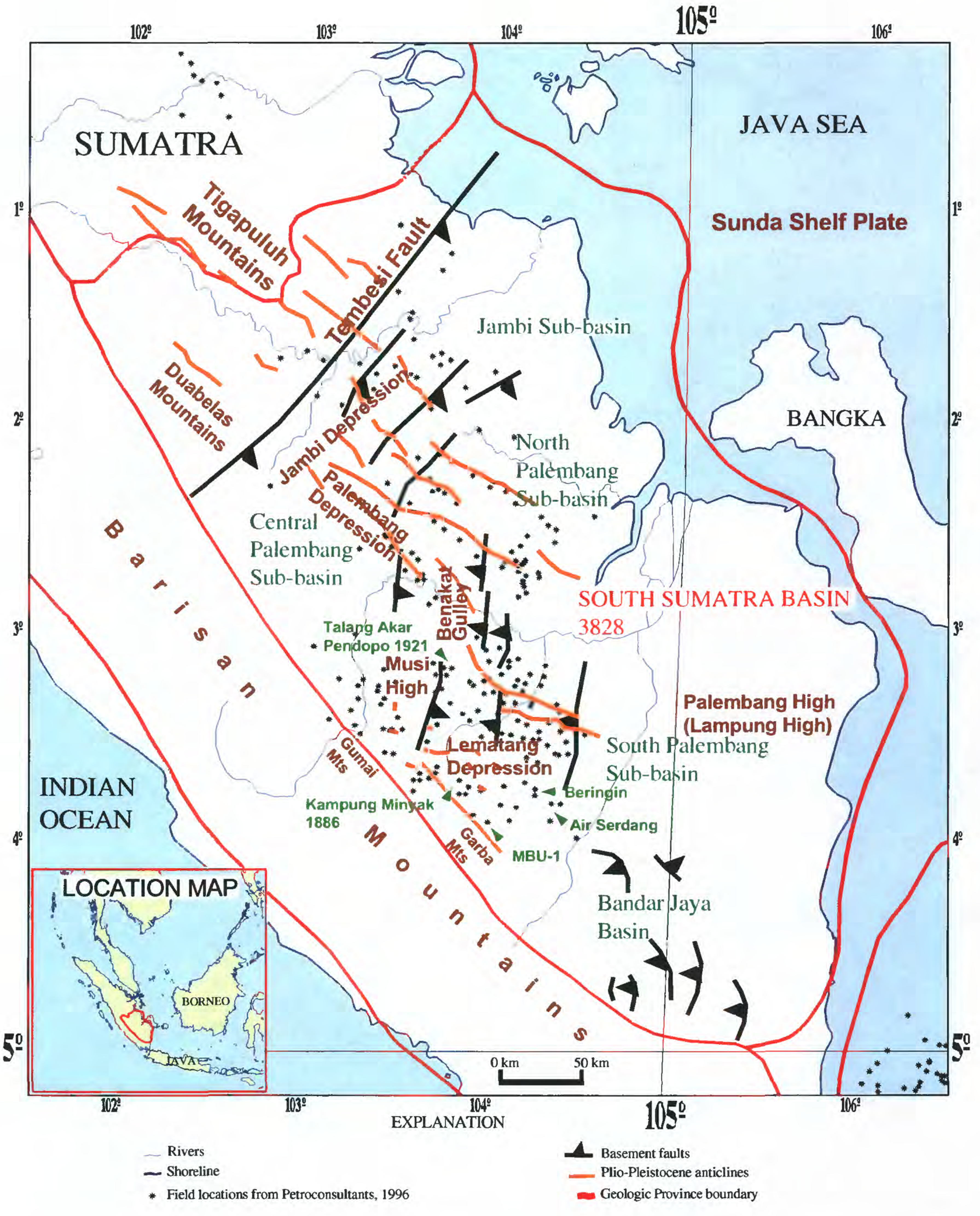

Figure 2. Index map of South Sumatra Basin Province, 3828 showing major structural features. Structure assembled from Hutchinson, 1996; Williams and others, 1995; Moulds, 1989; van Bemmelen, 1949.

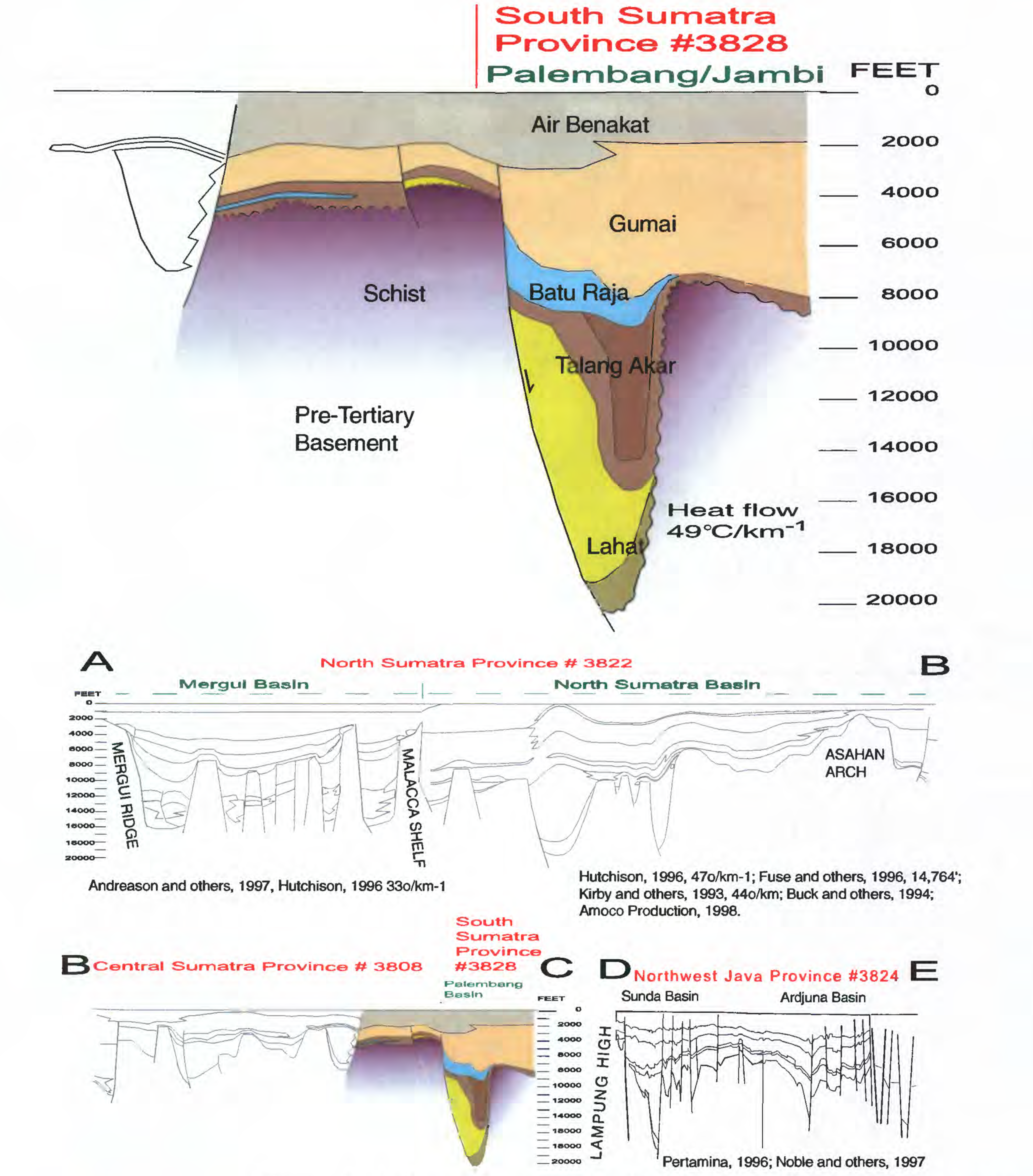

Figure 3. Schematic cross section, B-C, of the South Sumatra Basin Province 3828 (based on unpublished material from Amoco Production). This is part of a 1,200-mile-long (1,930 km) northwest to southeast cross section, A-B-C-D-E (Based on Andreason and others, 1997 Hutchinson, 1996; Fuse and others, 1996; Kirby and others,1993; Buck and others, 1994; Pertamina, 1996; Noble and others, 1997; and Amoco Production),showing major sub-basins of the southern edge of the Sunda Shelf Plate.

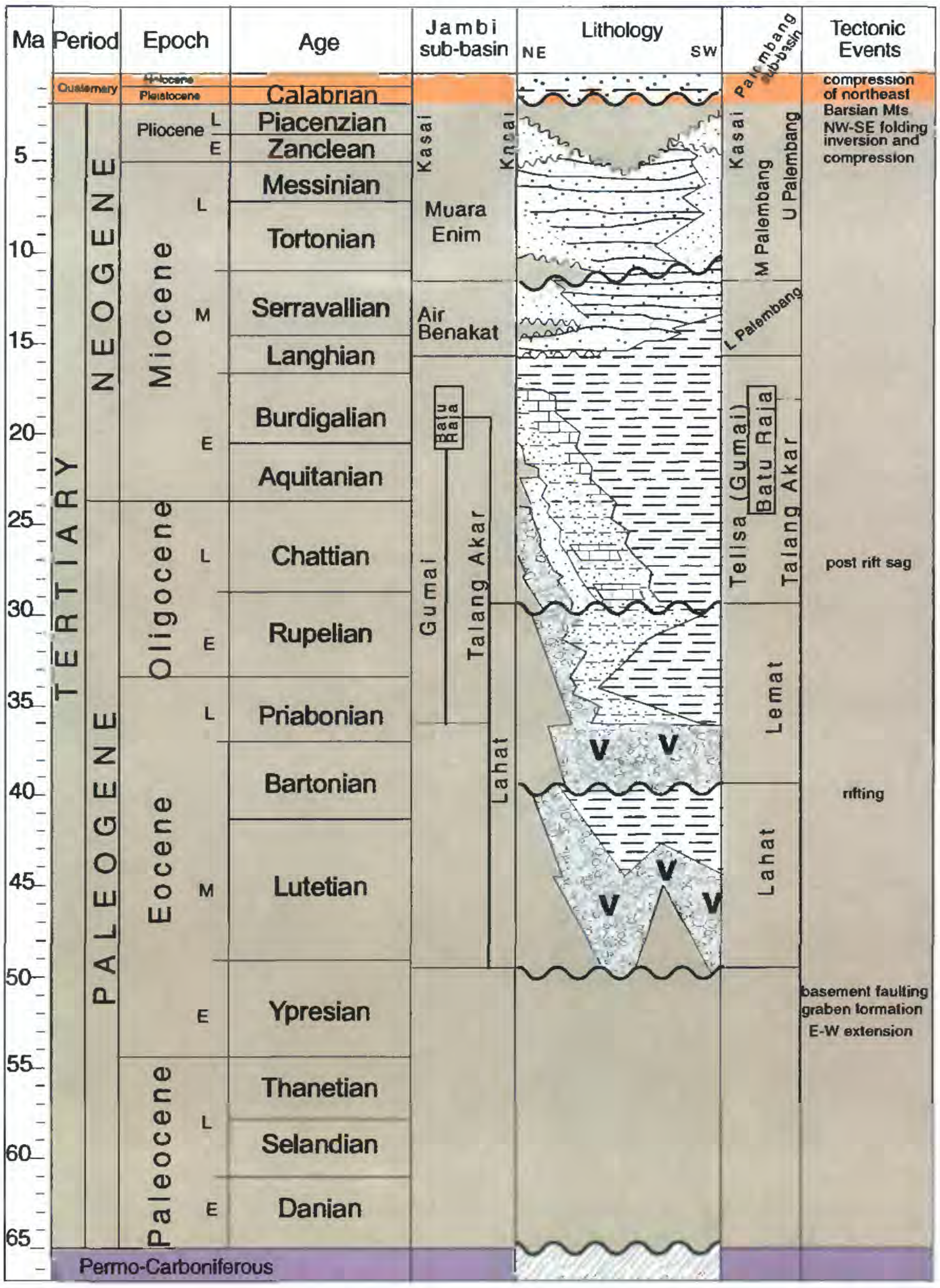

Figure 4. Generalized stratigraphic column for the South Sumatra Basin. Carbonate deposition occured earlier in the Palembang area. Terminology also varies between areas. Based on Courteney and others, 1990; de Coster, 1974; Sudarmono and others, 1997; Hutchinson, 1996; Sosrowidjojo and others, 1994.

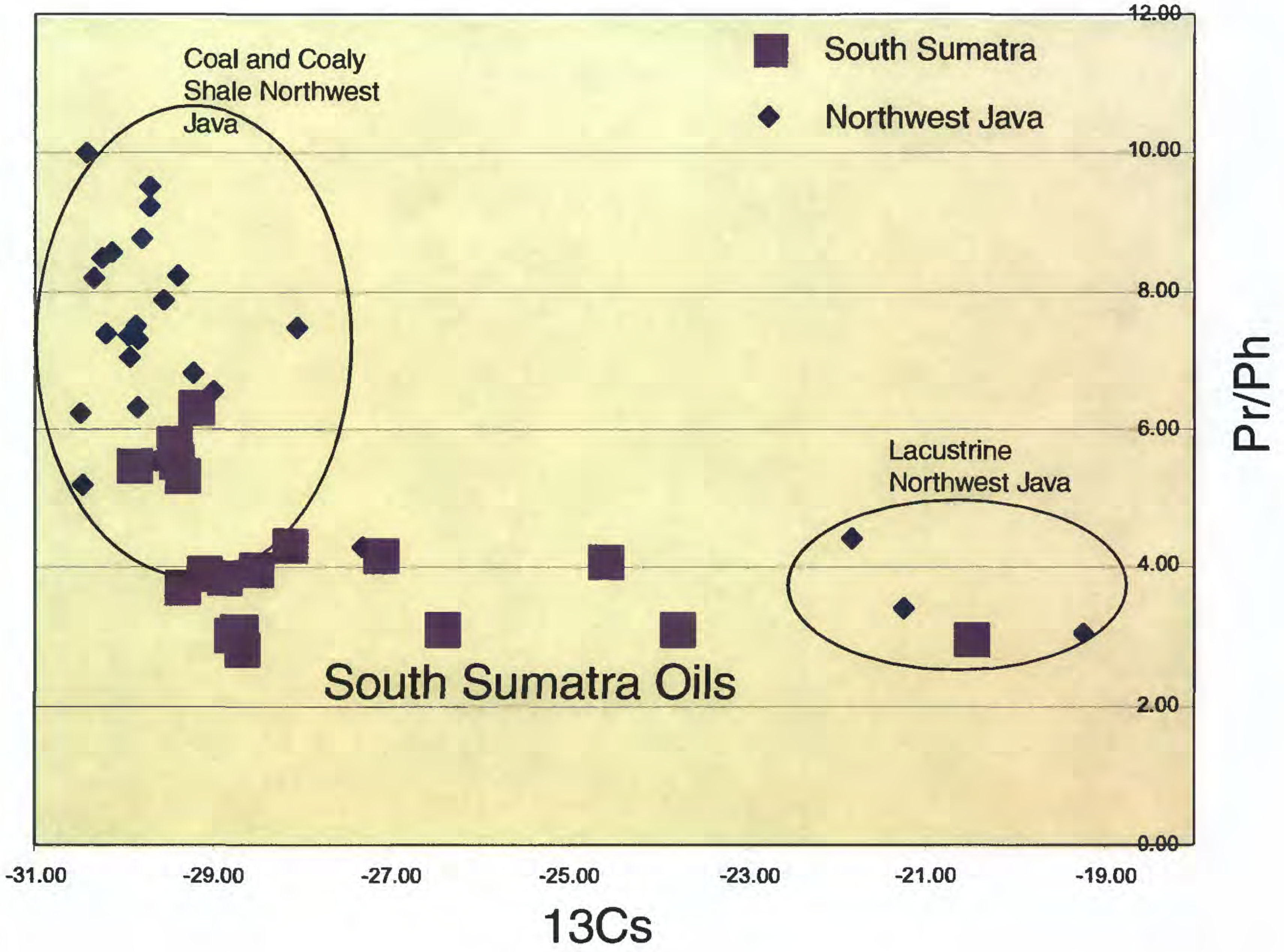

Figure 5. Graph of stable carbon isotope composition of the saturate hydrocarbon fraction (13Cs) plotted against the pristine to phytane ratio (Pr/Ph) of oils in the South Sumatra Province 3828 and Northwest Java Province 3824. Plot shows two groupings: lacustrine sourced and coal and coaly shale sourced (Bishop, 2000). Source data with permission from GeoMark Research, Inc., Oil Information Library System, 1998.

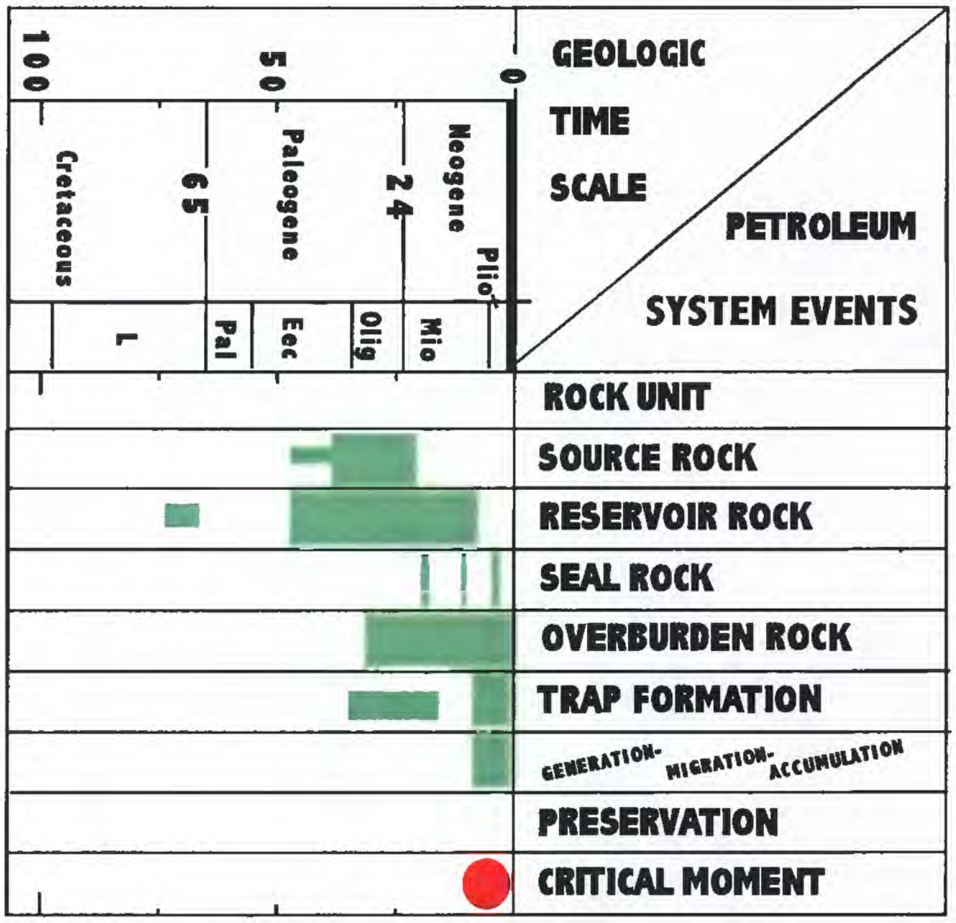

Figure 6. Events chart of the Lahat/Talang Akar-Cenozoic Total Petroleum System, 382801, of the South Sumatra Province.