Indian Plate Collision in Pakistan and Myanmar and its Impact on Hydrocarbon Prospectivity*

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Abstract

India is continuously subducted under the Himalayas and the direct contact is now concealed by Lesser Himalayan units. In the west, however, west of Indus River the Indian Plate docked with the Afghan Block, an already accreted part of the Southern Eurasian Plate assemblage, in an oblique mode along the northern extension of the Owen-Fracture Zone, manifested in the modern Chaman Fault System. East of it, an extremely stretched part of the Makran-Khojak-Katawaz Zone, composed of flysch and molasse sediments was reduced to merely 20 km across the strike. Strike-slip faults east of it segmented the Indian Plate in due course providing a further northward drift of the Indian Plate's main body. The reduction of drift velocity in the west resulted in an anticlockwise rotation of the Indian Plate. Indian Plate sediments contain favourable source and reservoir rocks yielding significant oil and gas accumulations both in structural and stratigraphic traps. Continuous exploration efforts are expected to result in more discoveries.

In the east, in Myanmar, flysch deposition commenced during the Paleogene, which continued through Lower Eocene and was followed by Oligo-Miocene molasse sediments. Only during Middle Miocene uplift of the Rakhine Yoma separated the Gulf of Bengal from the Inner-Burma-Tertiary-Basin. Shelf sediments of the Indian Plate comparable to Pakistan are missing here, as in Myanmar the geological setting is quite different. Oil and gas accumulations are restricted to the Innerburman Tertiary Basin and its southward offshore extension, which contains deep marine flyschoid sediments followed by shallow water limestone, marl and sandstones of mostly Neogene age. Towards the Bay of Bengal a fore-arc basin develops, characterized by gas driven mud-volcanoes and of oil deposits.

The off-shore areas of Pakistan, especially offshore Makran, are identical in several ways to the settings of Myanmar's offshore oil and gas fields. Mud volcanoes, gas-hydrates and heavy input of fine-grained sediments from Indus River and Nal River provide encouraging conditions for hydrocarbon prospecting.

Introduction

Plate tectonic models and the deciphering of collision mechanics have helped in exploration in developing hydrocarbon exploration concepts in the past fifty years. Important oil and gas discoveries are located in fold-thrust-belts and their foreland world wide in general and in Pakistan/Myanmar in particular, as well as in fore-deeps.
(Figure 1) The area of the India-Eurasia collision is no exemption. However, geological and structural models developed so far are not yet conclusive in details from regions under discussion. Detailed stratigraphic studies and geological mapping is largely missing for major parts of the India-Eurasia plate collision zone. Shelf sediments of the Indian Plate are mostly of marine origin and contain a number of promising source and reservoir rocks in Pakistan spread over Infra Cambrian to Miocene. In Myanmar all onshore oil and gas accumulations known so far are confined to Paleogene to Neogene molasse sediments. There, subsurface geology, paleogeographic setting, plate tectonic origin and structural settings are still scarcely known and understood. Discoveries of oil and gas in the Gulf of Martaban and the Bay of Bengal provided the momentum for further exploration in these areas.

Segmentation and Structural Development of the Western Indian Plate

In the west of Pakistan, east of Afghan Block (?), already accreted to the Eurasian Plate Margin, a geosynclinal flysch wedge developed with the plate subduction during Late Cretaceous/Paleocene. With the indention of the southern Eurasian Plate margin/Afghan Block and its subsequent northward recession, the Chaman Fault/Ghazaband Fault transform fault systems came into existence and are growing since then. They are regarded as extension of the Owen-Fracture Zone (Stoneley (1974), pp. 891) of the Indian Ocean. Indian Plate bypasses the Afghan Block rather than being subducted. This process started at the end of Late Cretaceous/Early Paleogene. Subduction of larger parts of Indian Plate oceanic material probably did not happen. Initial contact between continental Indian Plate and Eurasia is dated early Eocene. The first part of the Indian Plate involved in the collision was the Bela-Waziristan-Ophiolite Zone which obducted on to the margin of Indian Plate.

Principally we can differentiate four large plate tectonic units in the Western-Pakistan collision Zone (Figure 2):

1. The Afghan Block as part of the Eurasian Plate assemblage.
2. The Makran-Khojak-Katawaz Zone adjacent to the west.
3. The Bela-Waziristan Ophiolite Zone with its ophiolite components and associated sediments.
4. The Indian Plate with its sedimentary cover and its westernmost part, the Western-Shear Zone.

In Makran, a large flysch accretionary pile developed, which is still connected with the Katawaz Flysch of eastern Afghanistan through the Khojak Segment. The flysch basin (geosyncline) – today's Makran-Khojak-Katawaz Zone - was heavily affected during the obduction and collision.

The collision of the Indian Plate with Afghan Block is of a scraping nature. The Tethys II seafloor was extremely expanded together with the overlying flysch wedge and became extremely sheared by left-lateral strike-slip faults. The collision largely continued at the expense of the oceanic-sea-floor. This we find now as a chain of individual ophiolitic blocks, namely:

- Bela Ophiolites and overlying Kanar Melange,
- The Muslimbagh ophiolite and further on,
- The Zhob ophiolite body.

The regional geology is determined by the depositional history of Gondwana continent, known in Pakistan from the Potwar-Hazara area. The break away from Gondwana started around 160 Ma ago (Upper Jurassic). There was an Upper Jurassic hiatus in the southwest and east parts of the Chaman Fault System. It was followed by the sedimentary history of the Indian Plate drifting northwards after complete separation from Gondwana about 140 Ma ago (Heine, Chr. et al. (2004)) during Neocomian times.

Limestone, shale and mudstone are regarded as potential source rocks, if they have been deposited in anoxic environments. Lagoonal deposits and deposits of shelf-slopes with a chance of rich organic upwelling waters are among the potential source rocks. This demonstrates the necessity to arrive at a paleogeographic reconstruction as well in order to substantiate the hydrocarbon prospectivity of an area.

Structural Development of the Eastern Margin of the Indian Plate

Indoburman Ranges

Whereas on the western part of the subducting Indian Plate abundant shelf platform sediments from Cretaceous times onwards until Miocene prevail, there is a completely different scenario preserved on the eastern side. Parallels are found in the development of the obducted flysch wedge only. Palaeogene flysch deposits of the Rakhine Yoma (Arakan Mountains) last until the Oligocene, when from the north the molasse sediments of the Barails overlie discordantly the obducted flysch. These conditions are comparable to the situation in the Makran-Khojak-Katawaz Basin, suggesting a coeval development along the southern margin of the Eurasian Plate before the impact of the Indian Plate and the uplift of the Himalayas to an erosional level.

There are no remnants of the Indian Plate sediments besides olistolithes of Maastrichtian age within Paleogene Indoburman flysch (Brunnsschweiler (1966); Mitchell (1993); Bannert et al. in press). The triangle shaped Indian Plate forms the modern western Myanmar. However, in the eastern Bay of Bengal indications for the nearness of the Indian Plate have been found (Bannert et al. (1978)). With the clockwise rotation of the Yangtse Platform and East Myanmar Units from the Eastern Himalaya Syntaxis to the SW, Indian Ocean seafloor is subducted under the Indoburman Ranges after a shift of the subduction zone approximately 80 Ma ago during Coniacian-Santonian (Heine (2002)). In the north, west of the Naga Hills the Shillong and Mikir Hills (SW of Lahe in India; in (Figure 3) are the easternmost outposts of the Indian Plate. There are older rocks than Paleogene flysch deposit preserved in the obducted wedge.

The main hydrocarbon production comes from the southern and central part of the Innerburman Tertiary Basin. Shwebo Basin is also considered to be a prospective area. Chindwin Basin and Hukawng Basin are further targets. In southern Chindwin Basin, Miocene marine Natma Formation (Indaw oilfield), Eocene Yaw Formation, Eocene/Paleocene Tabyin-Laungshe and Cretaceous Kabaw Formation are regarded potential source rocks. Reservoir rocks are present in the Nanhizin Formation in the eastern margin of Chindwin Basin, which intercalates with the potential source-rock of Tabyin-Laungshe Formation. So far, there is no clear picture concerning the overall maturity of different formations.

The subsurface of the Innerburman Tertiary Basin is still poorly understood and various plate-tectonic models were offered in the past. Especially the question of presence of pre-Upper Cretaceous sedimentary rocks comparable to the development of Indian Plate sedimentary cover remains unresolved. Upper Cretaceous *Orbitolina* limestone occurs in the northern Chindwin Basin and in the SW west of Myittha Valley (Kalemyo area). Upper Jurassic hiatus in Pakistan prior to commencement of the drifting phase of the Indian Plate might yield a hint towards the missing of Jurassic sediments along the eastern Rakhine Yoma.

East coast of Bay of Bengal

Along the coast of the Bay of Bengal in Myanmar, the geology has been studied in some detail by Brunnschweiler (1966) and Bannert et al. (1978). It is the area west of the intensively folded Rakhine (Arakan) Yoma of Paleogene Indoburman flysch. Mitchell (1993) concludes as source area for the Paleogene Indoburman Flysch the magmatic arc, now to the east within the Innerburman Tertiary Basin.

The Rakhine coastal area hosts a Neogene flysch, which received its clastic material from the rising Himalayas in the north (Allen et al. (2008)). Paleocurrent measurements identified southeasterly and westerly directions of down-current-azimuths. The flysch sandstones are very fine grained; coarse sandstones and conglomerates are lacking and with sandstone/shale ratio amounts to 3.0. Shallow water foraminifers like *Nummulites* and *Lepidocyclines* are found in deep sea sediments of turbidite habitus and are regarded as displaced. Their original sediments were not yet diagenetically hardened and it is assumed that their age is more or less the age of their host turbidities.

Hydrocarbon Prospects of the Western Indian Plate

The Indus Basin part of the Western Indian Plate have petroleum system elements distributed throughout the stratigraphic column ranging in age from Infracambrian to Miocene mostly deposited in the form of platform sequence. (Figure 5a and Figure 5b) So far about 54 Tcf of gas reserves and 940 million barrels of oil reserves have been discovered the onshore Indus Basin. Its offshore extension is manifested by world’s second largest delta/fan system after Bengal Fan, deposited on Indian Plate’s passive margin. Indus delta system has been prograding from northeast to southwest with increasing sediment thickness in the center and eventually thinning into the deeper basinal areas. Offshore Indus Basin is divided into various elements from Karachi Platform, to Shelf-delta, to slope and basin. Some reefal development had also taken place on the top of Deccan volcanic ridges during Eocene (50 Ma) time, which continued until 10 Ma. Bombay High field in offshore India produces from the similar carbonate buildups. Pak Can-1, the only offshore well which produced hydrocarbons, was drilled in shallow water testing only the edge of the sand body.

On the other hand, Balochistan Basin and its offshore extension are formed by the Arabian Plate’s subduction under the Makran continental margin, hence offshore Markan is part of an active margin. Coastal Makran is identified by a number of active mud volcanoes, which continuously spew out the mud, which is often associated with methane gas. These mud volcanoes are the result of severe compression, where water bearing mud is squeezed out from greater depths.

Occurrence of gas effusing mud volcanoes, gas hydrates in the offshore as well as heavy input of both fine and coarse grained sediments from Indus and Nal rivers highlight the prospectivity of Makran onshore and offshore. As such, the similarities with the Bay of Bengal are evident. Along the Makran coast, from Iran in the west to the Porali plains in the east, mud volcanoes, extruding from Makran flysch, are quite well documented (Deslisle et al. (2001); Snead (1966)). Latest surveys by Deslisle et al (2002) recognized a bacterial origin for the gas driving the mud-volcanoes. That is quite surprising, since the channels are assumed to be 2–3 km deep. Furthermore, gas hydrates were sampled offshore along the Makran coast including the now submerged and eroded Malan Island mud volcano.

Pakistan's offshore hydrocarbon exploration history goes back to early 60's, when Sun Oil drilled three wells in the Creek area, testing the potential of extension of Onshore into coastal area. Wintershall, Marathon, and Husky were active during 70's and together drilled five wells. Since then only four wells have been drilled in the Offshore Indus: two during the 1980's and then in one each in 2007 and 2010; and one of which (Pak Can-1) flowed gas at a non commercial rate of 3.7 MMscfd. So far 17 wells have been drilled of which five on the onshore platform extending offshore, and four in the Makran Offshore. Three of these wells were abandoned pre maturely due to operational reasons, while quite a number of them were drilled off structure due to poor quality seismic.

Hydrocarbon Prospects of the Eastern Margin of the Indian Plate in Myanmar

Burmah Oil Company started producing light oil from the Yenangyaung Field as early as 1887, following Chinese hand-dug wells that targeted only ± 200 m deep reservoirs Yearly production primarily from three onshore basins peaked at 11.2 MMbo during 1984-1985 (Blakeley (2010)). Due to the usually fine grained nature of the reservoir rocks, hence low permeability, crude oil production is quite modest, but some of the wells have continued to produce oil since more than 50 years. The main oil fields are in Central Burma Basin and the onshore, northern part of Irrawady Delta.

Only generally surveyed during the late 1980s through beginning of the 1990s, the full blown petroleum prospectivity of Shwebo Basin (Figure 4), Chindwin Basin with the former Indaw Oil Field of Burmah Oil and the Hukawng Basin, which are all parts of the Innerburman Tertiary Basin, remains to be determined (Bender et al. (1982)). Neogene sediment thickness increases considerably north of 24°N, in the northern Chindwin Basin, and adjacent to the north Hukawng Basin. Myanmar's prospective offshore basins are located in fore-arc and back-arc settings. Bay of Bengal and Gulf of Martaban - Andaman basin are separated from each other by an island arc system, contrasting with the passive rift basins of east India.

Blakeley (2010) reports:

> "While a number of exploration campaigns were conducted offshore Rakhine Basin in the 1970s, it was South Korean company, Daewoo International Corporation, who unlocked the potential of this previously non-producing basin. They drilled a deep marine turbidite, Plio-Pleistocene play, resulting in the Shwe (2003), Shwe Phyu (2005) and Mya (2006) discoveries. The in-place resource of the Shwe structure is estimated to be 3.5-5.5 Tcf, while the northern, smaller Shwe Phyu has an in-place resource of 0.5-1.2 Tcf. The southern Mya structure is estimated to have an in-place resource of 1.8-3.4 Tcf. These were the first major discoveries since the Yetagun gas find, 12 years earlier. The company is continuing to explore the area with mixed results. As a result of Daewoo's success in opening up the Rakhine Basin, virtually all offshore western Myanmar is now under license to international E&P companies, including CNOOC, CNPC, Daewoo Petroleum, and ONGC Videsh Ltd."

According to estimates provided by British Petroleum, Myanmar has 21.19 trillion cubic feet of gas reserves or 0.3 per cent of the world's total, while Bangladesh has 13.77 trillion cubic feet or 0.2 per cent of the world total at the end of 2007. Much of this is located in the Bay of Bengal.

Discussion and Conclusions

A paleogeographic concept can be developed from these observations. During the Upper Cretaceous while the Indian Plate was still drifting, the Western Burma Plate had already docked to the southern Eurasian margin. This margin could have achieved a NW-SE direction. Later, with the subduction of the Indian Plate and the subsequent development of the Eastern Himalaya Syntaxis and the resulting escape tectonics (Tapponier et al. (1982)), the direction of subduction shifted from NE towards E, to its present position. Thus, the space between the southern Eurasian Plate margin and the eastern Indian Plate, occupied by the Indoburman flysch geosyncline, became narrower through the passage of time. The shelf sediments of the Indian Plate in Pakistan contain numerous proven source rocks and producing reservoirs. However, there is still an unclear picture of the paleogeographical development of the various stages due to the variety of tectonic concepts.

The Ganges-Brahmaputra peripheral fore-land basin extended further to the east into the still subsiding northern Indoburman flysch and the northern Innerburman Tertiary Basins, where large amounts of sandstone, probably comparable to Tipam Sandstone appear (Bannert et al., in press). While the main body of the Indoburman Ranges was uplifted during Miocene times, the former shelf to the east, today's Innerburman Tertiary Basin achieved its basin structure. West of the Indoburman Ranges, the Ganges-Brahmaputra Basin or Assam-Tripura-Bangladesh Molasse Basin (Nandy (1986)), came into existence after the impact of the Indian continental plate with the southern Eurasian Plate margin and final emergence of the Himalayan chains in the north. It was the southern shelf of the already docking Indian Plate. To the south, this basin opens into the oceanic Bay of Bengal with its enormous Bengal Fan receiving the erosion debris of the Himalaya. It came into existence during Oligocene as Najman's (2006, p. 12) compilation describes it. The observation of Upper Cretaceous/Paleocene shallow water sediments on Ramree Island, might hint conditions comparable to the western Bengal Fan off India.

There are encouraging parallels concerning hydrocarbon potential, if we compare western and eastern side of the Indian Plate collision zone. Indian Plate shelf sediments contain important source rocks on the Pakistan side, whereas in Myanmar these rocks are missing. There is a chance, however, that in northern Myanmar Hukawng Basin and northern Chindwin Basin, parts of the Indian Plate might have escaped from the direct continent-to-continent collision process in an eastward manner and settled at the northern fringe of the Western Burma Plate. This, however, is a very hypothetical approach and is not yet substantiated by field observations. But there emerges the concepts, comparing the Khost ophiolite complex, the eastern Indoburman Ranges and the Jade-Mines epi-metamorphic complex at 26°N latitude, which seem to have undergone similar developments prior to the collision. Today, they are in close proximity with the shelf sediments of the Indian Plate in Pakistan. It is expected that hydrocarbon exploration in northern Myanmar Chindwin Basin and Hukawng Basin will yield favourable results. Marine influence during Paleogene and lower Neogene could provide source rocks and an increasing depth of burial in the north at the expense of sedimentary pile would provide for source rock maturity.

The other parallel development concerns the modern offshore sedimentary areas along the Makran coast and Indus Delta fan and the Bay of Bengal fan. In the recent years the hydrocarbon exploration in the Gulf of Bengal and the Gulf of Martaban/Andaman Sea basin has yielded encouraging discoveries. Similar conditions can be expected in the Makaran coastal area. Mud volcanoes and hydrocarbon discoveries along the eastern coast of Bay of Bengal in Myanmar and Bangladesh are in sediments, comparable to Makran coastal areas with gas-hydrates, mud volcanoes (Delisle et al. (2002)) and a comparable geological situation in the Indus Delta.

The discoveries of sizeable hydrocarbon accumulations in the offshore areas of Myanmar, Bangladesh and India in Neogene sediments is encouraging and should lead to enhance the hydrocarbon prospectivity of offshore Pakistan.

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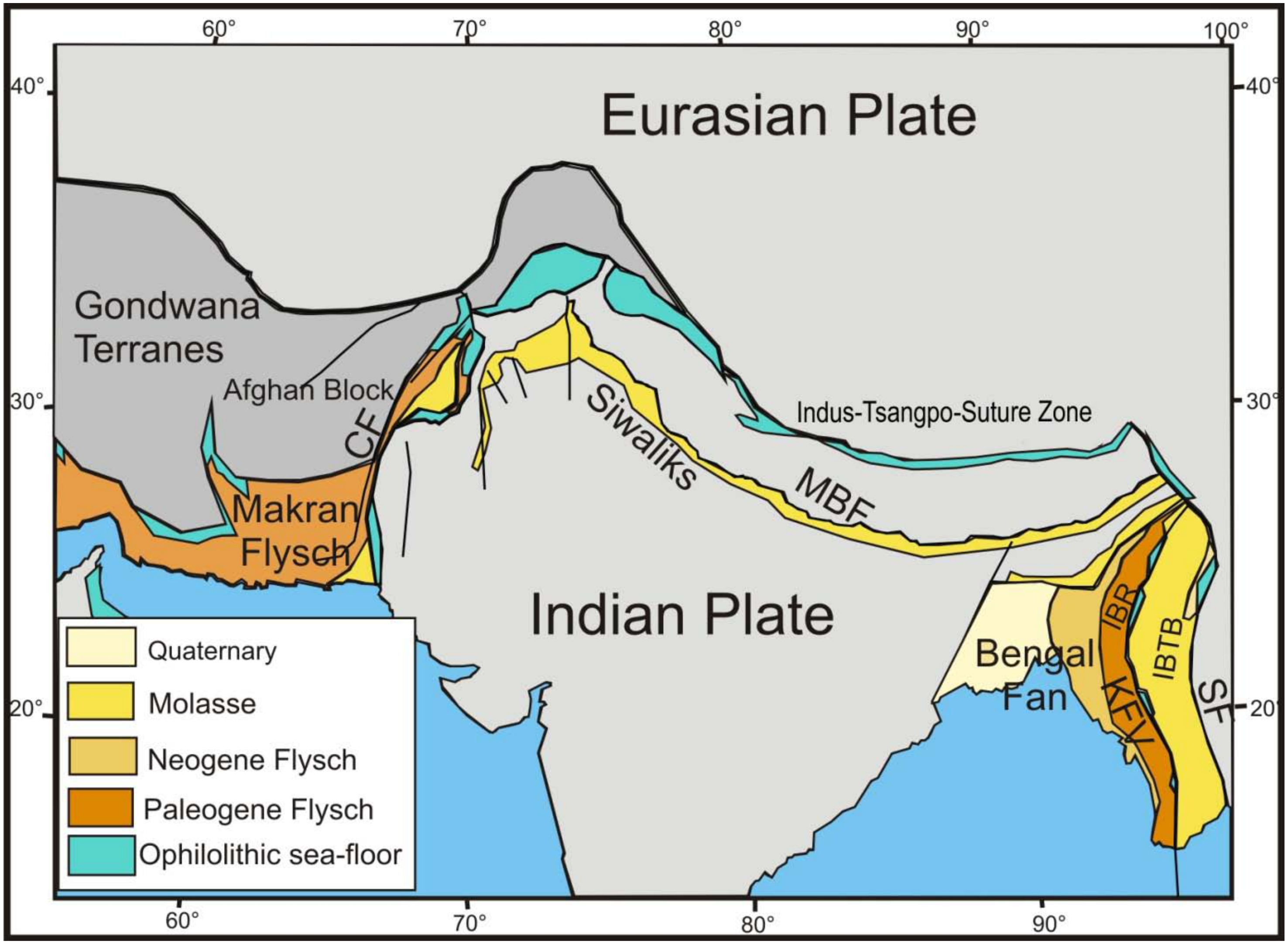

Figure 1. The collision zone of India and Eurasia, simplified from Stöcklin (1980). CF = Chaman Fault, IBR= Indoburman Ranges, IBTB= Innerburman Tertiary Basin, KFV= Kabaw Valley Fault, MBF = Main Boundary Fault, SF = Sagaing Fault.

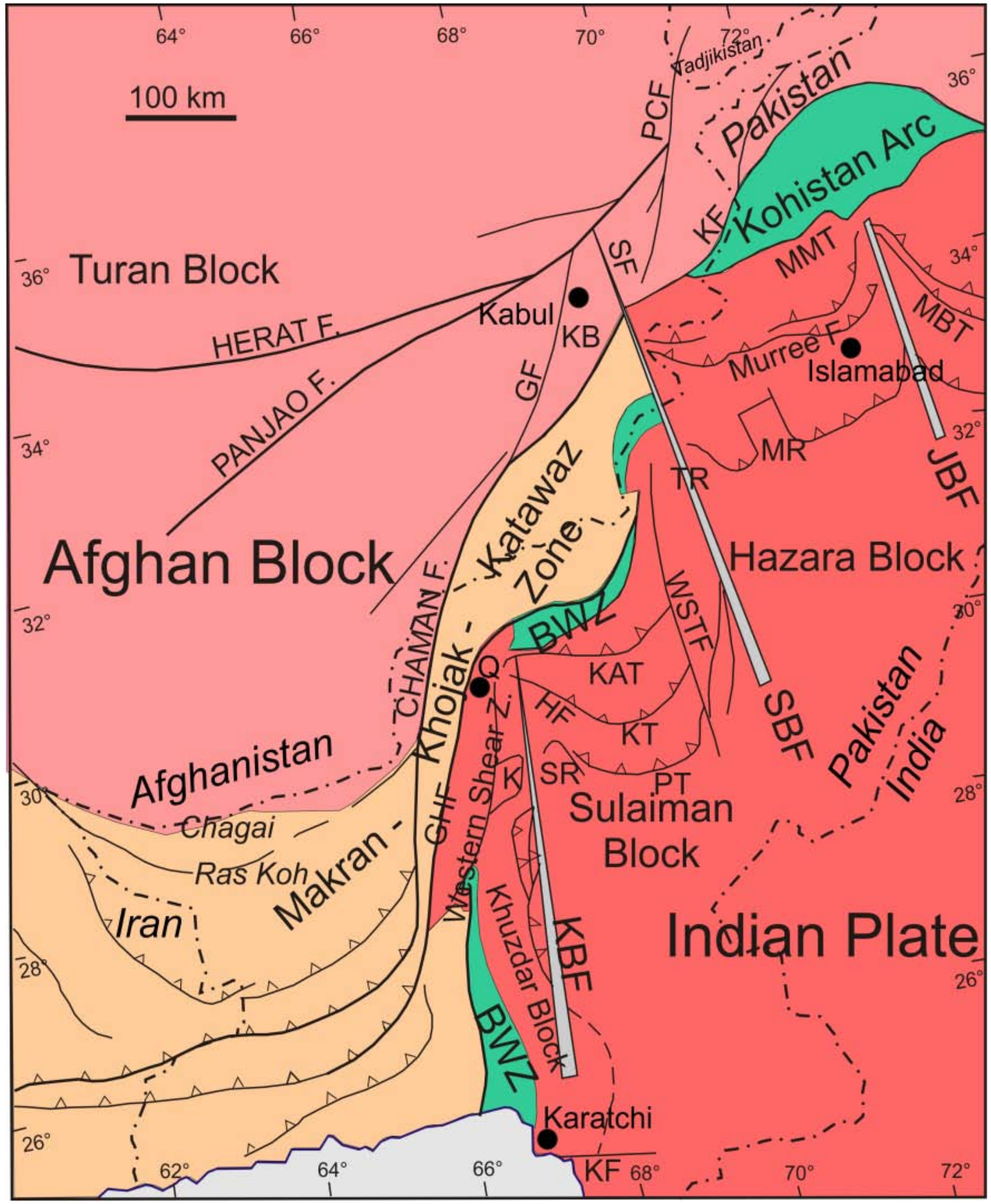

Figure 2. Segmentation of the western India Plate in Pakistan (amended after Bannert et al. 1992, Figure 1).

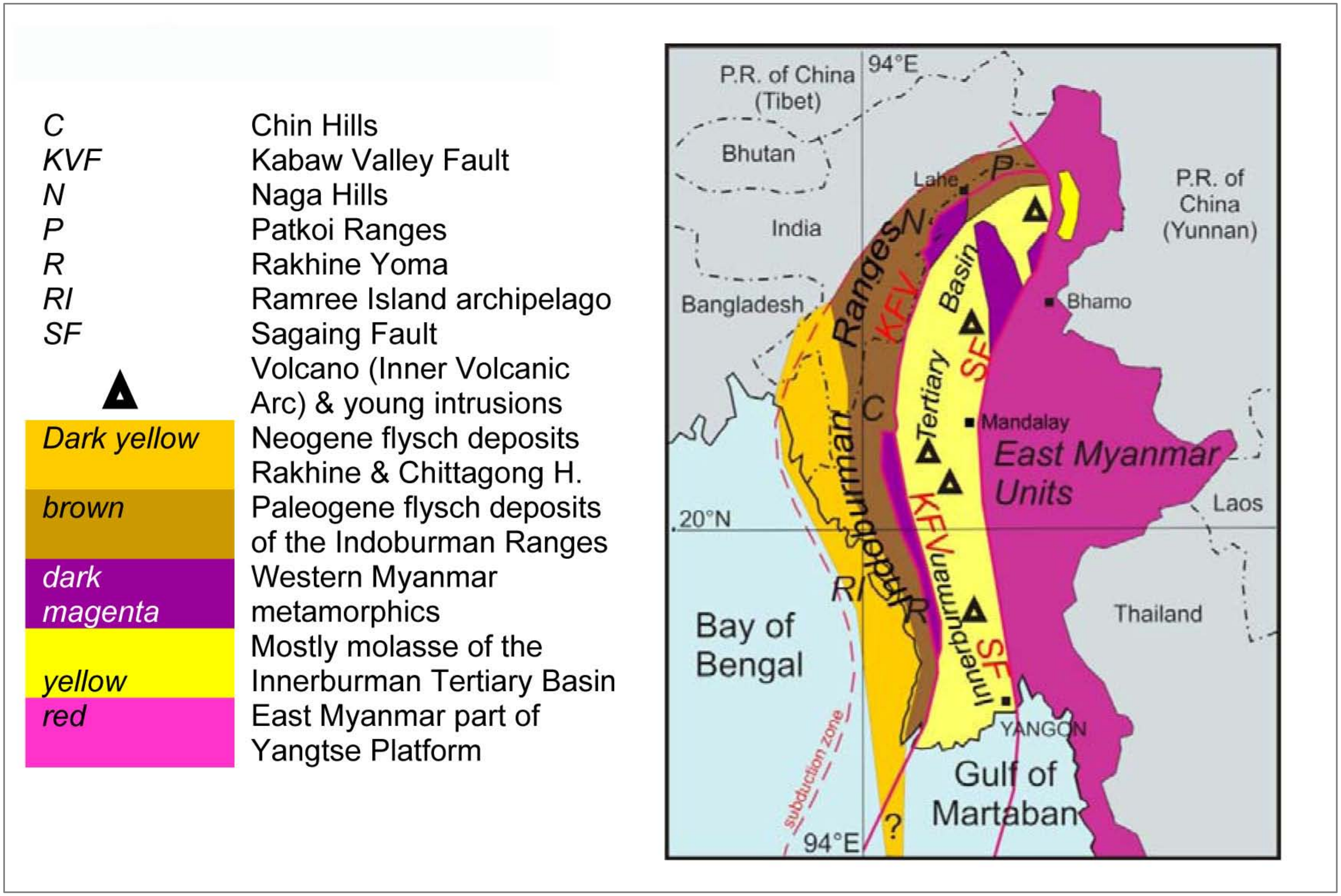

Figure 3. Structural units of Myanmar.

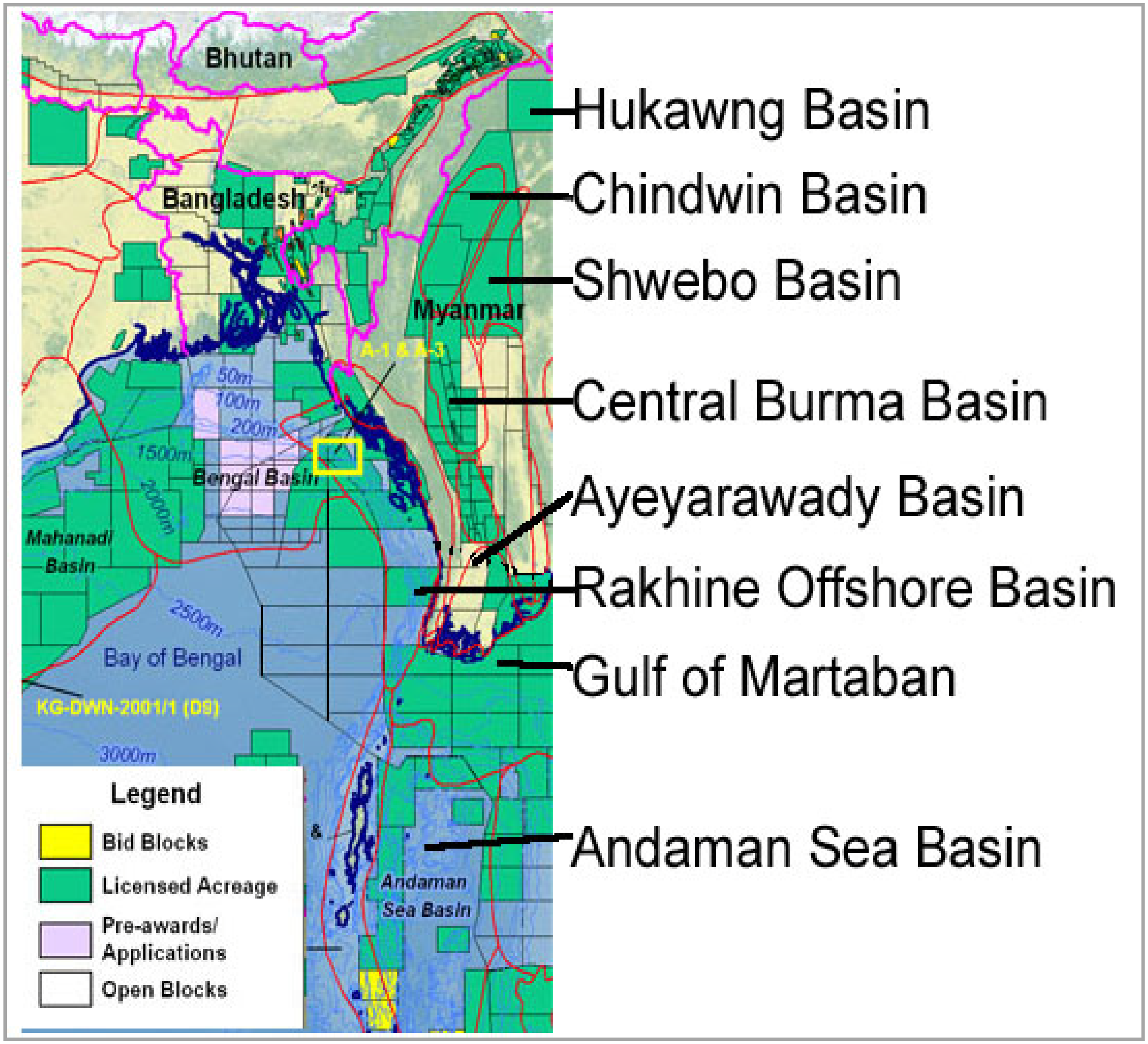

Figure 4. Prospective Tertiary basins in Myanmar (adapted from Blakeley (2010).

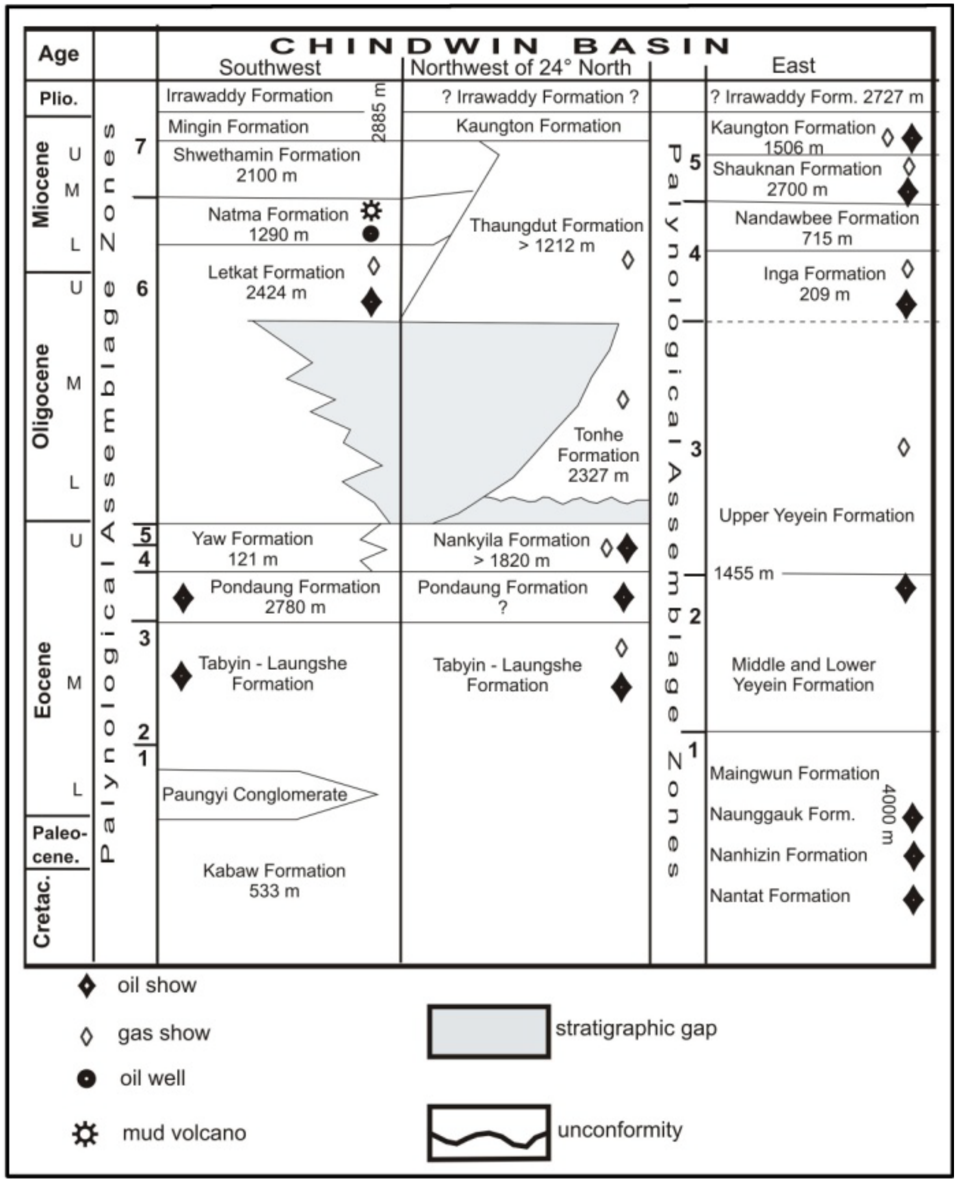

Figure 5a. Stratigraphy of Tertiary sediments of Rakhine (= Arakan) Coast, Ayerarwady (= Irrawaddy) Delta and Central Basin of Myanmar (after Bannert (1977), Table 6).

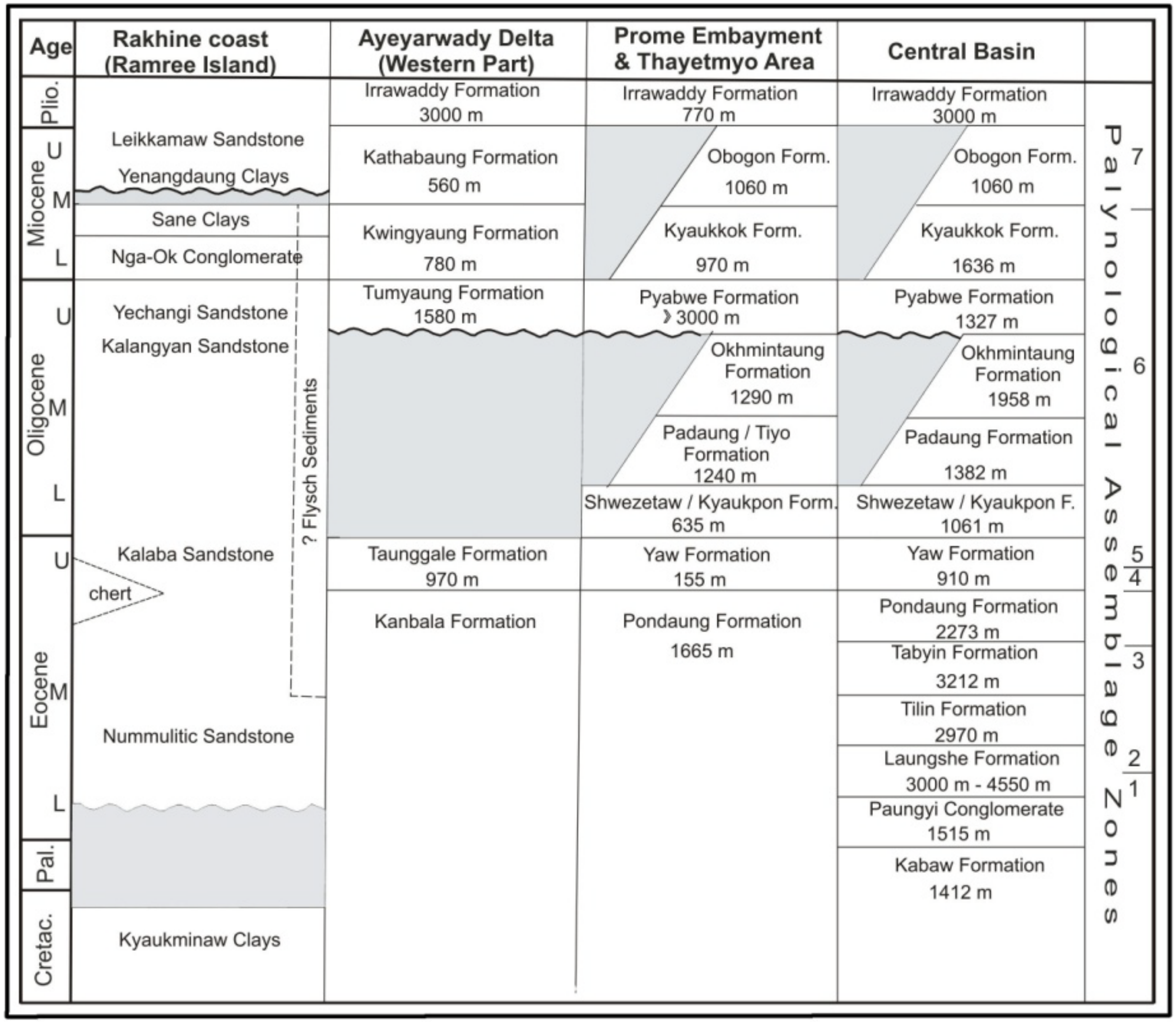

Figure 5b. Stratigraphy of Tertiary sediments of Chindwin Basin of Myanmar (after Bannert (1977), Table 6).