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GRAVITY TECTONICS IN INDONESIA: PETROLEUM IMPLICATIONS

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ABSTRACT

Gravity tectonics is about tectonic movement due to differential gravity between Earth's layers or two adjacent areas (primary vertical endogenic force/tectogenesis) and its ensuing gravitational reactions (secondary lateral tectogenesis) . This movement thoroughly concerns with equilibrium or isostatic compensation.

The origins of uplifts in the collision zones of Indonesia (Meratus Uplift-SE Kalimantan; Batui Uplift-eastern Sulawesi, Papua's Central Ranges Uplift , and Timor-Tanimbar Uplift) are satisfied explained by gravity tectonics. In these cases, vertical movement due to isostatic exhumation of once subducted micro-continent/ continent in collision zones provides mechanism for the uplifts.

The origins of regional compressive structures such as Samarinda Anticlinorium, eastern Kalimantan, offshore North Makassar toe thrusts, and North Serayu fold-thrust belt, northern Central Java are considered as secondary lateral tectogenesis of gravity tectonics. Their mechanisms of deformation are through gravitational gliding/sliding (gliding tectonics), compensating differential gravity due to hinterlands uplifts.

Gravity tectonics is essential in forming some elements and processes of petroleum system. It forms foreland basin; structural traps, mostly thin-skinned; and deposition of syn- and post collisional sediments burying sources to depth of oil and gas windows.

The paper will discuss some areas in Indonesia with structures related to gravity tectonics and their implications for petroleum accumulation.

INTRODUCTION

Meratus Mountains, SE Kalimantan border the Barito Basin to the east. The mountains were uplifted in the Neogene time and isostatically compensated by subsidence of the Barito Basin located just to the west of the mountains, forming a basin's foredeep. The Barito foredeep became the kitchen, generating hydrocarbons from middle Eocene Lower Tanjung fluvio-deltaic and lacustrine shales. Hydrocarbons migrated and trapped at structures formed in association with Meratus Uplift. In this case, uplift of the Meratus has petroleum implications.

Samarinda Anticlinorium, East Kalimantan, are prolific sites for hydrocarbon traps, and their synclinorium are kitchens. Oil and gas fields of onshore and offshore East Kalimantan/Mahakam are located in these anticlines. Continue eastward into deep water Makassar Straits, there are a number of structures called toe thrusts which also become sites for oil and/or gas fields.

Most authors consider the origin of Meratus Uplift, Samarinda Anticlinorium, and the Makassar Straits' toe thrusts relate to lateral compression due to collision of micro-continents of Buton-Tukang Besi and Banggai-Sula (such as van de Weerd and Armin, 1992; Guritno et al., 2003). Seismic sections across the Makassar Straits show no evidence of compressed structures in the Neogene, instead of extension as response to Neogene sagging phase.

This paper proposes another tectonic mechanism for the origin of Meratus Uplift, Samarinda Anticlinorium, Makassar Straits' toe thrusts, namely gravity tectonics. The paper also discusses North Serayu Anticlinorium, Central Java as structures formed by gravity tectonics (Satyana, 2010). Petroleum implications of gravity tectonics in these areas are also addressed.

METHODS

Four areas including: (1) Meratus Uplift, SE Kalimantan, (2) Samarinda Anticlinorium, East Kalimantan, (3) toe thrusts of the Makassar Straits, and (4) North Serayu Anticlinorium, Central Java

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are examples of the areas with structures resulted from gravity tectonics.

Published literatures, surface geology, gravity-magnetic data and modeling, and seismic data from these areas are examined to know their structural styles. Regional geology and tectonics of these areas are analyzed. All data and analyses are synthesized to understand the origin of structures and their petroleum implications. The results of this study can be used as analogues for other areas with structures due to gravity tectonics.

RESULTS

Gravity Tectonics

Vertical tectonics hypotheses attribute folding and thrusting to gravity sliding from the tops and flanks of vertically rising fault blocks, structural arches, mantle diapirs, and like phenomena (Meyerhoff and Hull, 1996). Consequently, the term gravity tectonics (de Jong and Scholten, 1973) commonly is used in place of vertical tectonics. Variants include the oscillation hypothesis (Haarmann, 1930) or the undation theory (van Bemmelen, 1931).

Distinction is made between endogenic vertical oscillations of the crust, called primary tectogenesis, and the ensuing gravitational reactions, called secondary tectogenesis. The primary tectogenesis causes wavelike deformations of the Earth’s crust, “undations” which can be classed in five orders of magnitude (van Bemmelen, 1931, 1932, 1949, 1987). The gravitational reactions to these primary, endogenic crustal deformations can be divided into two or three groups: those occurring in the outer veneer of unconsolidated sediments (epidermal secondary tectogenesis), and those occurring in deeper crustal or in subcrustal (magmatic) zones (bathydermal and subcrustal secondary tectogenesis) (van Bemmelen, 1949). Whereas the primary tectogenesis is a vertical movement with respect to the datum plane of the Earth’s geoid, the secondary tectogenic movements have chiefly a horizontal direction.

Gliding tectonics is epidermal secondary tectogenesis. Gliding tectonics is mechanism whereby large masses of rocks move down a slope under gravitational force (gravity sliding), producing folding and faulting of varying extent and complexity (Figure 1).

In this paper, gravity-driven exhumation (uplift of terrane once subsided due to differential gravity and density) is also grouped as gravity/vertical tectonics. Accordingly, in this context, tectonic transport of vertical/gravity tectonics through : (1) gliding tectonic transport/gravity sliding, and (2) gravity-driven exhumation/isostatic exhumation.

Gravity-induced downslope movement has been invoked by structural geologists to explain an almost dizzying variety of phenomena on almost all geologic scales. It has been used, for example, as an interpretation of the rumpled-cover nappe structures of the Alps, the decollement thrusting of the Canadian cordillera, the chaotic sedimentary sequences known as "mélange" (Fr. "mixture") or "olistostromes," the disturbed layering of single depositional layers, and the generation of growth faulting.

Gravity structures can very broadly be divided into those that are presumably related directly to orogenesis and those that are generated as a result of normal deposition. In relation to normal deposition along passive, divergent margins, so-called thin-skinned gravity sliding is seen to occur in close association with growth faulting and shale diapirism. No significant lateral tectonics involved in gliding tectonics.

Gravity-induced features are important to petroleum exploration mainly for their relation to growth faulting. The anticlines caused by the type of downslope movement faulting should be considered potential hydrocarbon traps in deeper-water areas off passive margins. Proven petroleum traps in Samarinda Anticlinorium and Tarakan growth faults, East Kalimantan and toe thrusts of North Makassar Straits are evidence of this.

Isostatic exhumation is the uncovering or exposure by erosion of a pre-existing surface, landscape, or feature that had been buried through uplift of the feature due to lower gravity/density compared to surrounding area. Vertical movement or uplift in this case is a response for obtaining an equilibrium (isostatic compensation). In tectonics, the term is specified for subducted continental crust beneath oceanic crust due to collision, causing the continental crust is uplifted due to its lower density than the surrounding mantle. No significant lateral tectonics involved in an isostatic exhumation. This exhumation in the collision zone will result in formation of foreland basin due to isostatic compensation. Foreland basin is prolific for petroleum accumulation.

Origin of Meratus Uplift, SE Kalimantan

The Meratus Mountains is a collisional orogen/ suture marking the collision between Schwaner and Paternoster micro-continents. The collision took place in the upper Early Cretaceous (Satyana and Armandita, 2008).

The Meratus Mountains has been uplifted since the middle Miocene. The origin of the Meratus uplift is difficult to reckon since the mountains has been located in the stable area since the latest Tertiary, far away from the continental margin. Many authors considered that the uplift related to plate tectonic kinematics by lateral compression due to collision of micro-continents to the east of Sulawesi in the Neogene time and/or rifting of the Makassar Straits (such as van de Weerd and Armin, 1992). Recent seismic data however, show the Neogene's undeformed sections of the South Makassar Straits and Paternoster terrane. If tectonic transport from collision of micro-continents through the South Makassar Straits and uplifted the Meratus Mountains, the straits should be deformed/ shortened. Seismic sections show no compressive structures in the middle and western parts of the Makassar Straits.

Satyana and Armandita (2008) proposed new mechanism of the Meratus Uplift based on gravity data and is called isostatic exhumation. The Bouguer gravity anomaly map of the Meratus Mountains and its adjacent area shows both positive and negative Bouguer anomaly trend SW-NE parallel to the mountains. The Barito Basin anomaly exhibits an asymmetrical form with a westward gentle gradient and a steep gradient in the east, suggesting a major fault contact along the border of the Barito Basin with the Meratus Mountains. The lower range of anomalies with minimum value of -30 mGal in the northwest can be interpreted as the basin's foredeep where the thickest sediments were deposited. The Meratus Mountains is characterized by a positive gravity anomaly with a maximum value of +80 mGal (Figure 2).

Results of gravity modeling from all previous authors (Situmorang, 1987; Subagio et al. , 2000 and Gaol et al., 2005 see Satyana and Armandita, 2008) (Figure 2) indicate that in the eastern and central part of the profiles, an ultrabasic/ophiolite (density 2.90 g/cm3, about 4 km thick) overlies granitic mass (density 2.68 g/cm3 thickness 26 km). Based on gravity data and modeling, it can be considered: (1) the ultrabasic rocks in the Meratus Mountains are thin allochthonous masses (rootless) instead of deep seated intrusive body and (2) there is a continental crust beneath the Meratus ophiolite. Therefore, the Meratus Mountains is a thin allochthonous (detached) oceanic slab overlying a thick subducted Paternoster continent (Figure 3). The presence of buoyant continental crust beneath dense thin oceanic slab and within dense upper mantle will cause the continental crust to resume its position to the surface (exhumation) due to differential gravity and densities. This will take place when the subducted continental plate break off from its frontal oceanic slab. The subducted Paternoster micro-continent broke off its oceanic front and started to exhume sometime between the Late Cretaceous-Paleogene time. The exhumation of the Paternoster continent has uplifted the overlying detached Meratus ophiolite since then, and effectively forming a subaerial mountains separating the Barito from Asem-Asem Basins in the Mio-Pliocene. This is the way of the Meratus Mountains has been uplifted. No lateral external compressional force is required.

Tectonic reconstruction of the emplacement of the Meratus ophiolites and its uplift in such a way was discussed in detail by Satyana and Armandita (2008) (Figure 4) and Satyana (2010). The origin of the Meratus Mountains was related to subduction, collision and exhumation at the southeastern margin of the Sundaland from Late Jurassic to Late Cretaceous/Paleogene. During the Late Jurassic-Early Cretaceous there was Andean-type north-directed subduction of Meso-Tethys oceanic lithosphere beneath the Sundaland margin. At upper Early Cretaceous, a Proterozoic-Paleozoic Gondwanan continental fragments (Paternoster terrane) collided with the eastern part of the subduction zone. The subducted Paternoster micro-continent broke off its oceanic front and started to exhume sometime between the Late Cretaceous-early Paleogene time and Meratus Uplift has occurred since then.

Origin of Samarinda Anticlinorium, East Kalimantan

The Kutei Basin is a deep Tertiary Basin bounded to the north and south by regions exhibiting a relatively thin, shallow water complex of Tertiary carbonates and relatively coarse siliciclastics. The basin lies to the east of the major Kuching Uplift, Central Kalimantan. The basin opens to the east into deep water area of the Makassar Straits. Deltaic sediments are predominating deposits in Kutei Basin called as Mahakam Delta complex. Numerous publications describe the nature of deltaic complex which presently progrades eastward into the Makassar Straits, as it has done since Early Miocene time.

Large scale linear folds, called Samarinda Anticlinorium, which generally parallel the arcuate coastline in SSW-NNE trends, are dominant structural features in the basin, mainly at its eastern part (Figure 5). Not as much is known about the structures of the western basin area, and though large structures are evident, a similarity in structural trend and style is not apparent from the available data. The western basin area is uplifted and inverted, with Paleogene sediments exposed on outcrops at many localities.

The origin of Samarinda Anticlinorium has been variably interpreted. The mechanisms proposed as diverse as vertical diapirism, inversion through regional wrenching, lateral compression due to micro-continents collision to the east of Sulawesi, detachment folding above overpressured sediments, differential loading on deltaic sediments, and inverted delta growth fault system. Detailed discussion on this can be found in Satyana et al. (1999).

From various tectonic mechanisms proposed, the author considers gravity tectonics is the most plausible mechanism (Figure 5).

The western part of the Kutei Basin was significantly uplifted. A minimum of 1500 m to over 3000 m of sediments have been removed by inversion (Satyana et al., 1999). A vast topographic low (Kutei Lakes region) is located at the western Kutei Basin, generally coincident with a large scale "basement uplift" (Central Kutei gravity high - Ott, 1987). The eastern Kutei Basin subsided marked by gravity low opening into the North Makassar Strait as embayment. Neogene deltaic sedimentation in eastern Kutei Basin was sourced by western basin's uplifted provenances. The presence of differential gravity between western and eastern parts of the basin and much uplifted sedimentary provenances in western basin had triggered gliding tectonics or gravity sliding. Samarinda Anticlinorium has been proposed as a response to gliding tectonics from western to eastern basin. Gravity sliding for the origin of Samarinda Anticlinorium was proposed in various details by: van Bemmelen (1949), Rose and Hartono (1978) and Ott (1987).

Folding in Samarinda Anticlinorium appears to have been contemporaneous with deposition, and some anticlines have diapiric cores. Juxtaposition of the tightly folded onshore anticlines (e.g. Sanga-Sanga, Klandasan) with very gently folded offshore structures (e.g. Attaka, Bekapai) is interpreted by Rose and Hartono (1978) as formed by gravitational compression rather than a distinct tectonic folding. Rose and Hartono (1978) interpreted that uplift of the Kuching High and its subsequent initiation of the Neogene regression in the Kutei Basin probably created the conditions necessary for gravitational sliding to the depositional center of the basin. Detailed interpretation of gliding tectonics as the mechanism for the origin of Samarinda Anticlinorium was made by Ott (1987) as summarized below.

The Kuching Uplift first experienced major movement during late Oligocene - Early Miocene time. Deformation continued until well into the Miocene and may be related to NW - SE oriented compressional forces resulting from subduction in the South China Sea. The Kuching Uplift thus triggered two very important events in the overall geologic evolution of the Kutei Basin. Firstly, it provided a major, local source of coarse clastics which initiated and fed the eastward progradation of the Neogene delta complex. Secondly, compressional tectonic forces which led to formation of the Kuching Uplift also caused the major orogenic folds of the western Kutei Basin.

Regional uplift in the western basin area resulted in reversal of the gentle regional western dip on the basement in the western basin area during the Early Miocene. This is an important consideration, because the regional "basement syncline" which was thus developed is invoked to help focus later structural development within the eastern basin area.

Sometime during late Middle to early Upper Miocene, a major event took place in the basin's history. It is interpreted that the Kuching Uplift of the western basin area had by that time achieved sufficient elevation and eastward slope to gravitationally destabilize a large area of the central basin interior. To the east there existed a large unstructured plain which sloped gently eastward. The overpressured, deepwater shale which underlay this plain provided a perfect detachment/ decollement zone on which a massive landslide then took place. It is doubtful that this grand scale landslide occurred during an instant, but rather it seems more likely that major slippage occurred over a relatively short time span with some lesser movement occurring over a considerably longer period of time. In any event, the eastward movement of this enormous landslide area was instrumental in the development of the Samarinda Anticlinorium and associated features (Figure 5).

As the massive landslide moved eastward, it encountered increasing gravitational resistance as it was pushed “uphill” against the interpreted gently westward dipping basement of the central and eastern basin area. Rather than continuing to move only horizontally, the highly mobile and fluidized shales thus moved upward and penetrated the relatively young and undercompacted, overlying sedimentary section in elongate diapiric fold trends. The elongate diapirs pierced or deformed the overlying sequence in an arcuate fashion similar to the wave fronts which must have formed as the landslide mass moved eastward.

The detached mass moved furthest, and probably fastest, in the central basin area, near the present day course of the Mahakam River. Along the north and south margins of the basin, movement was smaller and restricted by being “pinned” to the non-flowing”, stable carbonate and sandstone regimes of these flank terrains. Reduced thicknesses and coarser clastic content of the generally “slippery” bathyal shale section also probably hindered movement of the massive landslide block in the basin flank areas. Because the landslide moved from west to east, the structures can be seen to generally decrease in amplitude and complexity in that same direction (eastward).

Isostatic rebound is a phenomenon which provides a key element to this interpretation. After the mass moved eastward, a large expanse of crust was thinned due to the dilatory effect of movement along the listric decollement surface. This crustal thinning locally removed an enormous amount of sedimentary rock overburden of relatively low density. Isostatic forces within the Earth responded to replace the void, and the basement complex rebounded upward accordingly.

Origin of Growth Faulting and Toe-Thrusting of Tarakan and North Makassar Basins

Based on newly acquired deep offshore seismic data of Tarakan sub-basin, Eastern Kalimantan, combined with and published data/literature in onshore and shelf area, Hidayati et al. (2007) proposed two structures styles for this area: the onshore area, which is relatively stable, with basement involved tectonics, and the offshore area, Tarakan depocenter, characterized by thin skinned gravity-induced tectonics. Both areas are separated by a major regional normal fault (MRNF) which might have been active since Mid Miocene. The stable area is possibly underlain by continental crust (granitic core and/or accreted terrains), while the Tarakan depocenter is underlined by stretched continental crust, transitional to the oceanic crust that floors of the Celebes/Sulawesi Sea.

In the offshore Tarakan area (Tarakan depocenter), the deformation regime is dominated by thin-skinned tectonics with SSW-NNE trending growth faults and toe thrusts, where non basement is involved and detachment depth is estimated to be at a depth of 9 km within the Mid-Miocene section. The deformation in Tarakan depocenter was induced by differential gravity between onshore/shelf and depocenter areas. Miocene-Pliocene deltaic sediments of Meliat, Tabul, Santul, Tarakan and Bunyu formations were shed off western provenance and deposited prograding eastward. Presence of mid-Miocene shale detachment had induced gravity tectonics of extensional deformation in proximal area, assisted by heavy loads of sediments deposited rapidly, resulting in growth faulting, and then was balanced by compressive toe-thrusting in distal areas (Figure 6).

Gravity tectonics which occurs in onshore and offshore Kutei Basin as Samarinda Anticlinorium continues into deep water North Makassar Basin where the Kutei Basin opens into the Makassar Straits (Figure 6). The dominant structures in the present-day deepwater portion of the Kutei Basin are toe-thrust anticlines (Guritno et al., 2003). Differences in the timing, style and intensity of these structures enables a sub-division of the region into three structural provinces (northern, central and southern). The toe-thrusts in the northern province are better developed than those of the central and southern structural provinces and often displace strata all the way up to the seabed. Here higher uplift in the northern part of the basin has generated a gravity driven extension-toe-thrust system which results in an intensive thrust imbrication in the northern province of the offshore deep-water Kutei Basin. The resulting hanging wall anticlines are often manifested on the seabed as topographic highs and some have complex internal structures. Central and southern provinces do not develop good toe thrusting since the degree of uplift tends to decrease from north to south.

Origin of North Serayu Anticlinorium, Central Java

In the middle part of Java and along the island, trending west-east parallel with the axis of the island, there was Oligo-Miocene deep water depression area called Bogor-North Serayu-Kendeng Trough (van Bemmelen, 1949). Volcanic-clastic deposits shed off the Southern Mountains and northern platform were deposited rapidly into the trough (Satyana and Armandita, 2004). During the Pliocene and Pleistocene time, the trough was uplifted and compressed and presently formed as Bogor-North Serayu-Kendeng Anticlinorium (van Bemmelen, 1949).

The origin of the anticlinorium may relate to subduction of Indian oceanic plate to the south of Java, but structural styles of the North Serayu Anticlinorium need another explanation for its formation.

There is differential gravity between southern (South Serayu) and northern (North Serayu) Central Java (Figure 7). Bouguer anomalies of Central Java decrease from + 110 mGal in the southern Central Java (Karang Bolong High) to 0 mGal in the northern Central Java to the south of Brebes-Tegal area. Satyana and Purwaningsih (2002) interpreted this phenomena as related to the presence of two major strike-slip faults flanking the indented area of Central java namely Muria-Kebumen Fault Zone (SW-NE trending, sinistral) and its antithetic dextral fault NW-SE trending Pamanukan-Cilacap Fault Zone (Satyana, 2007). These faults are responsible for the uplift of southern Central Java causing a gravity high at south Central Java, and isostatically compensated by subsided northern Central Java making a gravity low. The presence of this differential gravity had triggered gliding tectonics or gravity sliding from southern Central Java to northern Central Java (Figures 7, 8).

The subsidence of North Serayu Trough started in the early Miocene as isostatic compensation to the uplift of South Serayu Range. The thick piles of sediments from South Serayu Range and southern contemporaneous volcanic arcs glided towards the deepest parts of North Serayu Trough. Gravitational tectogenesis (gliding tectonics/gravity sliding) took place resulting in anticline and thrusts which converged towards the depocenter of North Serayu Trough. Miocene formations, particularly plastic Merawu volcanic-clastic turbidites, were intensively folded. Due to this gravitational compression, the deposits of North Serayu Trough temporarily emerged above sea level and the anticlines were truncated by erosion before subsidence prevailed again and younger sediments covered gravitational anticlines.

Gravitational sliding movements from south to north in the North Serayu Trough/Basin occurred as response to the uplift of the South Serayu Range resulted in thin-skinned toe-thrust anticlines and/or fault-propagation folds (Figure 8). The Eocene to Late Miocene Worowari, Lutut, and Sigugur nonmarine to shallow marine beds and the Merawu and Lower Penyatan turbidites were deformed (Satyana and Armandita, 2004). Some sediments being ponded in the synclinal areas formed between the thrusted anticlines.

In the upper Pliocene, the North Serayu Range started to rise from the subsided area due to northward migration of magmatic and orogenic arc (migration of crustal waves of asthenoliths - van Bemmelen, 1949). The magma, which pushed up the North Serayu Range, finally broke through the overlying crust and the sedimentary cover, so that in the Young Pleistocene (Notopuro period) very intensive volcanic activity produced a great number of volcanoes on the top of the North Serayu Range. The load of these volcanic masses promoted the progress of gravitational spreading or collapsed where the volcanic cones block-faulted and slided down to their foots.

Petroleum Implications

In collision, the once subducted continent will eventually break off its oceanic slab due to its density/gravity and start to exhume and uplift its overlying collisional orogen. The gravitational uplift is isostatically readjusted by subsidence or collapse of the nearby basement due to flexure forming a basin. Post-collision sediments are deposited within the basin. The Neogene basins of the Barito, Buton, Banggai, Seram, Timor, Bintuni, Akimeugah, Iwur-South Papua, and Meervlakte-Waipoga-Rombebai (North Papua Basins) were formed in this way.

Continuing collision resulted in fold and thrust belts within the collided masses and its sedimentary basin migrating from the core of collisional orogen to the basin rim. Structural taps were formed and their multiple thrust sheets subsided the basin’s source rocks. The maturation of source rocks were also by the burial of molassic deposits eroded from collisional orogen areas. Generated petroleum migrated to the available traps formed by collision process. Thick post-collisional molassic deposits may degrade reservoir quality due to compaction. Intensive deformation could risk the traps by breaching them and complicate the migration routes. Petroleum plays of collision zones are unique and need comprehensive understanding of collision and post-collision tectonic history. Proven petroleum accumulation in some collisional basins of Indonesia may provide references for other unproven collisional basins.

Gravity-induced anticlines and their flanks, roll-over structures of growth faults and flank areas of toe thrusts in Neogene deltaic and deep water sediments of Kutei and Tarakan Basins have been proven as prolific areas for oil and gas fields from onshore, shelf, and deep water areas. In synclinal areas, down flank areas of growth faults, and synclinal limbs of toe thrusts are kitchens with Neogene deltaic source rocks. Understanding of these gravity structures therefore is very important for petroleum implications.

North Serayu Anticlinorium, being presently overlain by Pleistocene-Recent volcanic covers remain unexplored. Numerous oil and gas seeps are discovered in these volcaniclastic covers indicating that there are working petroleum system within the underlying North Serayu Anticlinorium. One small fields to the south of Kendal area in north Central Java, Cipluk Field, is an example of oil field of North Serayu Anticlinorium. Once seismic technology can uncover volcaniclastic covers, there are numerous traps related to North Serayu Anticlinorium available.

CONCLUSIONS

1. Gravity tectonics will apply in the area with differential gravity where there is uplift (gravity high) and adjacent subsided area (gravity low). Structures are formed by gravity sliding/gliding tectonics of prograding sediments from high to low areas. Gravity tectonics also occurred when subducted buoyant continent breaks off its frontal slab and start to exhume causing uplifting. No external lateral tectonics (compression) involved in the deformation.

2. Four areas in Indonesia indicate the role of gravity tectonics in forming their structures: (1) the Meratus Uplift, S.E. Kalimantan, (2) Samarinda Anticlinorium (Eastern Kalimantan), (3) growth faults and toe thrusts in Tarakan offshore and North Makassar Basins, and (4) North Serayu Anticlinorium.

3. Petroleum implications of gravity tectonics are obvious as proved by the four areas studied. Gravitational uplift of the Meratus Mountains forming oil producing-Barito foreland basin; oil and gas fields of Kutei and Tarakan Basins are all structural traps induced by gravity tectonics (anticlinorium, roll-over growth faults and toe thrusts). North Serayu Anticlinorium are under explored due to thick volcanic covers, but presence of numerous seeps and one oil field show their prospectivities.

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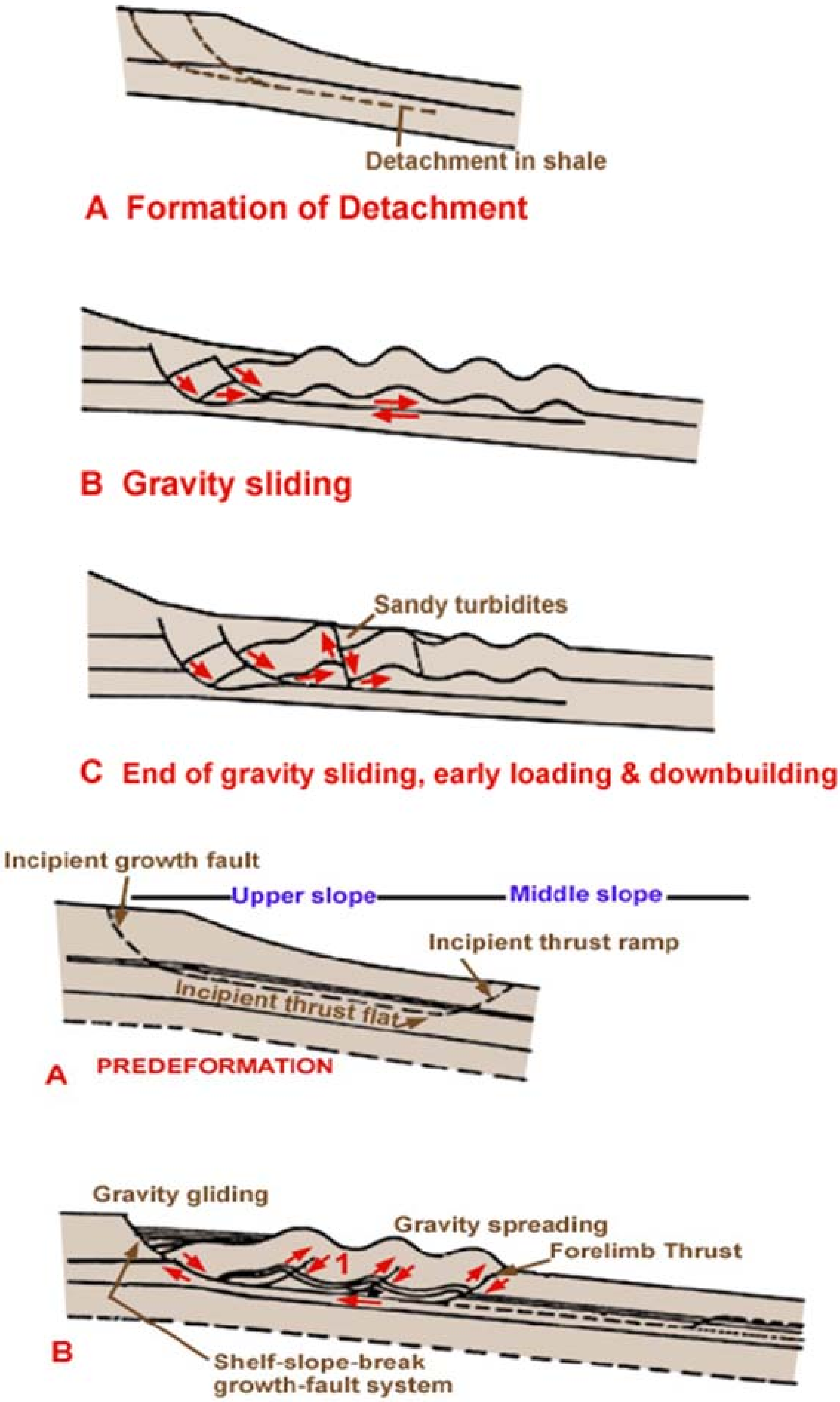

Figure 1 - Stages of gravity tectonics/ gliding tectonics/gravity sliding, including a formation of detachment/decollement surfaces and formation of thin-skinned fold and thrust belts by gravity sliding. (http://oilandgastraining.net).

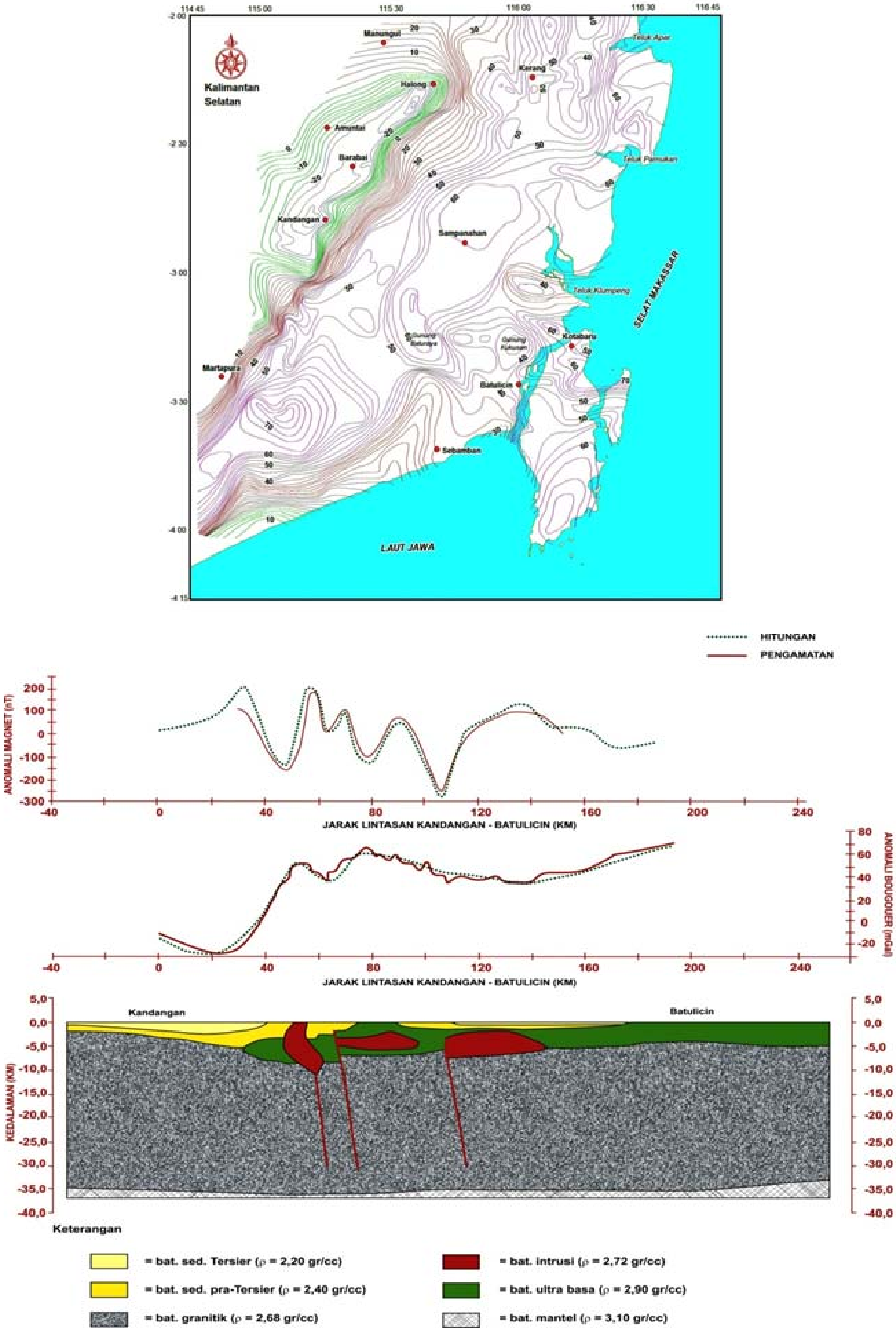

Figure 2 - Upper. Bouguer anomaly map of the Meratus Mountains, Southeast Kalimantan (Satyana and Armandita, 2008). Lower. Gravity modeling implying continental collision. Note that the Meratus ultrabasic rocks are thin and overlying granitic continent (Satyana and Armandita, 2008).

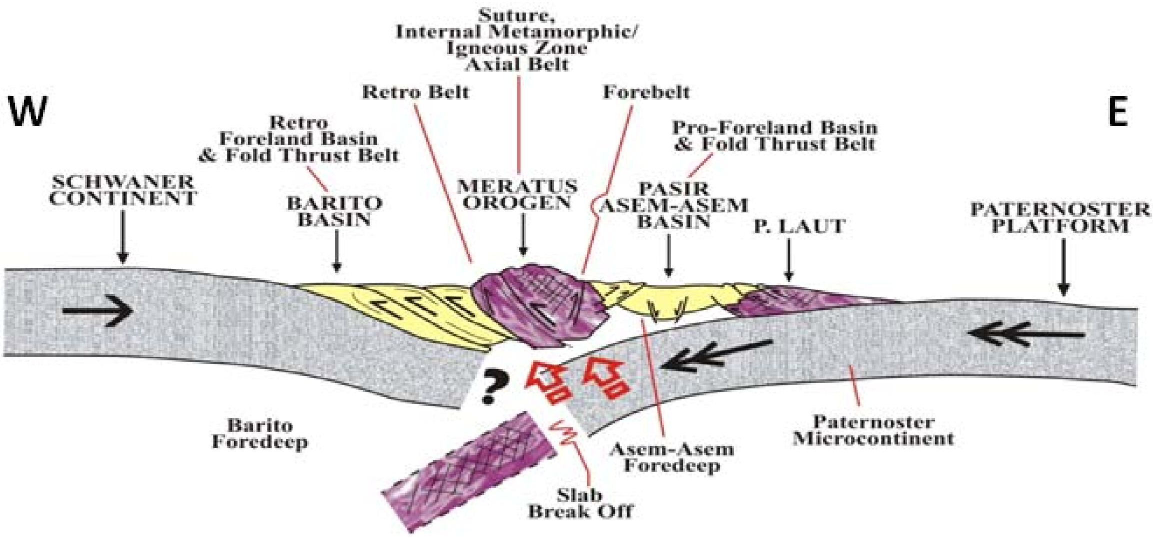

Figure 3 - Section across Schwaner continent, Barito Basin, Meratus Mountains and Pasir-Asem-Asem Basin. The Meratus Orogen is rootless overlying the subducted Paternoster continent. As the continent broke off its slab front, exhumation occurred and has uplifted the Meratus orogen (Satyana and Armandita, 2008).

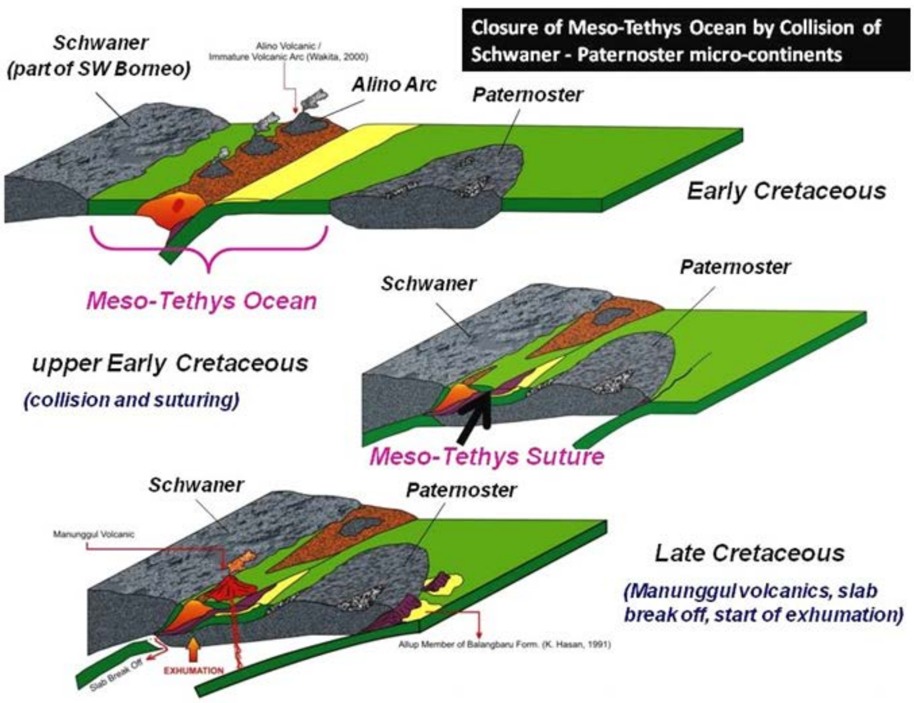

Figure 4 - Stages of tectonics related to emplacement of Meratus ophiolites, including: subduction of Meso-Tethys Ocean, closure of the Meso-Tethys by collision of Paternoster to Schwaner terranes, exhumation of the Paternoster terrane and uplift of the Meratus Mountains (Satyana, 2010).

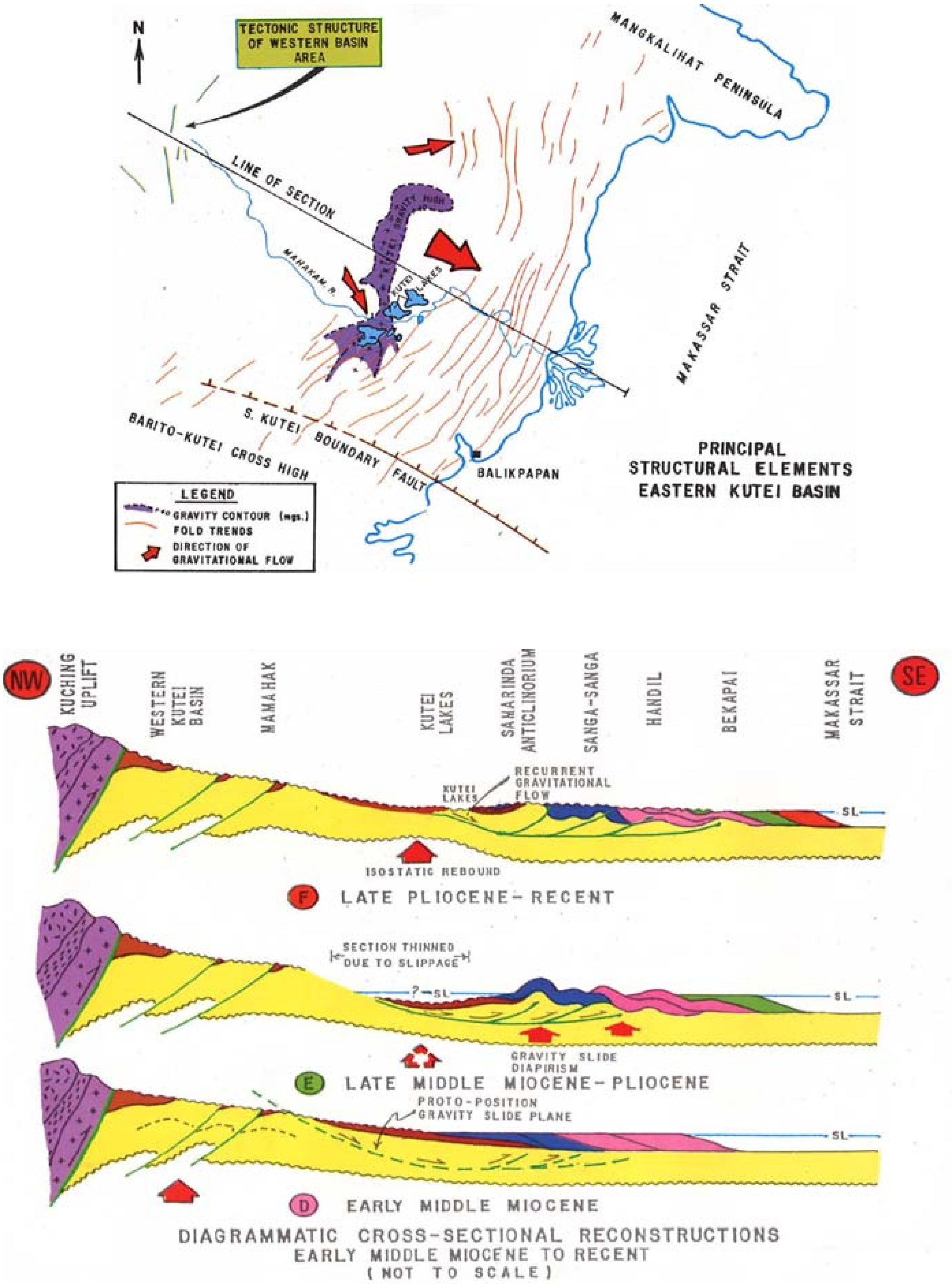

Figure 5 - Upper Kutei Basin, East Kalimantan showing Samarinda Anticlinorium as principal structural elements in the eastern Kutei Basin (Ott, 1987). Lower. Schematic sections (location of section see map of Kutei Basin) showing the evolution of Samarinda Anticlinorium formation by gravity tectonics (Ott, 1987).

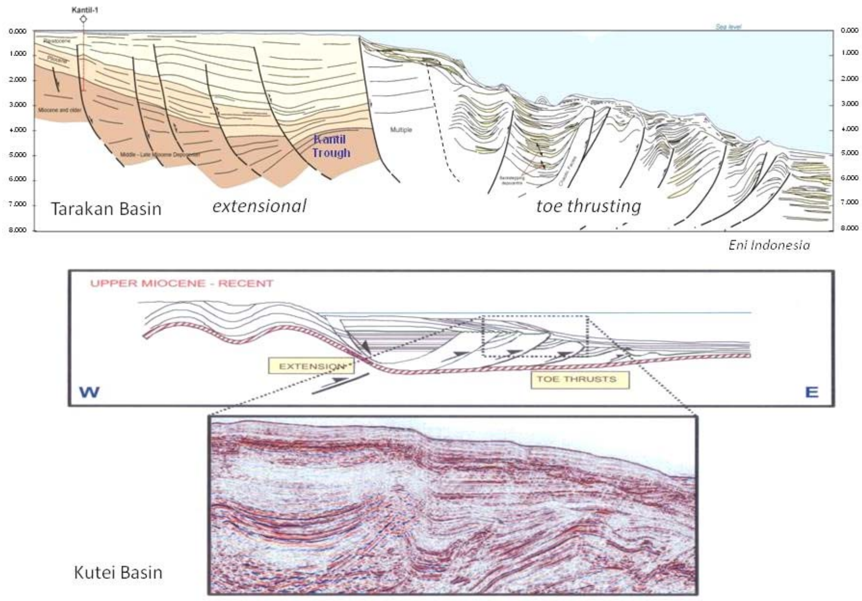

Figure 6 - Gravity tectonics in offshore Tarakan and Kutei Basins, represented by Samarinda Anticlinorium and toe thrusting in Kutei Basin and growth faults as well as toe thrusting in offshore Tarakan Basin.

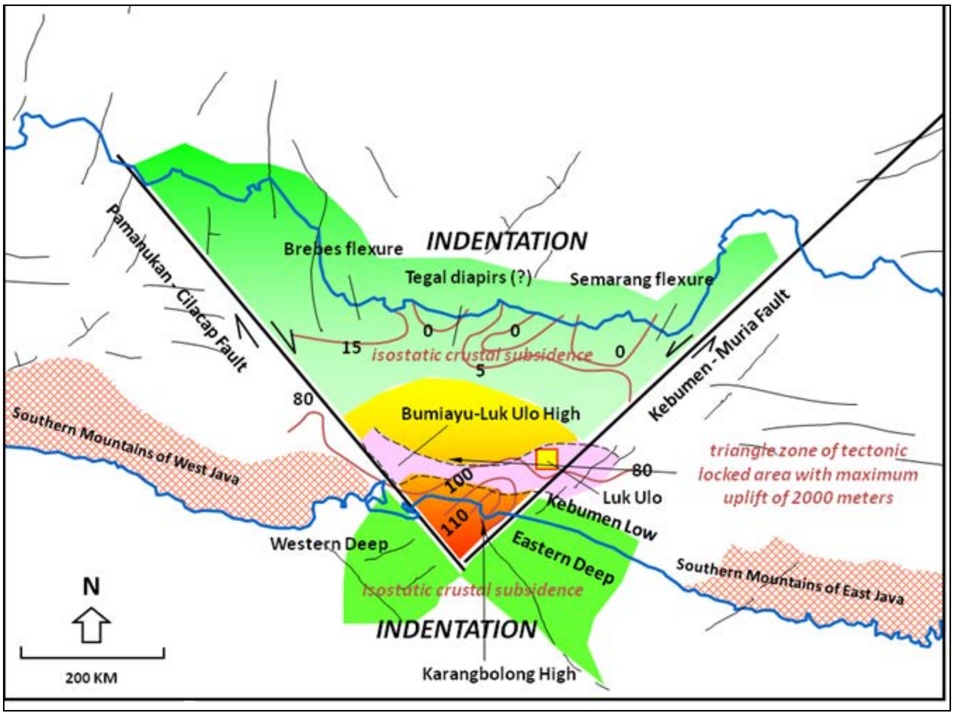

Figure 7 - Indentation of Central Java by couple major strike-slip faults (Muria-Kebumen and Pamanukan-Cilacap Fault Zone). Southward drag within the fault block had uplifted southern Central Java (South Serayu Range) with the maximum uplift at the apex of the triangle as shown by Bouguer gravity high of +110 mGal. Northern Central Java (North Serayu) was isostatically subsided as shown by minimum Bouguer anomaly (until -5 mGal). This differential gravity had induced gliding tectonic from the south to the north (Satyana and Purwaningsih, 2002).

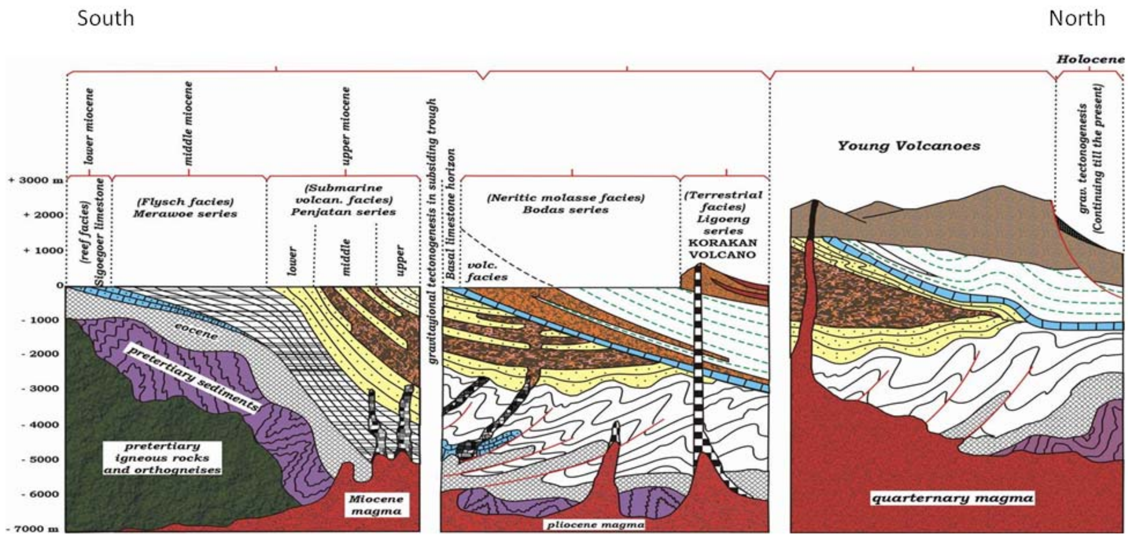

Figure 8 - Schematic section across Central Java showing uplift of the South Serayu Range (south) and subsidence of North Serayu (north). Thick sediments were deposited into North Serayu and deformed by gravity tectonics tectonics as thin-skinned fold and thrust belts. The structures were then covered by thick volcanic-clastic deposits of Late Neogene into Pleistocene (van Bemmelen, 1949; Satyana and Armandita, 2004).