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Aspects of the structural histories of the tertiary sedimentary basins of East, Central and West Kalimantan and their margins

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The Cainozoic structural history of west, central and east Kalimantan may have begun with formation of melange in the early Eocene, and a surrounding disturbed zone in which part of a mainly Cretaceous flysch trough and associated shelf deposits have been thrown into a confusion of dips and strikes. Uplift of the disturbed zone and adjacent southern outer shelf deposits of the trough was followed by sub-aerial extrusion of mid Eocene volcanics. Between early late Eocene and mid Oligocene times bursts of compression produced structural highs and a shifting pattern ofcomplementary flanking basin depocentres. Uplifted flysch-trough sediments became a northern provenance for the basins (and perhaps a southern provenance for more flysch deposition to the north) and may have been folded further in the process. In the south the Schwaner Batholith provided a bulwark to compression, although its northern margin was upwarped as a consequence. In the east deposits prograded southeastwards away from the northern provenance. As compression tailed off and basin downwarping and northern flysch provenance uplift consequently diminished, a peneplane may have begun to form on the flysch. This would have gradually decreased the amount of detritus available for filling the gradually shallowing basins. In the west downwarping and deposition probably ceased in the early Oligocene as a result of regional uplift. In the east renewed compression in the mid Oligocene caused uplift and folding, and interrupted prograding deposition. Penecontemporaneous intrusion of acid to intermediate stocks, plugs, dykes and sills occurred in both east and west. Prograding deposition recommenced in the east in the late Oligocene and has continued intermittently since; the northwestern provenance for the deposits has been uplifted from time to time, on occasion in conjunction with volcanism. The flysch fold belt that is central to the island of Borneo, on the evidence from the region analysed, was bent to its present shape in mid to late Tertiary times.

Introduction

This paper is based on Kalimantan Data Records completed by the Indonesia-Australia Geological Mapping Project (IAGMP), to some of which the author contributed, and the Geological map of the West, Central and East Kalimantan area (Pieters & Supriatna, 1990), which the author edited.

The IAGMP Data Records, which are Open File Reports of Indonesia's Geological Research and Development Centre (GRDC), accompany IAGMP's 1:250 000 scale preliminary geological maps. The Geological Map, at a scale of 1:1 000 000, differs in minor respects from the records; some of the differences are noted below. The area covered by the IAGMP map and records and this paper is shown on Figure 1. The generalised geology of the area is shown on Figure 2, and its structural domains in Figure 3. The paper concerns structural effects in the crust of the area, but deliberately essays few conclusions about tectonic causes.

The patterns of dips and strikes on the 1:250 000 scale IAGMP preliminary geological maps in the Data Records reflect difficult field conditions. Limited additional information can be got about deformed basin basement from imagery, which however supplies a great deal about basin bedding trends and dips, folding, and faulting. Basin dips are mostly shallow, occasionally horizontal or moderately steep, folds are open, and faults mainly normal.

General geology

Data Record and 1:1 000 000 map information show that the domains of the region are strung out in an arc that trends northwest in the west, west-northwest in the centre, and northeast in the east of the region (Figs 2, 3).

Cretaceous sediments occur throughout. Tightly folded and mildly metamorphosed probable deep-water flysch in the north is separated from less deformed and partly older outer shelf deposits in the south by a disturbed zone in which both occur in a confusion of strikes and dips, together with much undated melange. Some of the flysch deposits can be as young as early or mid Eocene. A few early and late Cretaceous granitoids intrude these rocks.

In the centre and east of the area there are sparse and scattered middle Eocene sub-aerial acid volcanics, and late Eocene to mid Oligocene sedimentary basins containing shallow marine and continental deposits, all overlying outer shelf and disturbed zone rocks. The volcanics and sedimentary basin sequences are only mildly deformed overall.

In mid to late Tertiary times most of the area was intruded by stocks, plugs, dykes and sills of granodiorite, diorite, dacite and andesite; in the northeast and northwest this igneous suite is overlapped in age and space by late Tertiary to Quaternary basaltic volcanics and much-dissected volcanoes.

A small cluster of Permo-Triassic inliers indicates a pre-flysch history of critical tectonic importance, but the structural implications of the occurrence of these basement(?) rocks as inliers are unclear.

Structural histories of the basins and their margins

The present-day basins that contain Late Eocene to Holocene deposits are structural basins that began as a shallow marine feature in the late Eocene. Later, they were separated by structural highs now represented by basement inliers.

Basins and their inliers are discussed below as elements of one domain. Adjoining domains consist mainly of pre-Eocene rocks with less clear Cainozoic histories, and these are accordingly given shorter shrift.

Domain of basins and inliers

The domain consists of the westerly trending Semitau High, the Juloi and Kembayan Inliers, the Busang-Murung Crescent, the Melawi, Ketungau, Mandai, West and Southeast Kutai Basins, and the Putussibau Depression. The Juloi Inlier is a term proposed here for a complex upwarp exposing Cretaceous outer shelf deposits between the Busang-Murung Crescent and the Schwaner Massif, and separating the Melawi and West Kutai Basins (see Figs 2 & 3).

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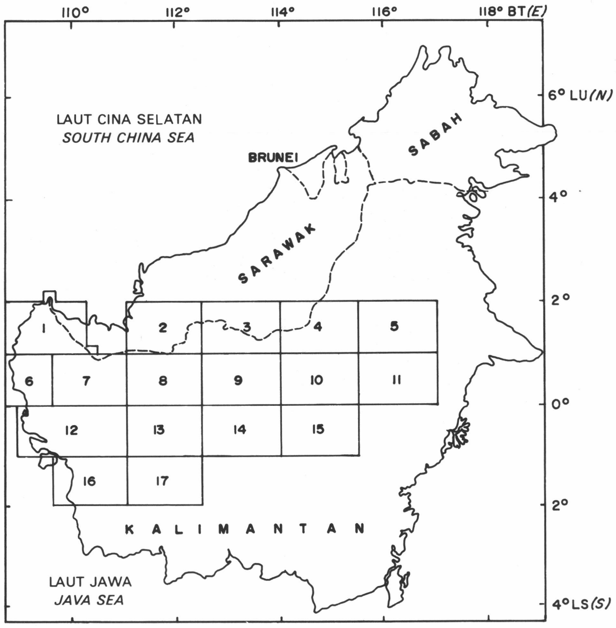
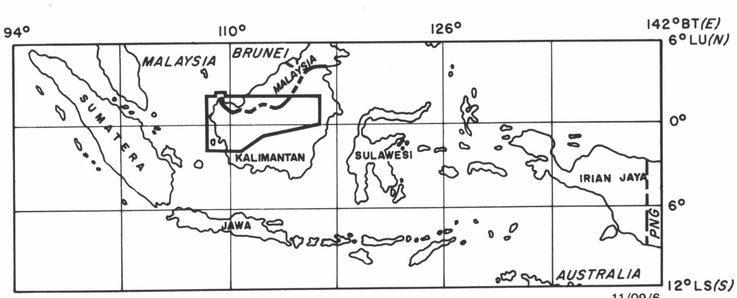


INDEKS LEMBAR PETA GEOLOGI SEKALA 1:250 000 YANG TERCAKUP DALAM PETA INI
INDEX OF GEOLOGICAL QUADRANGLES AT 1:250 000 SCALE COVERED BY MAP AREA

	Nama lembar *Quadrangles*	Penyusun *Authors*
1	Sambas & Siluas	E. Rusmana & P.E. Pieters (1989)
2	Nanga Obat	Y. Noya, P.E. Pieters & Surono (1989)
3	Peg. Kapuas	Surono, P.E. Pieters & Y. Noya (1989)
4	Long Nawan	Baharuddin, P.E. Pieters, D. Sudana & S.A. Mangga (1989)
5	Muara Wahau	S. Supriatna (in prep.)
6	Singkawang	N. Suwarna & R.P. Langford (1989)
7	Sanggau	S. Supriatna, U. Margono, P.E. Pieters, Sutrisno & R.P. Langford (1989)
8	Sintang	P.R. Williams & R. Heryanto (1985)
9	Putussibau	P.E. Pieters, Surono & Y. Noya (1988)
10	Long Pahangai	H.Z. Abidin, P.E. Pieters & D. Sudana (1989)
11	Muara Ancalung	S. Atmawinata & N. Ratman (in prep.)
12	Nangataman & Pontianak	P. Sanyoto & P.E. Pieters (1987)
13	Nangapinoh	Amiruddin & D.S. Trail (1987)
14	Tumbanghiram	T. Soejitno & T. Santosa (1986)
15	Muaratewe	A. Sudradjat & O. Koswanda (1977)
16	Ketapang	E. Rustandi & F. de Keyser (1988)
17	Tumbangmanjul	T. Soejitno & T. Santosa (1986)



LOKASI PETA/*MAP LOCATION*

Figure 1. Location of quadrangles and 1:1 000 000 scale geological map (after diagrams on 1:1 000 000 map).

The Melawi Basin is buttressed to its south by the Schwaner Batholith domain; to its north the basin has a folded relationship (the Silat Fold Belt of Williams & Heryanto, 1986) with the southern part of the Semitau High, perhaps the result of basin margin crumpling by High uplift.

The Ketungau Basin is downfaulted along most of its southern margin, essentially against melange of the disturbed zone in the northern part of the High. In the northeast this basin is faulted against early Eocene Lubok Antu Melange (Tan 1979, 1982), here treated as part of the disturbed zone, and to the north is flanked by alluvia (in Sarawak).

The Mandai Basin is probably an eastern continuation of the Ketungau Basin, being separated from it by the Quaternary Putussibau Depression. The Mandai is complexly faulted in the south against the Semitau High, but at the same time appears to be joined to the Melawi Basin. To the north and east, Mandai Basin strata rest unconformably on disturbed zone rocks of the Fold Belt domain.

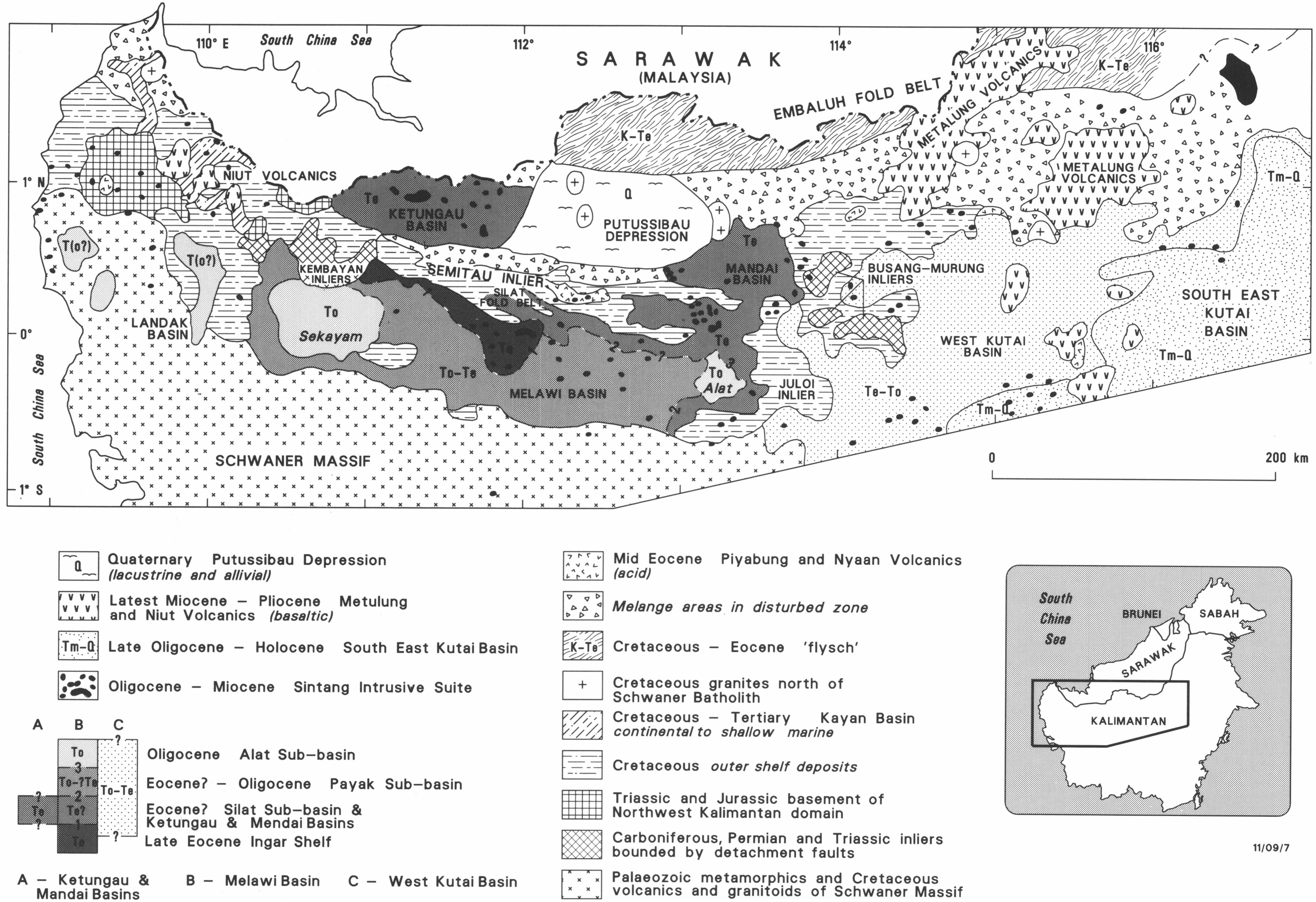


Figure 2. Generalised geology, IAGMP area, Kalimantan.

To the east of the High and its flanking basins, more particularly to the east of the Juloi High and the Busang-Murung Crescent, the West and South East Kutai Basins would seem to contain deposits derived from the Fold Belt domain; from their inception the deposits have been prograding seawards.

The Semitau High is given the appearance by its bounding structures and cover dips of a fault block tilted to the north. Outcrops of the High — which make up the Semitau Inlier — consist of large northwestern areas of disturbed zone melange faulted against southeastern areas of a deeper marine facies of the outer shelf Cretaceous sediments. Both formations are overlain in the east by radiometrically dated middle Eocene felsic to intermediate Piyabung Volcanics. To the north of the volcanics a few small bodies of fault-bounded Permo-Triassic rocks are surrounded by melange, of which they may be part.

The Semitau High terminates in the west against, or with, the Kembayan Inlier (Supriatna & others, 1989), a group of Carboniferous to Triassic inliers of similar area to those of the High's eastern terminator, the Busang-Murung Crescent. Carboniferous-Permian rocks of the Kembayan Inlier are cut by thrust faults. The Permo-Triassic components of both the Kembayan Inlier and the Busang-Murung Crescent are shown on the 1:1 000 000 map bounded by detachment faults (not mentioned in the Sanggau Data Record). Both types of fault are thought to be of late Tertiary age. There is a possibility that both the Kembayan and the Busang-Murung inliers are huge blocks within melange (D. Trail, AGSO, pers. comm. 1988).

The Sintang Intrusives Suite, superimposed in late Oligocene and Miocene times on all the structural basins and inliers, is referred to here as an igneous domain. The strings and groups of plugs and stocks have a rough alignment with the structural grain of the area, but give a stronger impression of structural control in the east.

Late Tertiary-Quaternary basalts of the Metulang Volcanics domain overlie the West and South East Kutai Basins, seemingly concordant with their structural trends; similar Niut Volcanics occur in the Northwest Kalimantan domain.

The Quaternary Putussibau Depression that separates the Mandai and Ketungau Basins contains lacustrine and alluvial deposits.

The east-southeasterly trends that dominate the Semitau High and Melawi Basins are said by Amiruddin & Trail (1989) to be controlled by pre-Cretaceous structure. Williams & Heryanto (1986) note the east-northeast faults that cut across this trend, affecting the youngest rocks of the Melawi Basin. Northeast trends dominate the West Kutai Basin.

Late Eocene to Early Oligocene basin formation

The deep sediment-filled depressions separated by the Semitau High are the present day structural Melawi, Mandai and Ketungau Basins. The most complex of them is the Melawi, with which correlation of the other two is a critical and fundamental matter. Published stratigraphic correlations depend on a few sparse fossil occurrences and perforce on lithological similarity — the Data Records and the 1:1 000 000 map Explanatory Notes are a good starting point for the details. This paper attempts to show *inter alia* that structural history can provide additional help with correlating, and that its constraints should be applied before resorting to lithological correlations. For this reason the structural history of the Semitau High is considered below in conjunction with that of the Melawi Basin before the other basins are examined.

Partial or comprehensive correlation proposals covering the Ketungau and Mandai Basins and the Melawi Basin succession include those of Williams & Heryanto (1986), Pieters & others (1987), Williams & others (1988), Pieters & Supriatna (1989) and Tate (1991). The unconformities of the Melawi Basin and the evolution of the Semitau High play minor parts, if any, in these proposals, and none of their correlations are wholly espoused here.

Unconformities and sub-basins

Unconformities can be regarded as surfaces bounding and in part defining sedimentary basins. Thus the mid Eocene to possibly early Oligocene surfaces south of the Semitau High could be said to separate and/or lead to the recognition of four basins. It is useful to see the four as sub-basins constituting the present day structural feature called the Melawi Basin; for example, the southwards migration of its depocentres can helpfully be related to sub-basin evolution. The present day structural Ketungau and Mandai Basins have no known internal unconformities, and so lack sub-basins of this kind. This paper's investigation of the histories of basin and sub-basin evolution and relationships leans towards this point of view.

This unconformity dominated concept has been touched on by Williams & Heryanto (1986) in defining their version of the Melawi Basin, which was the sequence between its second and third unconformities, their Melawi Group, a name retained by later workers (although revised by Pieters & Supriatna, 1989, 1990). The concept has been parallelled already in this paper in distinguishing between the West and South East Kutai Basins.

One might reasonably expect that the sequences between the unconformities should be regionally internally conformable and structurally homogeneous and that, for a best understanding of geological history, formal stratigraphic units will not transgress or include such basin-bounding and basin-defining surfaces. The 'Melawi Basin' of Williams & Heryanto (1986), and its sequence, conform to these criteria, but this is not always the case.

For example, in Pieters & Supriatna (1989), the formal stratigraphy of the present day Melawi structural Basin is completely covered by a basal Suwang Group (a term which they also apply to all the strata of the Mandai Basin) and an overlying Melawi Group. Both Groups contain an unconformity, neither of which is represented on their map. The structural and tectonic implications of the three unconformities and the four structurally contrasting sequences that they separate are thus somewhat obscured.

Melawi Basin Sub-basins

A history of the composite structural depression that is now called the Melawi Basin, which is confined between the Semitau High and the Schwaner Batholith domain, is presented below. Formation thickness figures are from Pieters & Supriatna (1989).

Ingar Shelf. The oldest of the Melawi's sub-basins is now represented by 1800—3000 m or more of fossiliferous upper Eocene shelf deposits (see Table 1), the Ingar Formation and its equivalent in the eastern part of the basin, the Mentemoi Formation (Pieters & others, 1987). Williams & Heryanto (1986) record boudinage, fracturing and cleavage in the Ingar Formation.

In Nangapinoh and Putussibau quadrangles Amiruddin & Trail (1989) and Surono & Noya (1989) have named an underlying unit the 'Haloq Sandstone' (see below). Examination of the IAGMP 1:250 000 scale preliminary maps suggests that this underlying unfossiliferous unit may not correlate with the West Kutai Basin

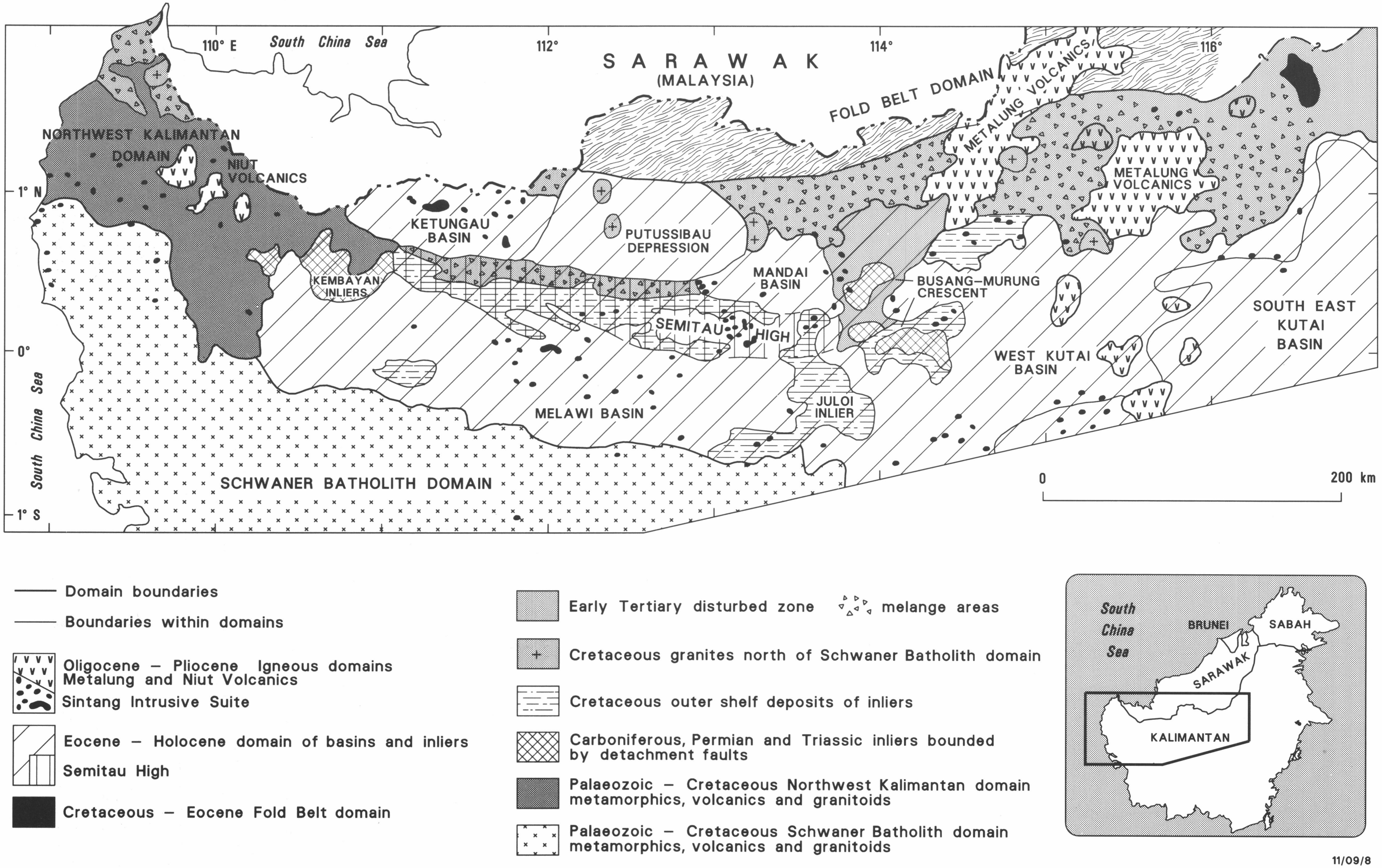


Figure 3. Structural domains, IAGMP area, Kalimantan.

fossiliferous upper Eocene Kiam Haloq Sandstone of Pieters & Supriatna (1989), and that its name could be misleading, at least in the context of a structural history analysis.

Further, Pieters & others (1987) mention a Mangan Sandstone underlying the Ingar in the Melawi Basin, and Pieters & Supriatna (1989) seem to place this at or near the base of their Suwang Group.

These units are truncated by an unconformity, and thus constitute a 'sub-basin', which is referred to in this paper as the Ingar Shelf (a possible misnomer — see later).

Silat Sub-basin. The Ingar Shelf was modified by the combination of rising of the Semitau High and downwarping to its south. In this new sub-basin at least 600 m of Dangkan Sandstone and 2000 m of Silat Shale accumulated conformably. Further uplift of the Semitau High probably caused formation of the Silat Fold Belt and ended deposition of the sequence. Williams & Heryanto (1986) noted slickensiding, shearing and large scale chevron folds in the Silat Shale. An unconformity later truncated the folded rocks and capped this second sub-basin. There is no evidence permitting direct dating of these events.

The Dangkan Sandstone and Silat Shale were combined as the Suwang Group by Williams & Heryanto (1986). It would seem appropriate, then, to speak of a Suwang Sub-basin, and Tate (1991, Table 1) shows this name on his correlation chart (albeit of Late Cretaceous age and related to a Melawi Basin of uncertain definition). However, Pieters & Supriatna (1989) included the Ingar Formation and Mangan Sandstone in the Suwang Group and applied the revised term to cover not only a Melawi Basin succession but also the complete Mandai Basin sequence. This renders erection of the name Suwang Sub-basin inadvisable, and in this paper the term Silat Sub-basin will be used.

Payak Sub-basin. The unconformity capping the Silat Sub-basin became the base of a third sub-basin as a result of downwarping. In it the Melawi Group of Williams & Heryanto (1986) was deposited. Up to 1200 m of Payak Formation and 800 m of Tebidah Formation are preserved, suggesting that compression was waning at this stage in the history of the Melawi Basin. It is uncertain whether an unconformity truncates the Tebidah — see Alat Sub-basin discussion below.

The Tebidah Formation may contain Early Oligocene nannoplankton (Dr G. Robinson, pers. comm., *in* Amiruddin & Trail, 1989).

Again, current usage of the term Melawi Basin, as well as the revision of the Melawi Group by Pieters & Supriatna (1989), precludes application of 'Melawi' as a name for the sub-basin, which is therefore referred to here as the Payak Sub-basin.

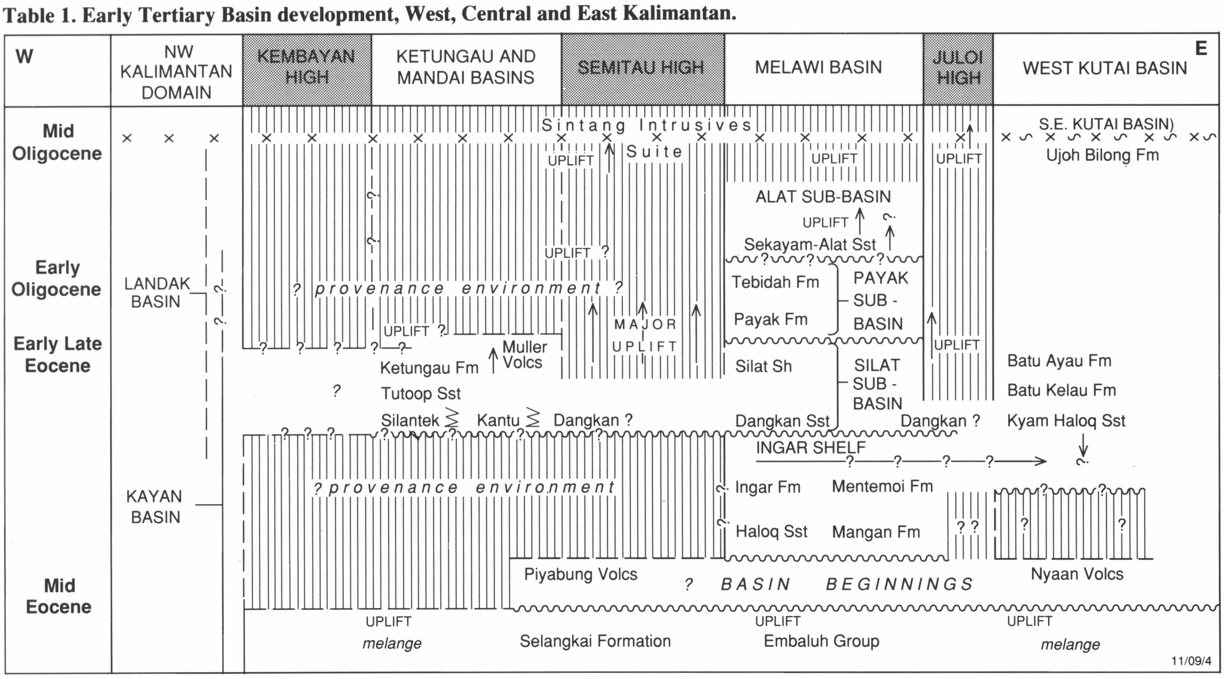
The 1:1 000 000 map shows an inlier of Jurassic—Cretaceous Kempari Sandstone (Pieters & Supriatna, 1990) in the south of the sub-basin; the inlier separates it into two lobes. It is not possible to choose between the alternatives of eastern and western depocentres and post-depositional uplift, although the latter seems unlikely.

Ingar Shelf and Silat Sub-basin units do not crop out between the Payak Sub-basin and the Schwaner Batholith domain, suggesting that the Payak depocentre migrated southwards. This situation is reflected on the 1:1 000 000 map, on which the Melawi Group is shown overlapping both the Suwang Group and the Schwaner Batholith domain.

In finer detail, within the Payak Sub-basin the Payak Formation crops out in the north and the Tebidah in the south. The Tebidah transgresses over the Schwaner, and presumably also over the Payak and older formations (Amiruddin & Trail, 1989). Overall, the maximum thickness of the sub-basin is in the north. From the point of view of structural history, this configuration may have resulted in part from the progressive weakening of a southwards migrating downwarp between the rising Silat Fold Belt (and Semitau High) in the north and the Schwaner Massif in the south during an episode of southwards compression.

Alat Sub-basin. The fourth and last of the preserved sub-basins of the Melawi structural Basin is here referred to as the Alat Sub-basin, as it contains the undated Alat Sandstone. This formation

Table 1. Early Tertiary Basin development, West, Central and East Kalimantan.



occurs only in the east of the Melawi Basin. It cannot be differentiated from the Melawi Group on the 1:1 000 000 map.

The Alat Sandstone is considered to lie unconformably on the Dangkan Sandstone and on Semitau High rocks by Williams & Heryanto (1986), and is up to 250 m thick. Amiruddin & Trail (1989) did not observe an unconformity between the Alat and Tebidah in Nangapinoh quadrangle, but suspected the presence of one because of the abrupt change to coarser Alat lithology.

In the west of the Melawi Basin, west of the Kempari Sandstone inlier, the undated Sekayam Sandstone is 500 m thick and is lithologically similar to the Alat Sandstone. The Sanggau 1: 250 000 preliminary geological map (Supriatna & others, 1989) shows open shallow folding of the Sekayam.

The Sekayam Sandstone also overlies the Tebidah Formation, unconformably according to Williams & Heryanto (1986), who exclude it from their Melawi Group, and to Supriatna & others (1989), but conformably according to Pieters & others (1987). It cannot be differentiated from the Melawi Group on the 1: 1 000 000 map. The two formations are named on Figure 2.

The coarse lithology of the Sekayam Sandstone is said by Supriatna & others (1989) to indicate 'regional uplift', and that of the Alat by Amiruddin & Trail (1989) to suggest 'topographic rejuvenation'. The change to coarse lithologies, and the claims of local unconformities, suggest that recognition of an Alat Sub-basin is possible on stratotectonic grounds. Further, although there is uncertainty about widespread unconformity below the two sandstone units, it seems useful to separate them from preceding Melawi Basin history by a conceptual device such as sub-basin, and to exclude them from any past or future combination with older units in formal stratigraphic Groups.

The Alat and Sekayam Sandstones are the youngest strata preserved in the Melawi Basin succession. Still younger units may have accumulated, but the uplift event that the Alat and Sekayam seem to reflect could well have ended sedimentation in the Basin and initiated its erosion. The thinness and limited distribution of the units may indicate that uplift of the sub-basin began during their deposition, possibly Oligocene—Miocene uplift associated with emplacement of the Sintang Intrusives Suite.

The Alat episode appears to herald the end of compressive tectonics in the west of the region.

Generation of the Semitau High

On the 1:1 000 000 map the Semitau High has the appearance of a horst. It also shows up as a high on gravity maps in later Data Records. The youngest rocks affected by the faults that bound it are shown as upper Eocene on the map. However, unconformities and folding in the Melawi Basin south of the High permit closer analysis. Their implications for Semitau High generation further illuminate the history of the Melawi Basin and also provide information relevant to the formation of the Mandi and Ketungau Basins.

Beginnings. The truncation of the upper Eocene Ingar Formation is the first evidence that may point to the beginnings of the Semitau High. No rocks of the Ingar or underlying units appear to have been derived from the melange of the High (or any other area) or its middle Eocene Pyabung Volcanics, and the sedimentary sequence would appear to be a shelf deposit that could have overlain melange and volcanics before uplift of the High.

However, the Kiam Haloq Sandstone of the West Kutai Basin (Pieters & Supriatna,1989) contains tuff clasts and, as already discussed, may have an equivalent below the Ingar in the Melawi Basin. The West Kutai unit may have derived its volcaniclastics from the nearby mid Eocene Nyaan Volcanics as a result of the uplift associated with the unconformity capping the Ingar. After truncation of the Ingar, a new downwarp received the deposits of the Dangkan Sandstone and Silat Shale. The Dangkan Sandstone appears to have been partly derived from nearby highlands with melange exposures (Williams & Heryanto, 1986). Faulting of the Ingar against the outer shelf Cretaceous of the High suggests that these highlands were in place before the Dangkan was deposited as this faulting does not affect the Dangkan in the Sintang quadrangle, although the possibility of its presence farther east is raised later.

The highlands may have been either the southern margin of an early version of the Fold Belt domain, or part of a Semitau Inlier of the times, an expression of the horst High which had been shaped (possibly as a stillstand feature) by the fault-margined downwarps of the Silat Sub-basin to its south and the Mandai and Ketungau Basins to its north.

The Dangkan Sandstone and Silat Shale are unfossiliferous. They might share a lower Oligocene age with the Tebidah Formation of the overlying Payak Sub-basin, which would mean that the uplift of the Semitau High that truncated the Ingar Formation was an Oligocene event. Much depends on preferred correlations for the upper Eocene Muller Volcanics of the Mandai Basin to the north of the High (see below).

Relation to Silat Sub-basin termination. The second unconformity in the Melawi Basin truncates one of the two long, simple, asymmetrical, easterly plunging synclines, each with a core of Silat Shale, that make up part of the present boundary between the High and the Basin. The synclines, unnamed on the 1:1 000 000 map, constitute the Silat Fold Belt (Fig. 2) of Williams & Heryanto (1986), who suggest that folding was a response of the sedimentary deposits to faulting below them. Increasing sand content towards the top of the Silat Shale may indicate uplift of the High; the later synclinal folding may mark continuation of this uplift.

Williams & others (1984) see the Fold Belt as one of the products of approximately 20 km of southerly thrusting. The high angle reverse faults that bound the Semitau High support the idea. If the faults between the High and the Ketungau and Mandai Basins were active at the time, then at least some of the downwarping and deposition in these basins could correlate with Silat Fold Belt rocks and their histories.

The unconformity is likely to have begun forming during the uplift and folding episode. Although the 1:1 000 000 map does not show unconformities with a specific symbol, the unconformity above the syncline is identical to the geological boundary on the map that separates the Groups subsuming its Eocene and proposed Oligocene sequences (cf Williams & Heryanto, 1986; Pieters & Supriatna, 1989). This boundary is not an unconformity in the West Kutai Basin, where it represents a conformable relationship between the Groups of that basin.

This is the unconformity at the base of the Payak sub-Basin, in which the Tebidah Formation is said to contain Oligocene fossils. But Williams & Heryanto (1986) report that the Payak Formation contains much volcanic debris. A possible source for this is the upper Eocene Muller Volcanics in the Mandai Basin, to the north on the other side of the High.

There may have been, therefore, a more or less continuous series of events beginning with the uplift reflected in the sands of the Silat Shale, continuing with the folding of the Silat and Dangkan and the truncation of the folds, and finishing with penecontemporaneous basin sinking and volcanism. The events, apparently in the late Eocene, would have constituted the most vigorous episode in the generation of the High.

Later history. Following development of the second unconformity, all subsequent deposits in the Melawi Basin including the youngest of them, the Alat Sandstone, appear to have been derived in part from a melange provenance (Williams & Heryanto, 1986). This was presumably to the north of the basin, and was most likely the melange of the Semitau High. It suggests the persistence of a northern structural high, in part at least as an early version of the Semitau Inlier shedding into the basin.

Uplift (in the Oligocene?) evidenced by deposition of the Alat and Sekayam Sandstones in the Alat Sub-basin may also have affected the Ketungau and Mandai Basin sequences, which could have provided some of the detritus deposited as the Alat on the High and as the sub-basin units. The uplift may have been associated with, and ceased after, emplacement of the Oligocene—Miocene Sintang Intrusive Suite.

The Semitau High is not just a palaeo-structure, although its existence as a modern high may be a result of late Cainozoic renewal. Before this, a considerable amount of the top of the High and its cover must have been removed from initial uplift times onwards until Sintang Intrusive Suite bodies were emplaced in what was left, and a good deal more of the High host rock must have been removed since. After the uplift causing the mid Oligocene unconformity which truncated the West Kutai Basin, further uplift may have been necessary to permit the unroofing of the intrusives. The modern outcrop component of the High, the Semitau Inlier, and the remnants of basin cover over its eastern end probably reflect its modification by such recent movements, particularly regional uplifts that changed drainage patterns or rejuvenated them, for example around the Busang-Murung Crescent.

It is difficult to envision the Busang-Murung and Kembayan Inlier rocks as solely the structural result of uplift of the High. Both masses could have preceded formation of the Semitau High as part of the melange event that affected the Cretaceous to early Eocene flysch trough and shelf, after which the masses could have been uplifted further as integral parts of the High.

The uplift episodes responsible for production of the Juloi Inlier could perhaps be linked with uplifts of the Busang-Murung body. The first of these, given the differences between the Melawi Basin and West Kutai Basin successions, probably occurred at the time of first uplift of the High. But the northeasterly trend component of the Juloi and Busang-Murung may indicate that their structural culmination took place after that of the Semitau High. Detachment faulting is thought by Pieters & Supriatna (1989) to have taken place in late Oligocene—Miocene times.

The Sintang Intrusive Suite, although showing much concordance with local structural trends, is quite discordant with them in a number of places, e.g. the line of plugs crossing the Semitau High west of the Busang-Murung Crescent. Overall the Suite gives the appearance of stitching together the basins and inliers.

Summary of Melawi Basin and Semitau High structural history

Deposition of upper Eocene Ingar Shelf strata was over a downwarped land surface of folded Cretaceous to lower Eocene rocks and perhaps sparse occurrences of mid Eocene sub-aerial acid volcanics. Ingar deposition was terminated by late Eocene uplift and downwarping, which resulted in the formation of an erosional unconformity truncating the Shelf succession.

Silat Sub-basin sedimentation followed, associated with uplift of a northern provenance taken to be the progenitor of the Semitau High. Continuation of this uplift caused deformation of the northern margin of the sub-basin, faulting it and beginning the formation of the Silat Fold Belt. As the Fold Belt evolved, penecontemporaneous erosion truncated it and the rest of the sub-basin, suggesting yet more uplift of the High, and the Payak Sub-basin began its southwards migration. Older sub-basin deposits have a volcanic component possibly derived from late Eocene volcanism just north of the present Semitau High and marking the end of its most vigorous episode of generation. Younger sub-basin deposits were probably derived in part from the High and may be of Oligocene age. Uplift of the High, taken together with formation of the Silat Fold Belt and southerly migration of the Payak Sub-basin, suggests an episode of north to south compression beginning in the late Eocene and dying out in the Oligocene.

An unconformity may have truncated the Payak Sub-basin before deposition of Alat Sub-basin strata, the composition of which suggests provenance uplift. This may have been a widespread phenomenon which affected not only the Semitau High — including production of the detachment faulting at either end of it — but also basin deposits north of it, and which eventually terminated deposition in the Melawi Basin. The uplift was probably associated with emplacement of stabilising Sintang Intrusive Suite bodies in late Oligocene and Miocene times. Further regional uplift led to the unroofing of the intrusives.

Melawi, Mandai and Ketungau Basins

Relationships. Correlating the Melawi, Mandai and Ketungau Basins can most easily begin by examining the implications of the continuity of strata between the Melawi and Mandai Basins as shown on the 1:1 000 000 map and the Putussibau 1:250 000 preliminary geological map. The lowermost strata in the southern part of the Mandai Basin continues unconformably over the eastern end of the Semitau High into the Melawi Basin, where these strata conformably underlie beds that disappear below the ?unconformity flooring the Payak Sub-basin.

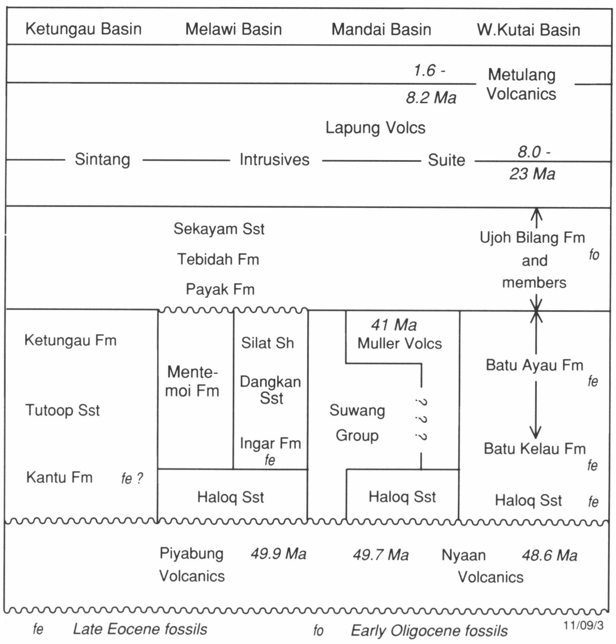
Melawi and Mandai Basins - 1:1 000 000 map correlations. On the 1:1 000 000 map the entire Mandai sequence is shown as Suwang Group, which extends into the Melawi Basin. In the terminology of this paper, the map correlates the Mandai Basin with the Ingar Shelf plus the Silat Sub-basin. Because there are no unconformities in the Mandai sequence and its timespan is uncertain, there have to be doubts about the correlation.

Inclusion of the Ingar Formation and Mangan Sandstone in the Suwang Group by Pieters & Supriatna (1989) raises the question of their possible equivalents in the Mandai. Unconformable overlap of Mandai strata on, as well as faulting of them against, the northern edge of the Semitau High is echoed by similar relationships between the Ingar and the southern edge of the High. The basal strata of the Ketungau Basin are also related to the High in this manner. However, this argument could be as easily applied to younger formations (see below).

Melawi and Mandai Basins - 1:250 000 preliminary map correlations. The Putussibau 1:250 000 preliminary map identifies the formation joining the two basins as the Haloq Sandstone (a name questioned above). Table 2, in part derived from this map, shows this 'Haloq' as the basal unit of yet another version of the Suwang Group, again covering the whole of the Mandai Basin sequence. Table 2 also shows the 'Haloq' beneath the Ingar Formation in the map area. Surono & Noya (1989) describe the two south of the Semitau High as part of a conformable sequence that continues upwards with the Dangkan Sandstone and Silat Shale.

This amounts to correlating the Mandai Basin with the Ingar Shelf plus Silat sub-Basin. If the Shelf and sub-basin prove conformable, then they would be invalid as defined, and should be replaced by a new sub-basin comprising their sum.

Table 2. Basin correlations, IAGMP Data Records (after Surono & Noya, 1989).



The 'basal sandstone' concept. These two map derivatives have their origins in the correlation paper by Pieters & others (1987). They assert that the Ketungau, Mandai and Melawi Basins share a common basal sandstone, and they lithologically equate the Ketungau and Mandai units that conformably overlie their shared basal sandstone with strata of this paper's Silat Sub-basin sequence. Their basal sandstone thus could be equated with the Dangkan strata of the Silat Sub-basin, or possibly with strata of theIngar Shelf. They do not consider the former alternative, which is explored further below.

Pieters & others (1987) assert that their basal sandstone unit is common to all four present day structural basins — Melawi, Mandai, Ketungau and West Kutai. Their unit contains all or parts of the Kiam Haloq Formation in the West Kutai Basin, the Mangan Sandstone in the Melawi Basin, the Behaba Sandstone in the Mandai Basin, and the Kantu and Silantek Formations in the Ketungau Basin. The Kiam Haloq and Silantek Formations yield upper Eocene fossils; beyond this there is little evidence for the assertion. Pieters & Supriatna (1990) use the term Kiam Haloq Sandstone for a unit of the Mahakam Group of the West Kutai Basin (see 1:1 000 000 map). They report that this unit subsumes the fossiliferous Kiam Haloq Formation of Pieters & others (1987), and the fossiliferous Haloq Sandstone of Abidin & Sudana (1989), both of which are West Kutai Basin units.

Contiguity of any of these West Kutai Basin units with the unfossiliferous 'Haloq Sandstone' of Putussibau and Nangapinoh quadrangles and with the Mangan Sandstone is a key issue. Map evidence does not clarify it, although contiguity with the Behaba Sandstone of the Mandai Basin seems possible.

The concept of a basal sandstone common to all four basins therefore seems to lack enough supporting data to use it as a starting point for correlating the oldest rocks of the Ketungau and Mandai Basins uniquely with particular strata of the Melawi and West Kutai Basins.

Melawi, Mandai and Ketungau Basins structural history — discussion and proposals

The absence of unconformities within the Ketungau and Mandai sequences can be used as a basis for proposing that their basal sandstones are younger than strata of the Ingar Shelf (Fig 2), perhaps correlating with the Dangkan Sandstone of the Silat Sub-basin.

The unconformity truncating the Silat Sub-basin probably did not form in the Ketungau and Mandai Basins, although it could have disappeared as a result of erosion. It might be equated with cessation of deposition in the two basins. The lower upper Eocene Muller Volcanics might mark the end of the Mandai as a depression.

The Dangkan Sandstone could well be the Semitau High cover that extends from the Melawi Basin into the Mandai Basin as part of the latter basin's basal strata. The Sintang quadrangle preliminary geological map suggests this, and raises questions about how the cover was recognised as being 'Haloq Sandstone' in the Putussibau quadrangle. If the cover is Dangkan, then the folding that it displays could be tied in neatly to that of the Silat Fold Belt. A Dangkan equivalent as basal strata for both the Mandai and Ketungau Basins would elegantly avoid uneasiness about the lack of unconformities in them. The age of the unconformity flooring both basins would be that of the unconformity between the Ingar Shelf and the Silat Sub-basin.

An episode of southwards compression first replaced the Ingar Shelf with the downwarps of the Silat Sub-basin and the Mandai-Ketungau Basin, then uplifted them and depressed the Payak Sub-basin along the southern flanks of the Semitau High which reacted with uplift, faulting and folding.

In the Mandai Basin open folds may reflect this episode, as may north-south bands therein of north-northwest and north-northeast trending imagery lineaments, which are probably conjugate sets of minor fractures.

Correlation is proposed, therefore, between the Dangkan Sandstone of the Silat Sub-basin with the Behaba Sandstone of the Mandai Basin and the Kantu Formation and fossiliferous upper Eocene Silantek Formation of the Ketungau Basin. It is also proposed that all these units are part of one continuous sheet which probably underlies the lower Upper Eocene Muller Volcanics of the Mandai Basin. The Ingar Shelf would then be the beginnings of only the Melawi Basin.

The Dangkan correlation implies exposure of basin basement rocks as a northern provenance for the Ingar Shelf. As mentioned above, there are no derivatives of melange or volcanics reported from the Ingar or Mentemoi Formations of the Melawi Basin, nor from its 'Haloq Sandstone'. 'Shelf' is possibly a misnomer. The feature may have been a shallow strait with a basement of melange, disturbed zone rocks and mid Eocene volcanics, with a northern shoreline south of a watershed that prevented it from acquiring detritus from the Lubok Antu Melange.

Post-Kantu (post-Dangkan) formations of the Ketungau Basin sequence may have had a melange provenance (Williams & Heryanto, 1986), perhaps the lower Eocene Lubok Antu Melange (Tan, 1979, 1982). If so, this may indicate a separate northern zone of uplift from that of the Semitau High. Such a northern uplift could have caused upwarping and deformation of flysch trough beds, initiating the Fold Belt domain. This domain then became a northern provenance for the Mandai and West Kutai Basins farther east, and for younger flysch deposits to the north in Sarawak. The beginnings of the West Kutai Basin may be no older than, or possibly equivalent to, Dangkan deposition.

Evidence for the Suwang or 'Haloq' based correlations include the fact that the Ketungau Basin sequence is approximately 7000 m thick (Pieters & Supriatna, 1989). Their Mandai and Melawi Basins Suwang Group totals 6000 m, suggesting a possible correlation in terms of the similar level of energy that went into the downwarping of all of them.

West Kutai Basin

The uplift/downwarp instability and associated east-southeast trends west of the Juloi High and Busang-Murung Crescent contrast markedly with the relative stability and northeast trends of the region to their east. Compare, for example, 8000 m of sediments in the intermontane Melawi structural Basin with 3500 m in the coastal-facing West Kutai Basin (thicknesses from Pieters & Supriatna, 1989).

The West Kutai Basin is apparently a southerly prograding sequence with no impeding distal high similar to the Schwaner Massif, and little provenance variation after uplift of its constituent disturbed zone rocks and adjacent flysch trough beds initiated the supply of sediments for the Basin. During deposition the West Kutai Basin downwarped more slowly than the western basins; sedimentation seems to have been continuous, with no unconformities forming in the late Eocene to early Oligocene sequence.

Quaquaversal folding of the conformable West Kutai Basin sequence may be solely the outcome of the late Oligocene deformational event that is reflected by the unconformity between this basin and the overlying late Oligocene to Holocene South East Kutai Basin. But while the northeasterly fold axes of the West Kutai could well have developed at this time, the north-northwesterly axes may be related to a mid Miocene or later event that produced northerly trending structures in the South East Kutai Basin (see below).

The Basin's characteristic northeast trends may reflect a concealed suture paralleling the Juloi High and the southeast margin of the Schwaner Batholith domain, and originally separating oceanic or Schwaner-like crust farther east from the Fold Belt domain flysch trough. Foss' gravity map of the region suggests that south of the Fold Belt domain in Long Pahangai quadrangle basement may be something like the Schwaner Massif (Abidin & Sudana, 1989). This may have provided a buttress against which the flysch trough was compressed and uplifted to become the provenance driving prograding sedimentation, possibly from Dangkan times until the onset of Sintang Intrusive Suite emplacement. These sediments now cover the buttress.

Late Oligocene to Holocene South East Kutai Basin

Achmad& Samuel (1984) attribute similar origins to the N.E. Kalimantan Basin and the Kutai Basin, describing five easterly prograding depositional cycles in both basins (Table 3). Where the cycles are separated by unconformities it is possible to consider each cycle as a sub-basin; however, persistence of onshore unconformities seawards is uncertain. The West Kutai Basin appears to be the oldest of the Kutai cycles and to conform onshore with the sub-basin criteria discussed above. The South East Kutai Basin does not, as it covers more than one of the younger cycles.

Pieters & Supriatna (1989, 1990) deal with only a small part of the South East Kutai. The 1:1 000 000 map shows the upper Oligocene tuffaceous Marah Formation, the Miocene tuffaceous Kelinjau Formation (the Anap of Abidin & Sudana, 1989), the Plio-Pleistocene Kampung Baru Formation, and Quaternary terrestrial and littoral deposits. The map also shows Sintang intrusive Suite bodies within the Kelinjau.

Achmed & Samuel (1984) present a Neogene correlation chart, incorporated in Table 3, which suggests that the Kelinjau may be part of their second or third cycle, the Kampung Baru (a Group on their chart) fourth cycle, and the Quaternary deposits (part of their Mahakam Group; cf Pieters & Supriatna, 1989) fifth cycle. The Marah (not shown by Achmed & Samuel) is second cycle by default and elimination and its unconformable relation with the West Kutai (Sub-)Basin.

In general the cycles reflect occasional northwest provenance uplifts— including that associated with the Metulang Volcanics domain episode which terminated cycle three and accompanied cycle four — and renewal of downwarping, mainly offshore to the east. The source of the volcanism during cycles two and three is unknown; some of it may have been produced during the last years of the Sintang Intrusive Suite domain episode.

On the 1:1 000 000 map the northeasterly trends characteristic of the West Kutai are less striking in the younger cycle sub-basins than the northerly trends, for example the northerly folds and thrust faults that deform the Late Oligocene and Miocene units, with which might also be included the cross folding in the West Kutai Basin. The north-south structures suggest an east-west compressive episode possibly of Metulang Volcanics age (the volcanics domain certainly has a dominant northeasterly trend, most probably inherited from mid Oligocene structures, but a northerly cross trend can be discerned).

The timing is supported by the probable culmination during cycle three of the northeasterly trending Samarinda Anticlinorium to the southeast of the map. Ott (1987) suggested that this feature resulted from southeastwards gravity sliding of basin deposits precipitated by provenance uplift in the late Oligocene to early Miocene.

The northerly trends parallel the northern part of the Fold Belt domain, to the north in Borneo, and the fold belt may have been bent to its present shape during Oligocene and Mio-Pleistocene east-west compression.

Notwithstanding this, cycle five is still active, and paired provenance uplift and depocentre deepening doubtless still in progress.

Quaternary Putussibau Depression

Quaternary sediments, mainly lacustrine, have been and are being deposited in the large oval Putussibau Depression, probably as a result of downwarping and fault damming. The Depression has formed mainly over the disturbed zone, but also overlaps the Fold Belt domain. The major axis of the Depression trends westerly. Foss (*in* Surono & Noya, 1989) explains the feature as an area of subsidence caused by isostatic forces acting on a large dense underlying body interpreted from his gravity anomaly map, those forces being consequent on the relaxation of the compressive tectonic forces associated with its emplacement.

Igneous domains

Mid Oligocene to Miocene Sintang Intrusive Suite domain

Mid Oligocene to Miocene igneous intrusive rocks have been generalised as the Sintang Intrusive Suite. The domain of intrusive bodies covers all other domains to a greater or lesser extent (Figs 2, 3). It comprises strings of small plugs and stocks. Emplacement of these took place after, or possibly during, the time that the West Kutai Basin was folded; the intrusives themselves do not seem to be deformed in any way. In many instances plugs locally domed up country rocks and instigated radial drainage. Lines of intrusions commonly occur along structural highs, for which their emplacement may be responsible. This is particularly the case in Long Pahangai Quadrangle, where the northeasterly trends of the highs and intrusives parallel the major structural grain, including the West Kutai Basin's structural margins. In Putussibau Quadrangle the intrusives have a less obvious westerly alignment.

The two trends cross where the Busang-Murung Crescent rocks crop out. The few Sintang Intrusive Suite radiometric dates (Bladon & others, 1989) suggest that the northeastern intrusions are younger than the western, and that the northeasterly trend may be superimposed on the westerly. The two intersecting trends are tangents to the arcuate Fold Belt domain.

The Suite may also be responsible for introducing or mobilising gold mineralisation in many places (Pieters, 1988).

Williams & Heryanto (1986) suggest that the Sintang Intrusive Suite was generated by crustal melting as a result of sedimentary basin downwarping combined with a rise in geothermal temperatures.

Miocene to Pliocene Metulang Volcanics domain

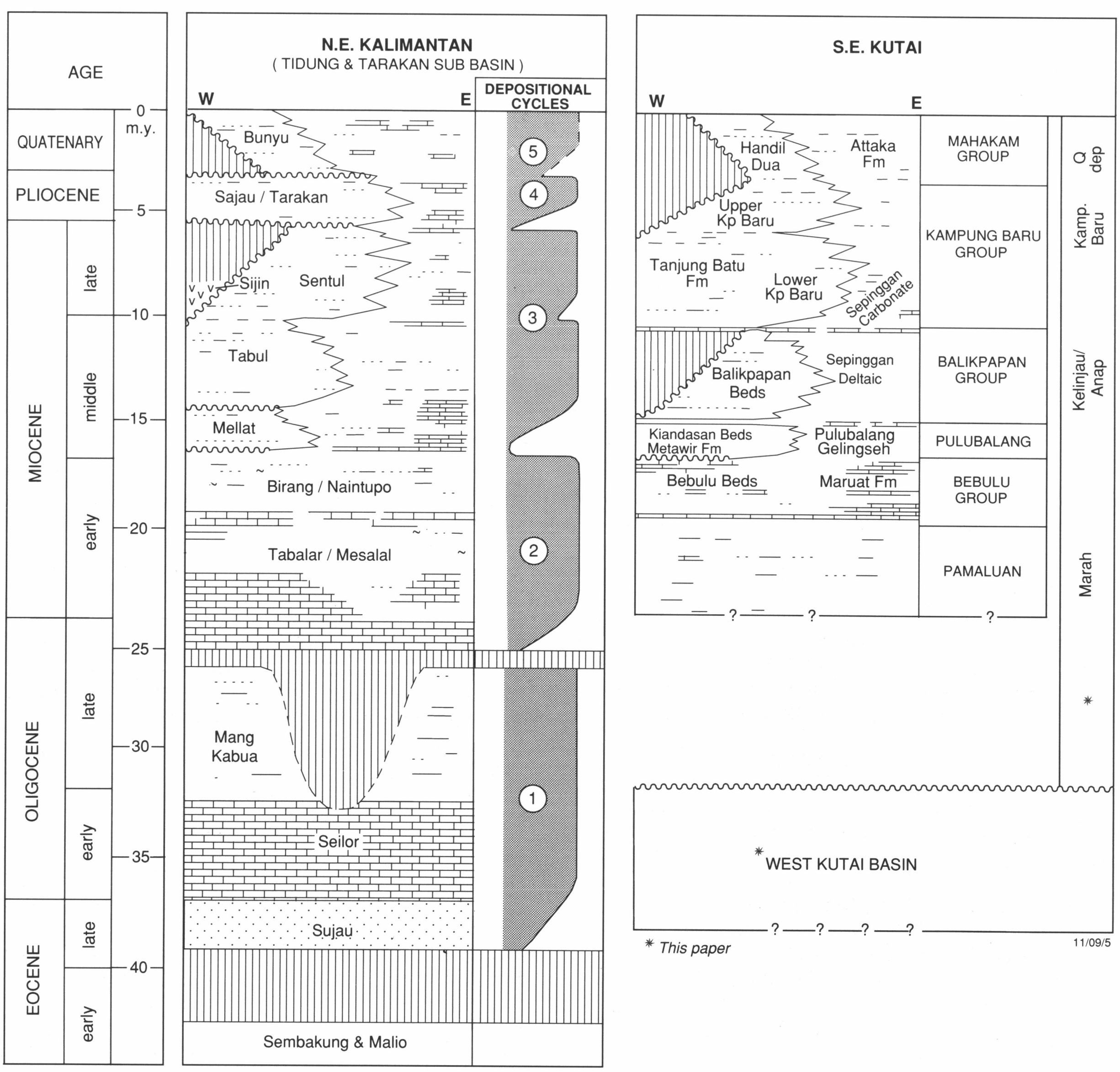
Before intrusion of the Suite ceased, basic lavas of the Miocene to Pliocene Metulang Volcanics domain began to be extruded in the northeast of the area, in Long Pahangai and Long Nawan Quadrangles (Abidin & Sudana, 1989; Baharuddin & Andimangga, 1989). This domain's general northeasterly trend is contiguous with that of the West Kutai Basin and the eastern part of the Sintang Intrusive Suite domain, and it overlaps both.

The volcanics seem to have been extruded on an old land surface, possibly a peneplane, to have been accompanied by uplift, and to be associated with structural highs. Uplift is reflected in river nick points; above these, the erosion suffered by the volcanoes does not seem to have been enough to unroof most of the intrusive bodies of the Sintang Intrusive Suite Domain, and the radiometric age overlap of the two domains needs looking into.

Tate (1991) suggests that the Metulang Volcanics represent 'the final stages of post-magmatic activity'.

The similar Niut Volcanics are dealt with in the next section.

Table 3. Comparison of depositional cycles, North East Kalimantan and South East Kutai Basins (after Achmad & Samuel, 1984).



Northwest Kalimantan domain

West of the Semitau High and its flanking basins, and to some extent overlapped by them, lies the Northwest Kalimantan domain of mainly Palaeozoic and Mesozoic rocks (Fig. 2 and 1:1 000 000 map). Younger Mesozoic rocks include western representatives of the outer shelf Cretaceous succession and unconformably overlying locally synclinal Kayan 'Basin' sandstones of Upper Cretaceous to Lower Tertiary age (Supriatna & others, 1989). Tate (1991) includes the Kayan in the Ketungau Basin and cites Tan (1986) as asserting that its deposition ceased in the late Eocene, at the time of Silat Fold Belt truncation.

Much of the gentle synclinal folding of the Kayan strata may be of the same age as that of the tight folding of the Embaluh Group flysch trough beds of the Fold Belt domain to their northeast. The milder structural scenario continued with limited Eocene or Oligocene Landak 'Basin' downwarping and sedimentation. This feature was possibly the western end of the Melawi Basin before being separated from it by basement uplift reminiscent of the Juloi High; the gravity map in Supriatna & others (1989) supports this idea. The relatively stable structural setting of the Kayan and Landak sequences lies south of the disturbed zone, whereas the Fold Belt domain is to its north.

The Oligocene and Miocene Sintang Intrusive Suite domain also occurs within the Northwest Kalimantan domain. Radial drainage commonly developed later, and the synclinal dips and possible bounding faults of the Kayan 'Basin' outliers may owe something to doming between the outliers by intrusive bodies not yet unroofed. However, substantial erosion must have taken place to expose those intrusives presently outcropping.

Northwest-southeast trends dominate in the Northwest Kalimantan domain. Sintang Intrusive Suite bodies trend southeast in places, a trend most noticeable in Singkawang quadrangle. The southeast-trending Pliocene basaltic Niut Volcanics extruded over the domain are a diminished mirror image of the northeasterly-trending Metulang Volcanics domain of the eastern quadrangles. And in a broad way there is something of a regional southeast plunging synclinorial aspect to the distribution of the older rocks of the Northwest Kalimantan domain.

Amiruddin & Trail (1989) comment on the dominance of the northwesterly trend in the Nangataman Quadrangle to the west of Nangapinoh, and its continuance through Singkawang quadrangle towards Natuna Island. This trend possibly originated during the Jurassic (Supriatna & others, 1989).

Schwaner Batholith domain

South of the Melawi Basin, and overlapped by it, is the Schwaner Batholith domain. It was originally coastal to the outer shelf Cretaceous rocks to its north; except at its present eastern end, in the Juloi Inlier, the contact is now hidden beneath the Melawi Basin succession.

On the 1:1 000 000 map the regional contact between the Melawi Basin and the Batholith domain is a fairly straight east-southeasterly line, although a few basin sediment outliers occur to the south of it. Overall the contact has the appearance of a monoclinal hinge which is parallel to the axis of the Melawi Basin, a warp that once controlled the Cretaceous shoreline, and which developed further as the basin deepened, perhaps. Amiruddin & Trail (1989) remarked that the presence of sedimentary breccia at the contact of the Tebidah Formation and Batholith domain rocks suggested that the southern margin of the Melawi Basin was considerably steeper than the present day northern slope of the Schwaner Highlands.

East-southeasterly trends also feature within the Batholith domain. Amiruddin and Trail (1989) reported this to be the trend of the schistosity within a metamorphic belt that lies close and parallel to the domain's boundary with the Melawi Basin, and suggest that it had pre-Early Cretaceous origins. The belt is better preserved in the east than in the west, reflecting perhaps a weak easterly component of plunge of the northern part of the domain, possibly acquired at the time of basin flank uplift in the early Tertiary.

Occurrence of an uplift is supported by the fact that the whole of the northern part of the Schwaner Batholith domain consists of eastsouth-easterly trending belts of rock that are older than those in the southern part. This may be the result of differential upwarping associated with downwarping of the Melawi Basin, and consequent erosion. Looking at this from a slightly different angle, Amiruddin & Trail (1989) suggest that the absence in the north of the domain of volcanics and of high-level phases marked by tonalite outcrops indicates deeper erosion than in the south,where pegmatites and volcanics occur. They also note the presence of easily eroded sandstone in the north at altitudes which suggest that some of the uplift of that part of the domain may be comparatively young.

While east-southeasterly trends are probably the most important in the domain, on the 1:1 000 000 map northwesterly and northerly trending structures are more obvious in some areas. Amiruddin & Trail (1989) remark that such regional differences exist, and that west of Nangapinoh quadrangle northwesterly trends replace the east-southeasterly trends.

In the southern part of the domain, belts of volcanics between granite highs trend northeast. This trend also shows up to a minor extent in the preservation of the northern metamorphics, and in the alignment of some of the few Sintang Intrusive Suite plugs that occur in the domain. The trend continues northeastwards beyond the domain as Sintang Intrusive Suite domain trends at the eastern end of the Semitau High. Farther northeast lies the northeast-trending Metulang Volcanics domain. This trend direction is also that of the southeastern margin of the Schwaner Batholith domain and of the regional strike of the deposits of the West Kutai Basin. The prograding deposits of the South East Kutai Basin dip southeasterly away from and normal to its northeast-trending West Kutai hinterland, so in this area the trend seems to have matured in Oligocene-Miocene times.

It appears that while the Schwaner Batholith domain may have played a buttressing role during Cainozoic compression episodes it did not escape internal modification by them (much constrained by pre-Cretaceous structure).

Fold Belt domain

The Fold Belt domain is the northern margin of the study area; the greater part of it is in Sarawak. Strictly speaking the domain should probably be restricted to the zone of strike ridges of Cretaceous to early Eocene flysch and exclude the disturbed zone and melanges. The strike ridge zone, mainly of Embaluh Group strata in Kalimantan, was named the Embaluh Fold Belt by the author (*in* Surono & Noya, 1989).

In Long Nawan quadrangle disturbed zone rocks and melanges are included in the Embaluh Group; in Long Pahangai and Putussibau quadrangles they are part of the Selangkai Formation. While the disturbed zone concept was developed by this author mainly to emphasise structural complexities, the zone could also be a useful informal stratigraphic unit. It would be characterised in part by melanges, and in part by younger outer shelf and older flysch trough strata (given northerly younging of the outer shelf deposits (Williams & Heryanto, 1986), and probably also of flysch trough deposits). If deformed zone rocks are excluded from the flysch Embaluh Group and the outer shelf Selangkai Formation, in which they are included by Pieters & Supriatna (1989, 1990) and the authors of relevant Data Records, this would enable a clearer appreciation of the disturbed zone, and cleaner-cut definitions for the outer shelf and flysch trough units.

The nature of deformation of the flysch deposits has not been studied systematically. In general it is flysch bedding strikes that indicate the regional arcuate trend (best seen on imagery and the 1:250 000 preliminary maps), westerly in the west and northeasterly to north in the east. Dips are southerly to southeasterly and steep, with some overturning. Some of the steepness and the arc of trend may well have been acquired after the mid Oligocene, on the basis of some South East Kutai Basin structures.

Air photographs and Landsat and radar imagery yield very little information about structures in the outer shelf deposits or disturbed zone. In strong contrast the flysch beds stand out as belts of strike ridges, in which isoclinal folding is recognised with difficulty in a few places — but it is tempting to assume it to be ubiquitous. Pieters (pers. comm. *in* Williams & others, 1988) asserts tectonically juxtaposed Cretaceous and Tertiary rocks in a zonally alternating outcrop pattern. Faults sub-parallel to bedding strikes are common; these and fold steepening probably increased progressively in conjunction with Eocene—Oligocene sedimentary basin downwarping and later events.

Local details of structures in the flysch are recorded in Surono & Noya (1989, field photo captions). Photographs taken by IAGMP geologist Peter Williams in 1985 show the following features, some or all of which could be Tertiary:

— D3 folding on a decollement;
— transposed bedding parallel to cleavage;
— transposed bedding on both sides of an intrafolial fold;
— a D2 fold, with rotated cleavage in the core.

The arc of strike ridges trends from east-southeast in the west to northeast and north in the east. It is paralleled by elements of the domain of basins and inliers. In the west, the interdependence of all of these features during late Eocene to early Oligocene basin evolution indicates some crustal shortening as compression pushed everything southwards towards the Schwaner Massif. In the east, the same east-southeasterly trends could have persisted during West Kutai Basin deposition, although the northeast trending mid Oligocene fold axes in that basin, and the similar trend of lines of Sintang Intrusive Suite plugs within the basin and nearby, suggest that the northeast trend either was established in the adjoining part of the Fold Belt domain by then, or was impressed on it at the time of folding and intrusive activity.

The development of a peneplane on the strike ridge zone constrains this timing. The peneplane is most obvious as an old land surface on which Metulang Volcanics have been extruded in Long Nawan quadrangle (Baharuddin & Andimangga, 1989). In a few places there has been relief inversion by erosion since lavas flowed down valleys of the old surface. More generally, maps and imagery show that, allowing for displacement by faulting, summit concordance of the strike ridges is widespread. How this surface relates to the Sintang Intrusive Suite is unclear, but it does not seem to have been produced during unroofing of the intrusions.

It is possible that the peneplane had its origins in the dying out of uplift and folding of flysch trough strata north of the disturbed zone in the early Oligocene, as already postulated, northeast bedding trends being set by then. Provenance uplifts during South East Kutai Basin deposition could have resulted in erosional etching of strike valleys and ridges in the peneplane, but possibly could point to the likelihood of much younger planation.

Summary of Cainozoic structural history, West, Central and East Kalimantan

On present evidence, the Cainozoic structural history of this area began with the formation of the lower Eocene Lubok Antu Melange. It is possible that formation of the melange signalled the end of flysch trough deposition and was penecontemporaneous with disturbed zone derangement, uplift of the Cretaceous outer shelf deposits and extrusion of the middle Eocene volcanics on them, and early deformation of the flysch trough farther north as the beginnings of the Fold Belt domain — all of this resulting from the one episode of compression.

Between early late Eocene and mid Oligocene times bursts of compression produced a number of structural highs separating shifting sedimentary basin depocentres. In the south the Schwaner Batholith domain provided a buttress to this compression, although its northern margin was upwarped as a consequence.

Basin history began with deposition on the Ingar Shelf. The basement of these deposits in central Kalimantan consists of disturbed zone rocks, Cretaceous outer shelf strata, and mid Eocene volcanics. Basement downwarping may indicate continuation of the southwards compression that caused its previous uplift.

Late Eocene to early Oligocene compressional uplifts of the Semitau, Juloi and other Highs modified the Ingar Shelf into the Silat, Payak and Alat Sub-basins of the Melawi Basin, embraced the Silat Sub-basin-equivalent Ketungau and Mandai Basins, and separated the West Kutai Basin from the Melawi Basin; uplifts also separated the Melawi and Ketungau Basins from their ?outliers sitting on the Palaeozoic and Mesozoic complexes of the Northwest Kalimantan domain. The uplifts were associated with mild deformation of the older basin sequences and rare volcanism.

To the north there were probably contemporaneous uplifts of the Fold Belt domain flysch, but as compression weakened and basin downwarping diminished a peneplane may have begun to form in the northern provenance, lessening the amount of detritus available for depositing in the shallowing basins.

The Kembayan Inlier and the Busang-Murung Crescent owe much to these uplifts, and may represent reaction of 'continental crust' margin (to which the Schwaner Batholith Domain was hinterland) with north-south compression episodes (but see Tate, 1991). Farther east, the West Kutai Basin may conceal a more stable oceanic or Schwaner-like crustal bulwark.

Renewed compression in the mid Oligocene caused folding of the West Kutai Basin. The detachment faults of the Kembayan Inlier and the Busang-Murung Crescent may also be attributable to this event. Penecontemporaneous emplacement of the Sintang Intrusive Suite is less clearly related to structural highs in the west than in the east; their younger northeasterly alignments may indicate a bending of the Fold Belt domain in this direction at the time.

South East Kutai Basin deposition unconformably followed the West Kutai sequence with four more prograding cycles, the youngest still accumulating. Each was triggered by provenance uplift; the second-last uplift was associated with extrusion of the Metulang Volcanics and northerly bending of the fold belt. The northwesterly trend of the Niut Volcanics of the same age seems to be simply a matter of long established structural controls in the Northwest Kalimantan domain.

Recent development of the Putussibau Depression (and a similar feature adjacent to the Samarinda Anticlinorium in the South East Kutai Basin) are ascribed to isostatic readjustment. No older examples are known.

A simplistic approach to structural genetics that takes into account the predominance of northwest trends in the west, east-southeast trends in the south, and northeast trends in the east is postulation of compression of crust and cover southwards. The northern margin of the Schwaner Batholith domain bulwark was upwarped at the same time as the east-southeast trending basins deepened against it. The northwest and northeast trends are taken to reflect similar warps in resistant crust already shaped by pre-Cretaceous structures. The occasional extrusion of volcanics may indicate relaxation, even rebound, between episodic bursts of compression. The Sintang Intrusive Suite may have been generated by extreme downwarping leading to melting, the Metulang and Niut Volcanics being a last expression of this process.

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