*Geological Society of Malaysia – Circum-Pacific Council for Energy and Mineral Resources*
*Tectonic Framework and Energy Resources of the Western Margin of the Pacific Basin*
*November 27 – December 2, 1992, Kuala Lumpur, Malaysia*

# Sedimentology of the Semirara Formation in Semirara Island: implications for the Miocene sedimentation and tectonics of south Philippines

C.S. BRISTOW[1] and P.R. BIRD[2]

[1] Department of Geology, Birkbeck College, University of London
Malet Street, London WCIE 7HX, England
[2] Kirkland Resources, 3 Vaughan Road, Harpenden, Hertfordshire, AL5 4HU, England

**Abstract:** This paper describes the sedimentology of the Semirara Formation in the type locality, Semirara Island, which lies south of Mindoro on the western side of the Philippines volcanic arc. The history of sedimentation is set within the evolution of a series of rift basins which were compressed and inverted during collision with the arc. The Semirara Formation is mostly composed of continental clastic deposits of Upper Miocene age. The outcrop is dominated by fluvial channel sandstones interbedded with thick coals and estuarine and floodplain siltstones. Palaeocurrent analysis indicates that the rivers flowed towards the North and the petrography of the sandstones indicates that they were derived from a continental landmass rather than the volcanic arc.

It is suggested that the Palawan/Mindoro microcontinent was being uplifted and eroded during the late Miocene and shedding sediments into a series of rapidly subsiding basins which developed under an extensional regime within the Palawan block, prior to collision with the Philippines volcanic arc. At the present day the basins are partially inverted following collision with the arc, beginning in late Miocene times. Inversion occurred in a regional sinistral strike slip regime and spread southward away from the northern edge of the indenting microcontinent.

Coal in the Semirara Formation is currently being worked in an open cast coal mine, associated sandstones and organic rich mudstones form potential reservoir and source rocks for petroleum exploration in the three basins described. The sandstones are mostly fluvial channel sandstones deposited by a variety of rivers which can be summarised as four types: 1) Mixed load meandering rivers, 2) Sand-bed meandering rivers, 3) Large sand-bed braided rivers and 4) Shallow braided streams. The fluvial sandstones are interbedded with thick coal seams, up to 20 m thick, and siltstones which are interpreted as freshwater swamp and floodplain deposits. Occasional marine incursions are also recognised indicating an overall depositional setting on a coastal plain.

## INTRODUCTION

The area of this study is largely constrained by the outline of licence area GSEC 60 which contains three major sedimentary basins, the Tablas basin, Semirara basin and Sibay Basin (Fig. 1). The basins are arranged in a N-S trend along the western side of the Philippines volcanic arc and lie to the south and east of Mindoro Island. They are interpreted to have formed on the leading edge of a microcontinent which has collided with the Philippine arc. The microcontinent includes parts of Palawan, Reed Bank and Mindoro and is believed to have rifted from China with the opening of the South China Sea in the mid-Oligocene (Bird *et al.*, in press). Through a combination of seismic interpretation and field studies a story of initial subsidence, associated with South China Sea rifting, followed by drifting in the late Oligocene with renewed rifting in the Miocene and sequential inversion of the three basins from Late Miocene onwards is proposed. The Upper Miocene to Pliocene inversion history is attributed to the progressive southward spread of deformation from the northern edge of the microcontinent.

### Tablas Basin

The Tablas Basin lies in the Tablas Straits and is approximately 80 km long (NW-SE) and 40 km wide (NE-SW), it has an elongate form oriented NW-SE parallel to the Mindoro Suture Zone and the East Mindoro Fault Zone, with E-W trending intrabasinal faults (Fig. 1). The southern Basin bounding fault has been correlated to the East Mindoro Fault zone by Bird *et al.* (in press). A geoseismic transect through the Tablas Basin along the line B-B' shows that the basin is an asymmetric graben (Fig. 2) with sedimentary sequences thickening towards the southeast. The basin is undrilled, and there are no dates available for the

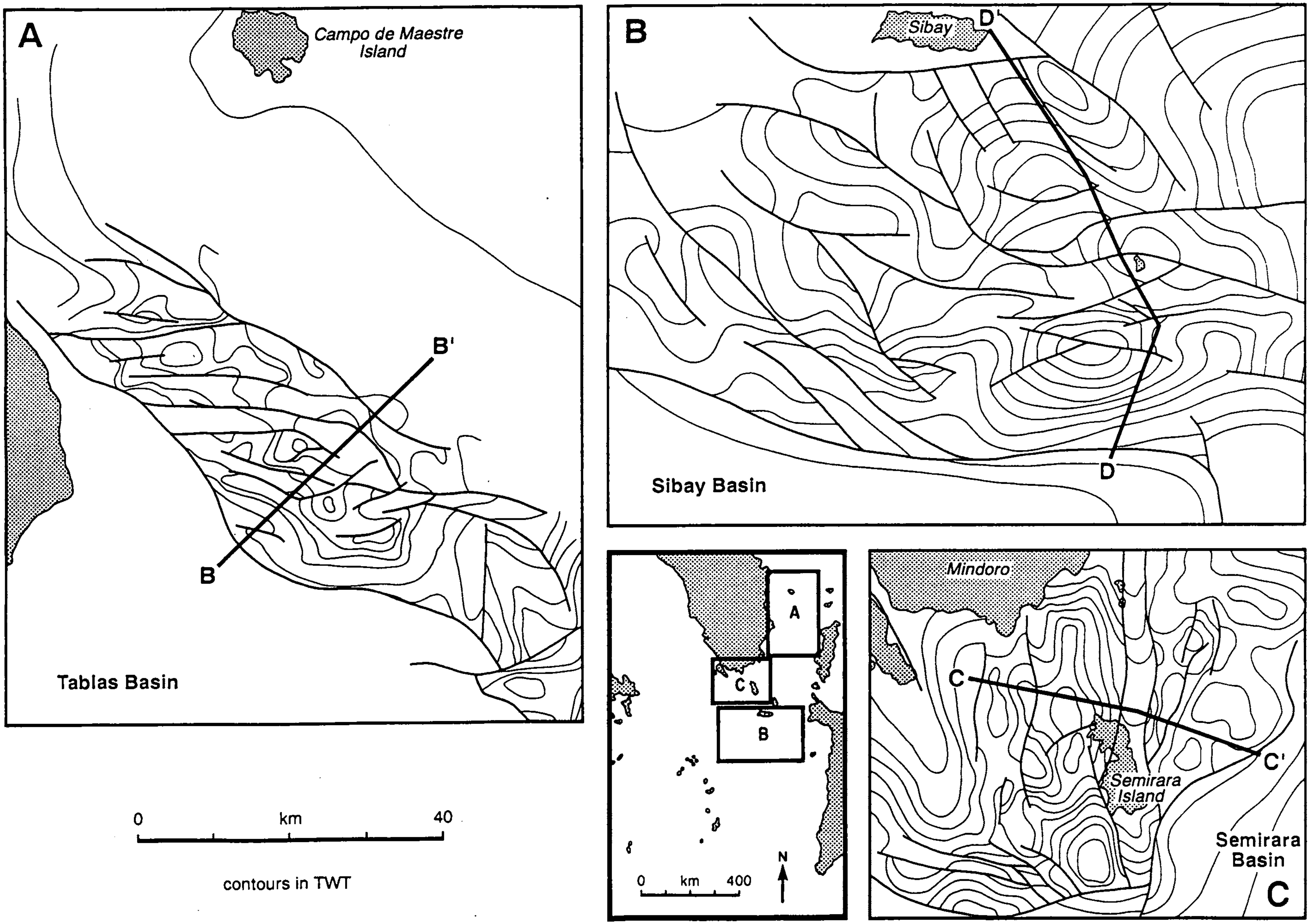

**Figure 1.** Structural maps of the Tablas Basin (A), Sibay Basin (B) and Semirara Basin (C) the relative positions of these basins is shown in the inset diagram.

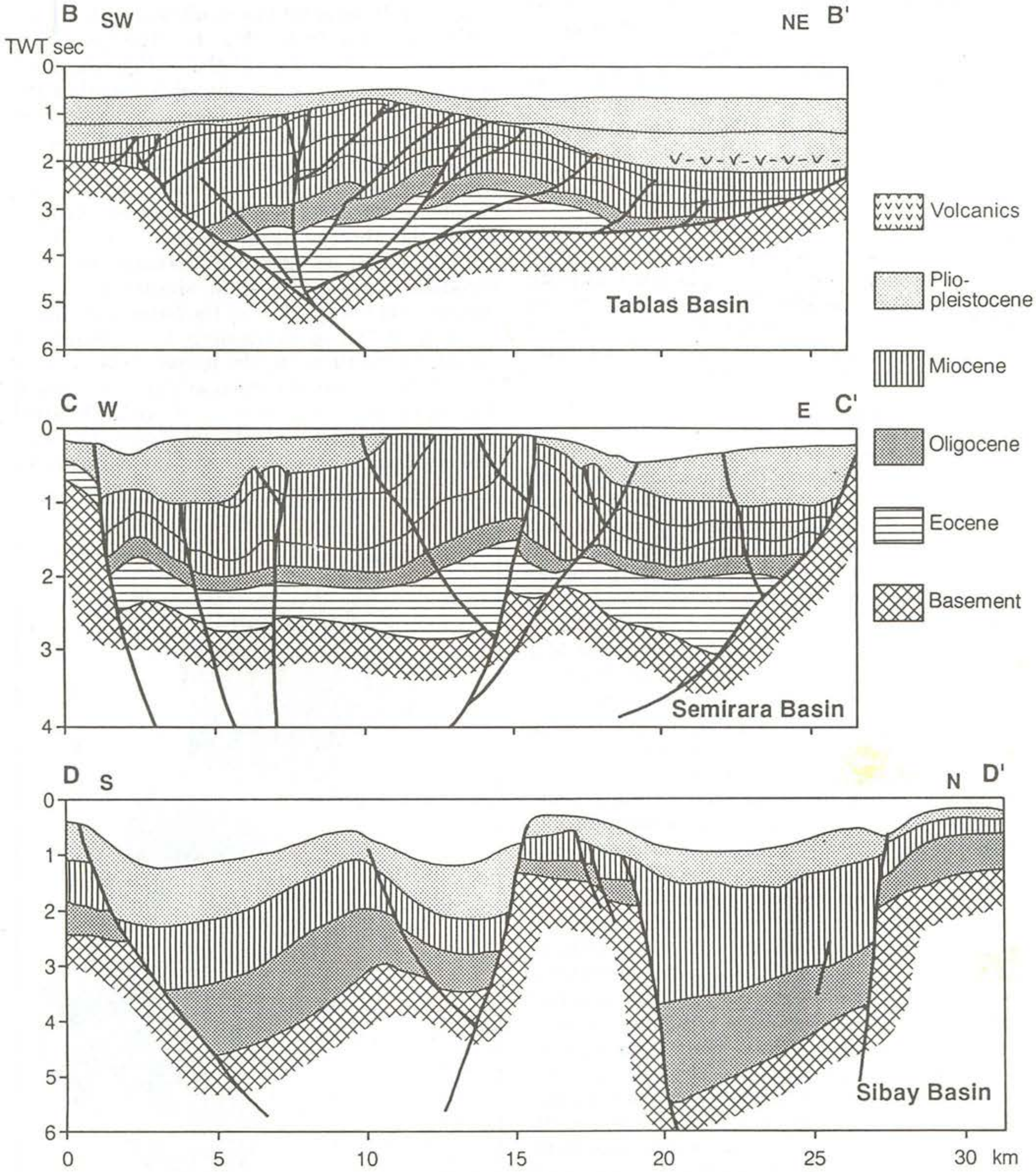

**Figure 2.** Geoseismic sections through the Tablas Basin B-B', Semirara Basin C-C' and Sibay Basin D-D', the location of the sections are shown in Figure 1.

age of the sedimentary fill. However, volcanics interpreted on seismic lines in the north of the basin can be correlated with the Campo de Maestre Island (Fig. 1). The island is one of a chain of volcanoes extending into east Mindoro, where K/Ar dating has yielded an age of 4.3 Ma (Marchadier and Rangin, 1990). The main unconformity (Fig. 2, B-B' lies just beneath the volcanics, dating it as end of Miocene. The underlying Miocene section appears to thicken towards the southeast, indicating that the basin was undergoing active extension at this time. The basin shows significant inversion which appears to have occurred in the late Miocene (Fig. 2). This inversion was accompanied by shortening on NE verging thrust faults. Bird *et al.* (in prep.) propose that the Tablas Basin locked into place against the Philippines volcanic arc at approximately the end of the Miocene. The top Miocene unconformity is onlapped by Plio-Pleistocene sediments up to 2 km thick.

## Semirara Basin

The Semirara Basin occupies an area of about 40 x 40 km due south of Mindoro Island. Mapping the top Lower Miocene reflector in the Semirara Basin (Fig. 1) reveals N-S trending normal and reverse faults which truncate against an E-W trending basin bounding fault in the south and are projected northwards onto the southern end of Mindoro Island. The geoseismic profile (Fig. 2, C-C') is based on a seismic section which runs E-W 3 km north of Semirara Island along the line C-C' (Fig. 2). This section shows that the basin is a N-S oriented graben with a major inversion axis along the basin centre beneath Semirara Island.

Thickness changes in the sedimentary fill reflect deposition within an extensional graben setting. From regional considerations, extension probably began in the Palaeogene (Taylor and Hayes, 1983). However, well to seismic correlation shows that extension and major fault controlled subsidence was occurring in the Miocene, well after spreading stopped in the South China Sea, cf. 15.5 Ma (Briais *et al.*, in press). Upper Miocene sediments outcrop on Semirara Island in a major inversion anticline (Fig. 2, C-C'). At least 2 km of uplift has taken place on an earlier normal fault bringing sub-bituminous coal to the surface. The Early Pliocene has also been uplifted and partially eroded above this inversion anticline, it outcrops at the north end of the island with a 30 degree dip, lying conformably on the Miocene, but overlain unconformably by Pleistocene limestones (Fig. 3). A mid-Pliocene unconformity, visible on seismic lines, dates the beginning of inversion. Recent fault activity, which has displaced coal boreholes, indicates that inversion is still active.

## The Sibay Basin

The Sibay Basin is the southern most basin considered in this paper, it is about 60 km wide (N-S) and 80 km long (E-W) and is comprised of a series of E-W oriented blocks divided by E-W and NW-SE trending faults (Fig. 1). The geoseismic cross-section D-D' (Fig. 2) shows that the fault bounded depocentres are rotated half-graben tilt blocks with sediments thickening towards E-W trending normal faults which throw down towards the north. The orientation of the faults and their throw suggests dip slip movement under a N-S oriented extensional regime. Thickness changes within the Miocene again indicate active rifting and differential subsidence at this time. The Plio-Pleistocene sediments show similar thickness changes and the sea floor in the basin axes lies at a depth of 700 m indicating that differential subsidence continues to the present time. There has only been minor inversion within the basin and this appears to be associated with sinistral movement along NE-SW trending strike slip faults. The inversion is very recent and these structures

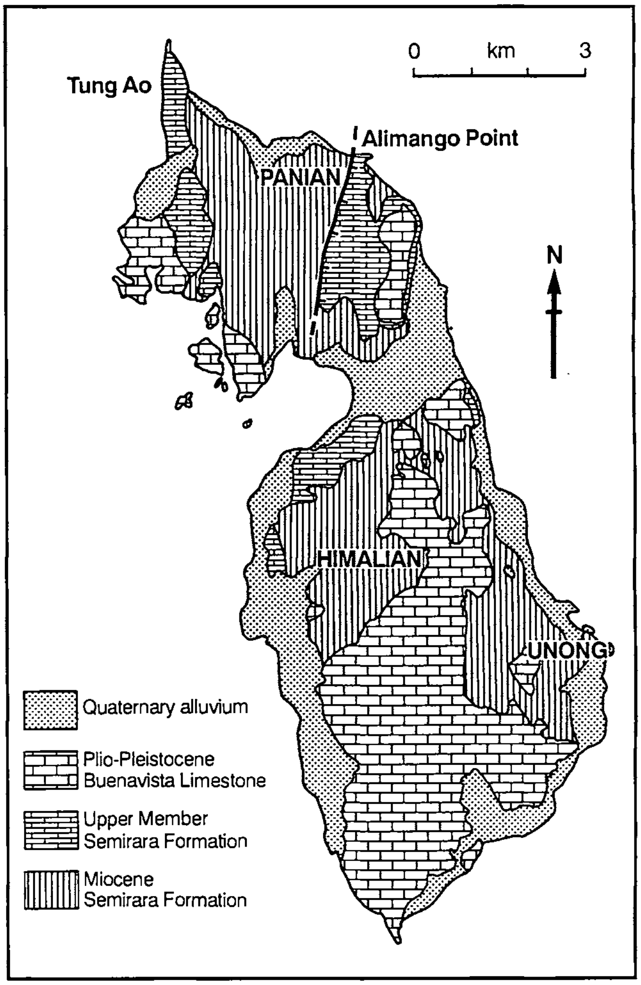

**Figure 3.** Geological sketch map of Semirara Island after Vergara, 1956.

show a combination of subsidence at releasing bends and compression and inversion at confining bends.

### Basin overview

Overall the Tablas, Semirara and Sibay Basins show clear evidence of Miocene rifting, overprinted to a greater or lesser extent by inversion. The inversion has been shown to decrease from north to south, with the greatest degree of inversion in the Tablas Basin and very little inversion in the Sibay Basin. Furthermore, it has been shown that inversion started earlier in the Tablas Basin (Late Miocene) than in the Semirara Basin (Plio-Pleistocene) and the Sibay Basin (Holocene). It is clear that inversion has spread through the basins from the north and this is believed to have been driven by continuing indentation of the Palawan-Mindoro microcontinent into the Philippines volcanic arc. The origin of the Miocene rifting is less clear, the variable orientation of the basins and apparent extension directions inhibits the application of a simple strike slip model; no single strain ellipse can be applied to explain extension on the known basin bounding faults. Basin orientation is attributed to inherited basement structural trends.

The nature of the basement and the position of basement boundaries around Mindoro are disputed (Bird *et al.*, in press). The main area of dispute is the East Mindoro block, which forms part of the northern mountains, the eastern coastal plain of Mindoro and the Tablas Basin. Sarawitz and Karig (1986) consider it to be part of the Luzon-Mindanao arc, whereas Marchadier and Rangin (1990) and Rangin *et al.* (1985) ascribe its origin to the South China Margin, in common with the Palawan Mindoro block. What is clear is that there is a significant basement feature, the Mindoro Suture Zone, between the Tablas and Semirara Basins. The Mindoro Suture Zone strikes NW-SE through the uplifted mountain belt of Mindoro and is so called because ultrabasic rocks and pillow lavas outcrop along its northwestern portion. These igneous rocks lense out southeastwards along the suture zone and are not present on the southeastern coast of Mindoro. Uplift and deformation is much less intense here and in the offshore area to the SE, between the Tablas and Semirara basins. Bird *et al.* (in prep.) suggest that the Mindoro Suture Zone does not represent the site of an old ocean, but rather the closure site of a deep pull-apart basin at the NW edge of the Mindoro-Palawan microcontinent.

Tilt block orientation and fault throw in the least deformed and inverted basin, the Sibay Basin, suggests that the principal extension direction may have been N-S. The driving mechanism for this extension is unclear, but the Sibay Basin shows a similarity in tectonic fabric to the South China Sea and NW Palawan. In a recent review of South China Sea evolution Briais *et al.* (in press) indicate that seafloor spreading in the South China Sea includes at least one ridge jump to the south at around 27 Ma, accompanied by a change in extension direction from N-S to NW-SE, with spreading ceasing around 15.5 Ma. It is suggested here that the Miocene extension described from the Semirara and Sibay basins may have been caused by an attempted, further southward, jump in the spreading centre. In this case extension was curtailed by the arrival of the Philippines volcanic arc from the East which affected the northern Tablas Basin first, causing late Miocene inversion. The Tablas Basin locked into place against the Philippine Volcanic Arc at the end of the Miocene and basin inversion ceased at this point. Compression was then transferred southwards to the Semirara Basin, probably accommodated by sinistral strike slip movement along the East Mindoro Fault and/or the Mindoro Suture Zone with inversion of the Semirara Basin and Sibay basins occurring in latest Miocene to Pliocene times. Further field studies are required to determine the origin and the nature of the fill of the Tablas Basin.

## SEDIMENTOLOGY OF THE SEMIRARA FORMATION

The Semirara Formation is exposed on Semirara Island, Caluya municipality, Anique Province, Philippines. The island which is oriented North-South is approximately 15 km long and 6 km wide. There are three main areas of exposure on the island; Panian in the northern part of Semirara, Himalian in the centre and Unong on the southeastern side of the island (Fig. 3). Reconnaissance visits were made to Himalian and Panian, some small outcrops were observed and sampled. Samples were also obtained from the three boreholes in the Panian area but these were generally very degraded. The best exposure is in the open cast coal mine at Unong the majority of this paper is based on observations made in Unong pit with a summary of observations made in the Panian and Himalian areas.

### Panian Area

In the Panian area the Semirara Formation outcrops across an area approximately 3 km wide with an average dip of 30 degrees towards the west (Fig. 3). There are several small North-South trending anticlines and synclines towards the eastern end of the outcrop but all together the width of outcrop suggests an approximate thickness of 1.5 km although the base of the formation is not exposed. The lowest part of the section exposed at Alimango point contains organic rich siltstones and very fine sandstones which are overlain by coarse to very coarse grained sandstones, organic rich mudstones, and sub bituminous coal exposed in old opencast coal workings and stream section. The sandstone are interpreted as fluvial channel sandstones and show sedimentary structures which indicate palaeoflow towards the North and West. The overall depositional environment for these facies was probably an alluvial plain. The rivers appear to have had large low sinuosity braided channels with a channel depth on the order of 6 m. Further up the section, towards the northwest, near Tung Ao the sandstones and siltstones become red. The change in colouration could be a weathering effect due to leaching in the tropical climate of the Philippines. However the red colour could be a primary feature, in which case a change in climate to more arid conditions would explain both the lack of coal seams and the red colouration in the upper part of the Semirara Formation. Palaeocurrents measured from cross-stratified sandstones indicate palaeoflow towards the south and the northwest.

The western most outcrops at the top of the Semirara Formation on Tung Ao point are bioclastic grainstones with a diverse shallow marine fauna including forams, red algae, echinoderms, bivalves, oncolites and other bioclasts of the Upper Member of the Semirara Formation (Vergara, 1956). These limestone are interpreted as a transgressive unit at the top of the Miocene.

## Himalian Area

In the Himalian area there are small deeply weathered outcrops of coarse to very coarse grained sandstones and siltstones. The strong weathering and leaching of these outcrops has made the exposures unsuitable for sedimentological studies.

## Unong Pit

The Unong Pit is approximately 200 m deep with the floor of the pit approximately 130 m below sea-level. There are more than 400 m of section exposed within the pit with an overall dip towards the south cut by East-West trending faults which throw down to the North, possibly induced by extension across the crest of a N-S trending anticline which plunges to the south. Almost 392 m of section have been measured in Unong Pit at a scale of 1:25, graphic logs of the section at a scale of 1:1000 with details of specific sections at 1:100 are shown in Figure 4. The section is remarkably sandy with around 190 m of sandstone and minor conglomerates, 158 m of siltstones and 42 m of coal. Eight different lithofacies (Table 1) are described and interpreted below. Forty nine individual channel sandbodies have been identified, which are numbered from the bottom up.

Lithofacies 1 contains interbedded fine grained sandstones and siltstones often with a primary sedimentary dip, in fining upwards sequences overlying a sharp erosive base with minor intraformational conglomerates (Fig. 4). These are interpreted as the deposits of low energy meandering rivers. The dipping bed of inclined heterolithic stratification were deposited as lateral accretion surfaces on point bars at the bends of meandering rivers. The presence of both sand and silt shows that the rivers had a mixed load of fine sand (bedload) and silt (suspended load). The alternation suggests either a seasonally fluctuating discharge or were on a low coastal plain at the edge of tidal influence where tidal oscillation can affect river discharge without reversing the current

**Table 1:** Lithofacies of the Semirara Formation exposed in Unong Pit.

| | |
|---|---|
| **Lithofacies 1** | Cross-stratified and ripple laminated sandstones and siltstones in fining upwards units with an erosive base and lateral accretion surfaces |
| *interpretation:* | Mixed load meandering rivers |
| **Lithofacies 2** | Cross-stratified sandstones with an erosive base and lateral accretion surfaces |
| *interpretation:* | Sand-bed meandering rivers |
| **Lithofacies 3** | Cross-stratified sandstones more than 3 m thick with an erosive base and no lateral accretion surface |
| *interpretation:* | Large sand-bed braided rivers |
| **Lithofacies 4** (orange) | Cross-stratified sandstones less than 3 m thick with many erosion surfaces and abundant conglomerates |
| *interpretation:* | Shallow braided stream deposits |
| **Lithofacies 5** | Intensely bioturbated fine grained sandstones with occasional marine fossils |
| *interpretation:* | Shallow marine sandstones |
| **Lithofacies 6** | Bioturbated med–dark grey siltstones with thin shelled bivalves and occasional gastropods |
| *interpretation:* | Marine or brackish water lagoon |
| **Lithofacies 7** | Grey and brown siltstones with occasional plant fragments |
| *interpretation:* | Floodplain and floodplain lake deposits |
| **Lithofacies 8** | Coal |
| *interpretation:* | Coal swamp |

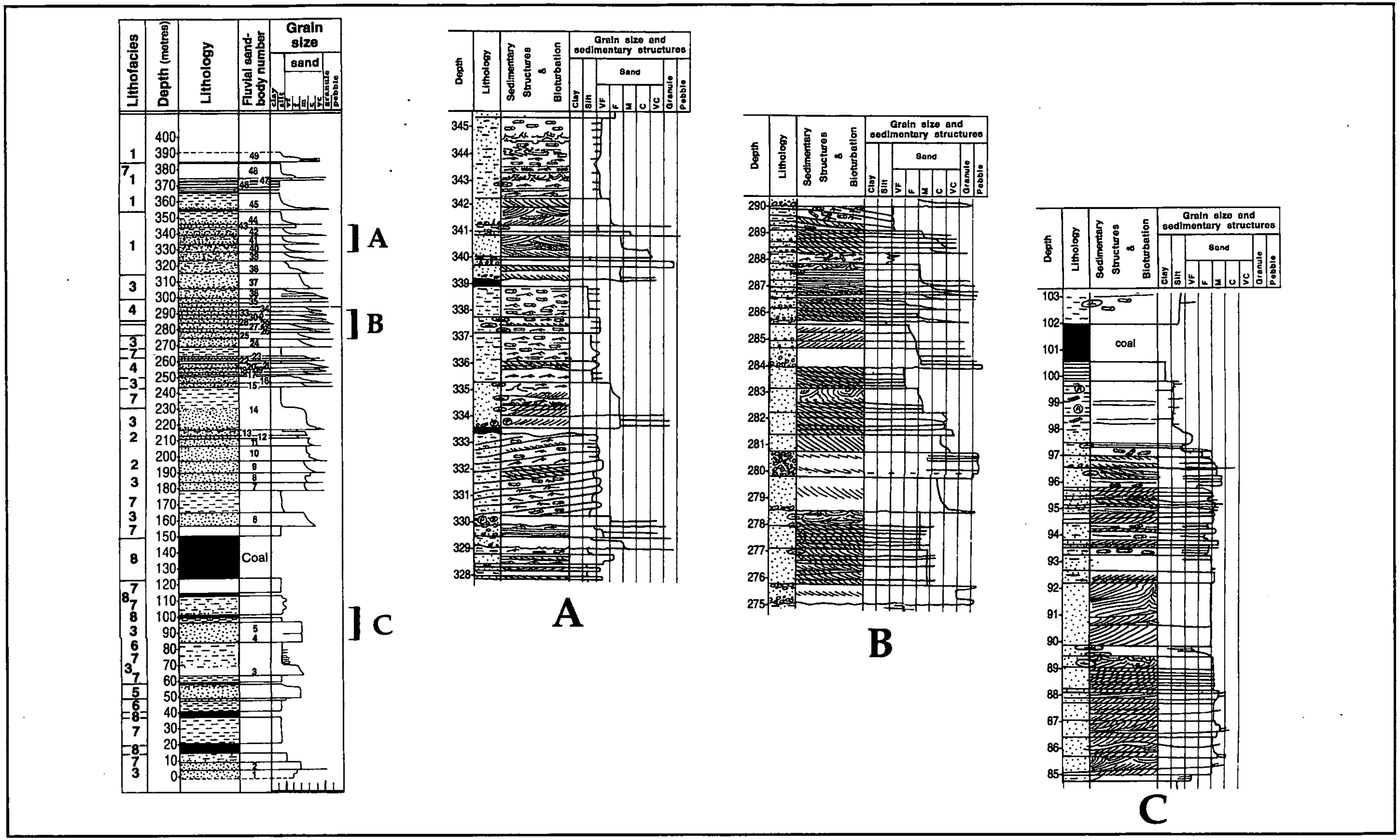

**Figure 4.** Summary sedimentary log from the Unong Pit at a scale of 1:1000 with details of typical examples of lithofacies 1,3,4,6,7 and 8 at a scale of 1:100.

(Smith, 1987). The channel fills and associated abandonment deposits suggest a palaeochannel depth of around 5 m with a channel width of around 30 m. These are interpreted as small, local, intrabasinal streams. The palaeocurrents measured from lithofacies 1 (Fig. 5) show a very wide spread dispersion which is compatible with a low gradient, intensely meandering river deposit (Le Roux, 1992).

Lithofacies 2 contains well sorted medium to fine grained sandstones with abundant cross-stratification, a sharp erosive base and lateral accretion surfaces. Lithofacies 2 is interpreted as the deposits of sand-bed meandering rivers. The palaeocurrents show a marked divergence with palaeocurrents towards the East and the northwest (Fig. 5). This apparent divergence of flow could be due to preservation within alternate point bars from a meander belt where overall palaeoflow is towards the north. However, the small number of palaeocurrents measured from this facies does not give great confidence in the palaeocurrent interpretation.

Lithofacies 3 contains well sorted medium grained sandstone with abundant trough cross-stratification in units 3 m – 13 m thick which have sharp erosive bases. The cross-stratification is predominantly trough cross-stratification with occasional planar lamination. Palaeocurrents show a broad spread with a dominant trend towards the North and northeast (Fig. 5). The sedimentary structures indicate relatively high discharges in a sandbed braided river systems like the South Saskatchewan (Cant and Walker, 1976, 1978). The good sorting and high maturity of the sediment suggests considerable transport, (hundreds of kilometres) rather than local sourcing (tens of kilometres). There is abundant soft sediment deformation within these sandstones produced by dewatering. Early catastrophic dewatering of a sandstone may be triggered by seismic activity (Leeder, 1987). The abundance of deformed cross-stratification suggests that these sediments were deposited in a tectonically active basin. These mature well sorted sandstones are barely cemented and have extremely good porosity and permeability.

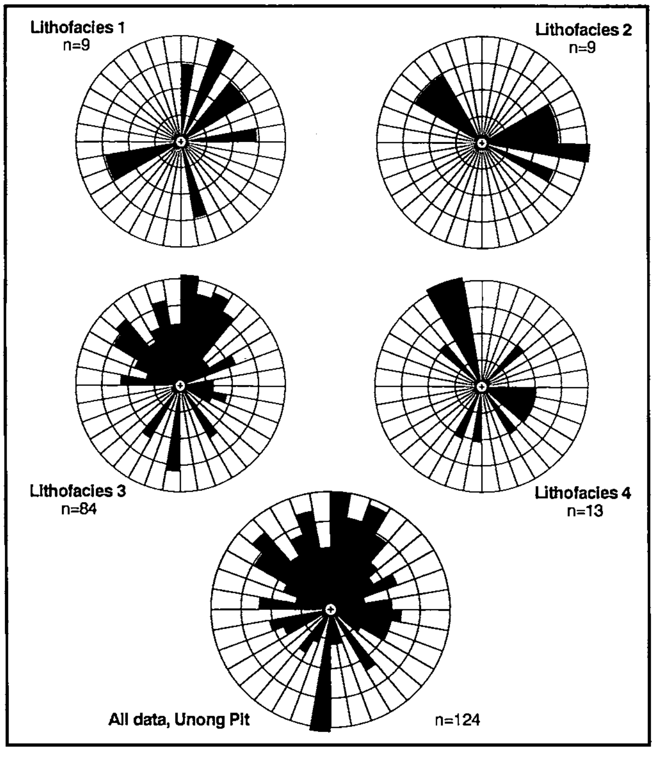

**Figure 5.** Palaeocurrent rose diagrams for the Semirara Formation in Unong Pit by lithofacies and all data using an equal area projection.

Lithofacies 4 contains thin sandstones and conglomerates often with coarse gravel to pebble grade intra and extra formational conglomerate clasts. The conglomerates include extraformational clasts of vein quarts and chert. The intraformational clasts include reworked pyrite concretions, amber and mudstone clasts. The thickness of the units is generally less than three metres. Palaeocurrents measured from lithofacies 4 have a particularly wide dispersion (Fig. 5) with no clear palaeocurrent trend. These thin units of sandstone with conglomerate are interpreted as the deposits of small high energy braided streams (Allen, 1978 and 1983; Bluck, 1979; Rust, 1978; Williams and Rust, 1969). The abundant intraformational conglomerate clasts indicate reworking of Semirara Formation sediments. Some of the mudclasts may have been derived from reworking of overbank material as the rivers migrated across their floodplain but the abundant reworked pyrite and carbonate concretions suggests some tectonic uplift and erosion of intrabasinal clastics. Uplift and an increase in slope would also explain the change in character of the fluvial systems with small high energy braided streams sourced from intrabasinal highs.

Lithofacies 5 contains intensely bioturbated fine grained silty sandstone with a carbonate cement and occasional bioclasts including gastropods and bivalves. The fauna indicates a marine environment and lithofacies five is interpreted as shallow marine sandstones. Primary sedimentary structures have been totally overprinted by bioturbation so it is not possible to determine the dominant shallow marine processes or any palaeocurrent from these sandstones. The sandstones are enclosed within siltstones, they could be distal mouthbar deposits but they do not appear to be part of a complete coarsening upwards deltaic sequence. The lack of a delta top facies associated with these sandstones does not preclude a deltaic setting but the lack of coarsening upwards sequences throughout the exposed section suggests that the fluvial-marine transition may have been estuarine rather than truly deltaic. The silt content and carbonate cement in these sandstones results in low porosity and relatively low reservoir quality.

Lithofacies 6 contains bioturbated medium grey to dark grey siltstones with occasional thin sandstones. These sediments are often bioturbated and contain thin shelled bivalves and occasional gastropods. The fauna and bioturbation indicate a shallow marine depositional environment with low energy, where thin shelled bivalves lived and fine grained silts were deposited from suspension. At outcrop these siltstones appear to be quite rich in organic matter and are predicted to have a moderate source potential.

Lithofacies 7 contains pale grey, medium grey and brown siltstones and claystones with occasional plant fragments. These sediments are generally structureless, occasionally laminated or ripple laminated. Lithofacies 7 is generally found in association with the fluvial sediments (lithofacies 1 - 4) and the coal seams lithofacies eight. They are interpreted as floodplain deposits. The colour changes are attributed to changes in organic content. Brown siltstones are rich in disseminated organic matter, while the pale grey siltstones and claystones which are often found beneath coal seams have been leached by organic acids during early diagenesis.

Lithofacies 8 is coal. The coals in the Semirara Formation are subituminous, bright and fissile. The thickness of the exposed seams vary from a few centimetres to 25 m. They contain remains of tree trunks which appear to be smooth trunked and circular. The abundant amber associated with the coals suggests that these trees may have been conifers. However, there are other trees in the Philippines including 'Almaciga' which produce resin. One of the tree trunks also carried markings which resemble a tree fern. Seam splits are generally silt grade with roots or coalified tree trunks, these are interpreted as flood deposits from the river channels. Changes in dirt content within the seams may reflect the proximality of river channels.

### Palaeocurrents

Plotting all the palaeocurrent data from Unong pit on a rose diagram shows a broad palaeocurrent trend towards the north (Fig. 5). The discrete southerly component is almost entirely due to the lowest sandbody exposed in the section. Interpreting the southerly palaeoflow from this sandbody presents a problem, does it represent a complete change in regional palaeoslope? Or, is it an exceptional result? Unfortunately the position of this sandstone at the base of the pit prohibits testing these ideas.

Breaking the palaeocurrent data down by facies (Fig. 5) reveals some interesting results. Lithofacies 1 shows a very broad spread of palaeocurrents with a dominant trend towards the northeast. The broad spread of results may be attributed to be meandering nature of the channels in this lithofacies (Le Roux, 1992). However, the small number of measurements (9) from this facies gives a high degree of uncertainty to this interpretation. Lithofacies 2 shows a strong bimodal palaeocurrent distribution which could be interpreted as opposite bends from point bars within a lithofacies 2 meander belt. The small number of observations (9) implies a relatively low degree of confidence for this interpretation. Lithofacies 3 shows a broad spread of palaeocurrent measurements with a dominant trend towards the north. This pattern is typical of braided stream deposits (Miall, 1974; Williams and Rust, 1969; Shelton *et al.*, 1974) and the large number of observations (84) gives a relatively high degree of confidence in this interpretation. Lithofacies 4 shows a very broad palaeocurrent divergence. The southeasterly trend is unusual and is rare in other facies, it is possible that this trend may be due to changes in palaeoflow influenced by intrabasinal tectonic uplift. This interpretation is consistent with the rejuvenation of the braided streams and intrabasinal conglomerates in lithofacies 4.

### Sandstone petrography

The sandstones of the Semirara Formation are lithic arenites with reworked chert, monocrystalline quartz, polycrystalline quartz and lithic fragments as the dominant clasts. The sandstones contain subrounded clasts of moderate to high sphericity in a grainstone fabric. Sorting varies from good to moderate which is not unusual for fluvial sandstones. The sandstones generally show good porosity, up to 30% in thin section, and are predicted to have high permeabilities. Porosity is largely primary and intergranular with variable amounts of secondary porosity due to dissolution of feldspars during uplift and weathering. The major porosity occluding phases are iron oxide cements and calcite cements. The iron oxide appears to be a weathering effect and is unlikely to be present at depth. The carbonate cement usually occurs as large diagenetic concretions which locally reduce porosity to zero but these are widely spaced and have a maximum diameter of two to three metres and should not form major permeability barriers.

Some of the detrital chert clasts contain *Radiolaria* indicating derivation from reworked oceanic sediments while the polycrystalline quartz and rock fragments show high pressure metamorphic fabrics. The K feldspar is probably derived from granitic material, possibly from a calc-alkaline arc on an active continental margin. Some feldspar has been removed during diagenesis but the feldspar content is still less than I would expect for sandstones derived directly from an active arc, or from an active continental margin. The dominance of chert is most significant and suggests that the sediments are second cycle material and that the major source is reworking of uplifted sedimentary rocks. The provenance of the Semirara Formation sandstones is interpreted as a mixed sedimentary and metamorphic terrain. The relative maturity of the sandstones and the size of the rivers implies a large drainage basin and transport on the order of hundreds of kilometres.

## *Sequence development*

Through the 400 m section exposed in Unong Pit there are marked vertical changes in facies (Fig. 5). At the base of the section a medium grained fluvial sandstone with a quartz pebble conglomerate and southerly palaeoflow is exposed. This is overlain by thin coals and floodplain siltstones which pass up into shallow marine sandstones and siltstones at 50 m. The sequence is then dominated by siltstones and fluvial channel sandstones of lithofacies 3 and 6 with occasional marine incursions (lithofacies 5) up to the base of the main coal seam at 128 m. Above the 25 m thick main seam the sequence is dominated by sandbed braided and meandering rivers, lithofacies 3 and 2, where the rivers were around 5-10 m deep. Above 250 m there is a change to thinner sandstones with conglomerate lags deposited by shallow braided streams with no clear palaeocurrent trend. At around 300 m there is a transition through large sandbed braided rivers into low energy mixed load meandering river sediments which dominate the sequence to the top of the exposed section.

## *Controls on sedimentation*

The vertical changes in facies described above are probably due to a combination of relative sea-level change and intrabasinal tectonic activity. The change from fluvial to shallow marine at the base of the section is due to a relative rise in sea-level. This could be due to an increase in subsidence, a decrease in sediment input or an absolute rise in sea-level. At present it is not possible to determine which, although tectonic activity is suspected to have had the most significant effects on sedimentation in an extensional half graben (Leeder and Gawthorpe, 1987). The cause of the change in

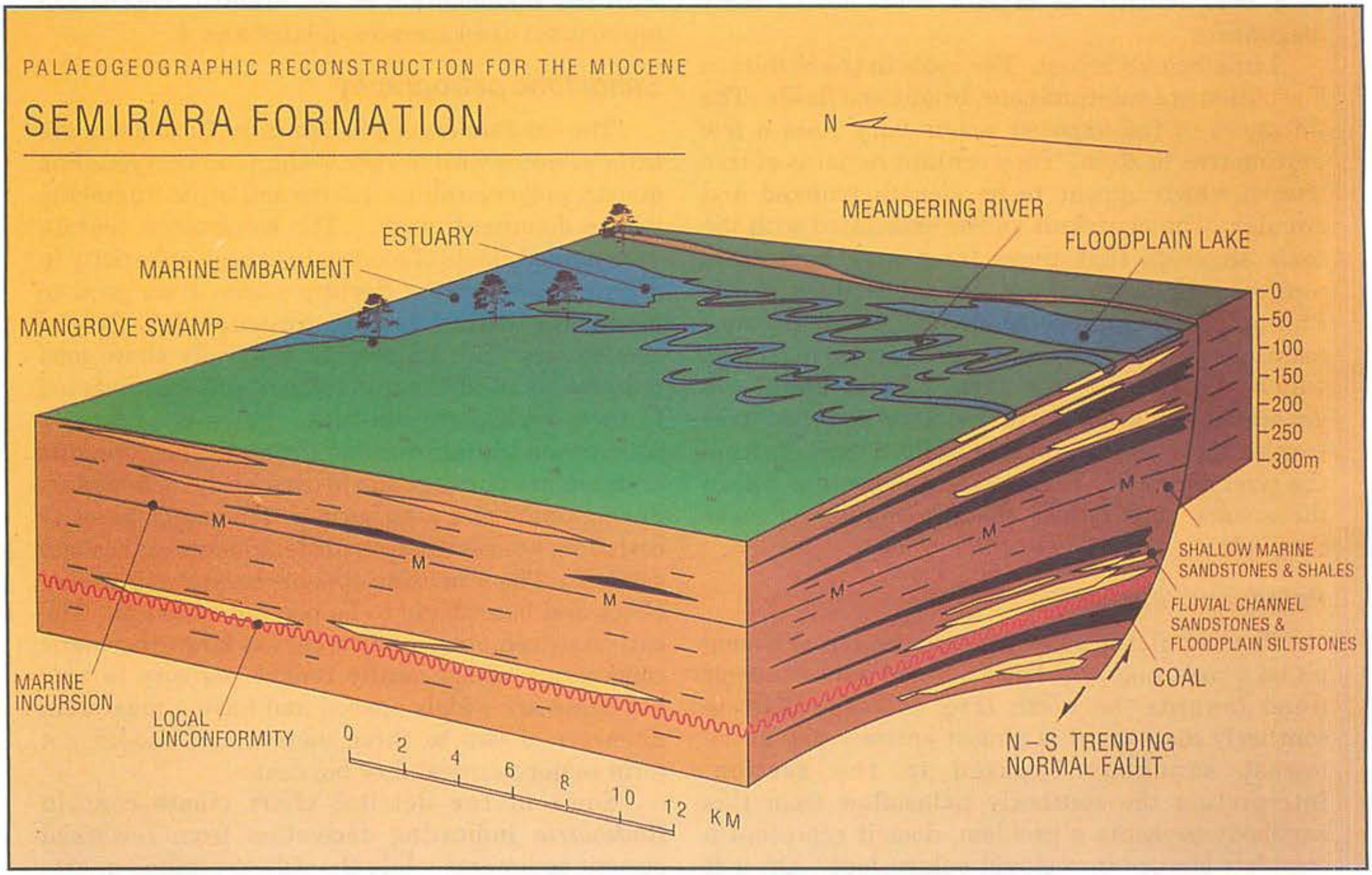

**Figure 6.** Facies model for the Semirara Formation in the Upper Miocene as exposed in the Unong Pit on Semirara Island.

palaeocurrents from a southerly direction in the lowest sandbody to a dominantly northerly direction is also unknown, although tectonic tilting has been shown to have a considerable affect on river behaviour (Alexander and Leeder, 1987). It may be a coincidence that this change appears to occur across a marine incursion, the cause of which is uncertain as discussed above, although tectonic subsidence is again suspected as the dominant control. Further evidence for active tectonics is the presence of synsedimentary seismic activity indicated by the abundant soft sediment deformation in the fluvial sandstones (Leeder, 1987).

Reworked concretions, coal clasts and amber in lithofacies 4 indicate contemporary uplift and erosion of intrabasinal sediments. Tectonic uplift could also explain the change in fluvial character from large sandbed, extrabasinal, river systems, to smaller, shallow braided streams with intrabasinal conglomerates and the change in palaeocurrents. The change to mixed load meandering river deposits above 310 m indicates a marked decrease in depositional gradient and a change to lower energy sedimentation which could be due to tectonic activity in the hinterland, a decrease in palaeoslope due to base level rise, or possibly a climatic change.

These changes imply an overall tectonic control on sedimentation which is reflected in the palaeogeographic reconstruction of the Semirara Formation (Fig. 6). The reconstruction is based on the section exposed in Unong Pit and the surface shown represents a palaeogeography at the time of deposition of Upper Rider Three. The illustration shows a meandering river (lithofacies 1) flowing north along the axis of a tilted half graben. On either side of the river fine grained floodplain siltstones (lithofacies 7) are being deposited in the overbank environment and within small abandoned oxbow lakes. Coal swamps (lithofacies 8) are developed in larger lakes in depressions on the floodplain surface. The river is shown debouching into an estuarine system flanked by mangrove swamps, with open marine conditions developed to the north. In cross-section sediments are shown thickening into a half graben basin with coal seams and fluvial channel deposits increasing in thickness towards the fault. The cross-section also includes occasional intraformational unconformities, possibly linked to intrabasinal seismic activity which may also have controlled the changes in vertical sequence described above. Reverse movement along this structure has uplifted the Upper Miocene Semirara Formation and probably generated the inversion anticline exposed in Unong Pit. The petrography of the sands shows that sedimentation occurred outside the influence of the Philippines volcanic arc. It is suspected that collision with the arc occurred in the latest Miocene. The collision changes the basin setting from extensional to compressional, reversing fault movement and inverting the basins. There is clear picture of sequential inversion from North to South through the Tablas, Semirara and Sibay basins as deformation extended into the Mindoro-Palawan microcontinent from the NE. The present tectonic resetting of the basins appears to be transpressional within a sinistral strike slip regime.

## CONCLUSIONS

The Miocene sediments on Semirara Island are exposed in an opencast coal mine at Unong where 400 m of section have been measured. The Semirara Formation exposed on Semirara Island is a continental clastic sequence with minor marine incursions. The overall depositional setting is interpreted as a low lying coastal plain. Environments of deposition include sandbed braided and meandering rivers, mixed load meandering rivers, shallow braided streams, floodplain lakes, coal swamps, estuarine and shallow marine sediments. Palaeocurrent measurements indicate a dominant palaeoflow towards the north, with a broad spread due to the variable orientation of braided and meandering channels on the coastal plain. The sandstones are mostly medium grained well sorted lithic arenites with chert and polycrystalline quartz as the dominant detrital minerals. The petrography of the sandstones indicates derivation from a mixed sedimentary and metamorphic terrain. The sediments are relatively mature, and a transport distance of hundreds of kilometres is possible. The net to gross in the section exposed in Unong Pit is almost 50%, sandbody thickness varies from a few metres to metres. The thickest sandbodies are made up of stacked channel sequences, maximum channel depth is around 10–13 metres, sandbody width is predicted to be around 1 km, with such a high net to gross there should be good interconnection. The fluvial sandstones of the Upper Miocene Semirara Formation have excellent reservoir quality. Shallow marine sandstones contain more detrital clay and authigenic calcite cement, they have lower porosity and permeability than the fluvial sandstones. The palaeogeographic reconstruction suggests that reservoir quality may decrease towards the north but that source potential may increase in more distal shallow marine facies. The sedimentary sequence appears to change vertically with braided river sandstones and occasional shallow marine estuarine incursions at the base overlain by a thick coal seam. Above the coal meandering river sandstones are dominant but these pass up into small, shallow braided river deposits. At the top of the section in the Panian area the sandstones are red, this could be attributed to a change in climatic to more arid conditions but may also be due to recent weathering. Controls on sedimentation are believed to have been primarily tectonic. Thickness changes seen on seismic sections indicate active differential subsidence during the Miocene and extensive soft sediment deformation in the sandstones is attributed to seismic shock induced dewatering. It is likely that the distribution of fluvial facies which are the best potential reservoir sandstones in the area will be strongly influenced by subsidence and synsedimentary tectonics.

## ACKNOWLEDGEMENTS

The author would like to thank Kirkland Resources and their partners: Monument, Oriental Petroleum and Minerals and Petrofields Exploration and Development for funding this study. The author would also like to thank Semirara Coal Corporation and its employees for their cooperation in allowing unlimited access to outcrops within Unong Pit, and providing essential support in the field on Semirara Island. Particular thanks are owed to George Baquiran (Resident Vice President), Cesar Villanueva (Resident Geologist) and Herminio Garrido (Engineering Geologist) for their assistance and cooperation and last but by no means least Nelson Laban who is a most able field assistant.

## REFERENCES

Alexander, J. and Leeder, M.R., 1987. Active tectonic control on alluvial architecture. *In*: Ethridge, F.G., Flores, R.M., and Harvey, M.D., 1987, (Eds.), Recent developments in Fluvial Sedimentology. *SEPM special publication* 39, 243-252.

Allen, J.R.L., 1978. An exploratory quantitative model for the architecture of avulsion-controlled suites. *Sedimentary Geology*, 21, 129-147.

Allen, J.R.L., 1983. Studies in fluviatile sedimentation: Bars, Bar-complexes and sandstone sheets (low sinuosity braided streams) in the Brownstones (L. Devonian), Welsh Borders. *Sedimentary Geology*, 33, 237-293.

Bird, P.R., Quinton, N.A., Beeson, M.N., and Bristow, C.S., in press. Mindoro: a rifted microcontinent in collision with the Philippines volcanic arc, basin evolution and hydrocarbon potential. *Proc. GEOSEA VII Bangkok.*

Bird, P.R., Cartwright, P., Moffat, D. and Bristow, C.S., in prep. Geology of the Mindoro area. *Proc GEOCON 92 Conf. Manila, December 1992.*

Bluck, B.J., 1979. Structure of coarse grained braided alluvium. *Trans. Roy. Soc. Edinburgh.* 70, 181-221.

Briais, A., Patriat, P., and Tapponier, P., in press. Updated interpretation of magnetic anomalies and seafloor spreading stages in the South China Sea: Implications for the Tertiary tectonics of SE Asia. *Journal of Geophysical Research.*

Cant, D.J. and Walker, R.G., 1976. Development of a braided fluvial facies model for the Devonian Battery Point Sandstone, Quebec. *Can. Jour. Earth Sci.* 13, 102-119.

Cant, D.J. and Walker, R.G., 1978. Fluvial processes and facies sequences in the sandy braided South Saskatchewan River, Canada. *Sedimentology*, 25, 625-648.

Leeder, M.R., 1987. Sediment deformation structures and the palaeotectonic analysis of extensional sedimentary basins. *In:* Jones, M.E., and Preston, R.M.F. (Eds.), Deformation in sediments and sedimentary rocks. *Geological Society of London Special Publication 29*, 137-146.

Leeder, M.R., and Gawthorpe, R.L., 1987. Sedimentary models for extensional tilt-block/half graben basins. *In*: Coward, M.P., Dewey, J.F. and Hancock, P.L. (Eds.), Continental extensional tectonics. *Special Publication of the Geological Society of London 28*, 139-152.

Le Roux J.P., 1992. Determining the channel sinuosity of ancient fluvial systems from palaeocurrent data. *Journal of Sedimentary Petrology*, 62, 283-291.

Marchadier, Y., and Rangin, C., 1990. Polyphase tectonics at the southern tip of the Manila trench, Mindoro-Tablas Islands, Philippines. *Tectonophysics* 183, 273-287.

Miall, A.D., 1974. Palaeocurrent analysis of alluvial sediments: a discussion of directional variance and vector magnitude. *Journal of Sedimentary Petrology* 44, 1174-1185.

Rangin, C., Stephan, J.F., and Muller, C., 1985. Middle Oligocene oceanic crust of South China Sea jammed into Mindoro collision zone (Philippines). *Geology*, 13, 425-428.

Rust, B.R., 1978. Depositional models for braided alluvium. *In*: A.D., Miall (Ed.), Fluvial Sedimentology. *Memoir of the Canadian Soc. of Petroleum Geologists*, 5, 605-625.

Sarewitz, D.R., and Karig, D.E., 1986. Processes of allochthonous terrane evolution, Mindoro Island, Philippines. *Tectonics* 5, 525-552.

Shelton, J.W., Burman, H.R. and Noble, R.L. 1974. Directional features in braided meandering deposits, Cimarron River, North Central Oklahoma. *Journal of Sedimentary Petrology*, 38, 747-754.

Smith, D.G., 1987. Meandering river point bar lithofacies models: modern and ancient examples compared. *In*: Ethridge, F.G., Flores, R.M., and Harvey, M.D., 1987 (Eds.), Recent developments in Fluvial Sedimentology. *SEPM special publication 39*, 83-91.

Taylor, B., and Hayes, D.E., 1983. Origin and history of the South China Basin. *In*: Hayes, D.E., (Ed.), The tectonic and geologic evolution of southeast Asian seas and islands: Part 2. *Geophysics monograph*, 27, 23-56.

Vergara, J.F., 1956. Reconnaissance geologic map of Semirara Island, Philippine Bureau of Mines, 1 sheet.

Williams, P.F. and Rust, B.R., 1969. The sedimentology of a braided river. *Journal of Sedimentary Petrology*, 36, 649-679.

*Manuscript received 30 November 1992*