The structural style of Lower Miocene sedimentary rocks, Kudat Peninsula, Sabah

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Abstract: Kudat Peninsula, consist mostly of Lower Miocene sedimentary rocks that shows a complex structural style due to continuous deformation. The deformation produced large-scale folds on three major imbricate thrust slices that trends WNW-ESE in the northern, middle and southern part of the peninsula. The northern thrust slice shows a huge fold plunging steeply to the southeast. The middle thrust slice shows a Z-shaped drag fold, whereas the southern thrust slice shows a W-shaped fold pattern. The Bangau Fault Zone and Parapat Fault Zone which are characterised by melange separates the northern, middle and southern thrust slice is separated from the Crocker Formation by the Laya-laya Fault Zone. The deformation was probably caused by progressive N-S transpression related to the collision of the Dangerous Grounds with NW Sabah along the NW Borneo Trough.

INTRODUCTION

Northwest Sabah, which includes the Kudat Peninsula, exhibits a complex structural style. Offshore, NE-striking structural grain changes sharply to E-striking (Mazlan Madon et al., 1999). The E-striking structural grain changes further to SE-striking onshore Kudat Peninsula (Tongkul, 1990). A better understanding of the geological structures onshore Kudat Peninsula can benefit hydrocarbon exploration activities offshore. Earlier work in the Kudat Peninsula by Ibrahim Abdullah et al. (1996) identified three domains, each having different structural style and regional trend, but was not able to elaborate on how these structural domains developed. This paper presents additional insights on the structural elements and deformation mechanism of the Kudat Peninsula. The study utilised radar images to complement field work carried out intermittently over the past few years.

REGIONAL GEOLOGICAL SETTING

Tectonic Setting

The northern part of Sabah lies adjacent to the rifted continental margin of southern China, presently occupied by the Reed Bank and Dangerous Grounds carbonate platform (Fig. 1). The opening of the South China Basin during the Oligocene-Middle Miocene (Taylor & Hayes, 1983; Briais *et al.*, 1993) has had a profound impact on the geology of NW Sabah. Southward drifting of the continental margin collided with the Mesozoic and Tertiary rocks in this region producing regional fold-thrust belts trending NE-SW and NW-SE offshore and onshore north Sabah (Hinz *et al.*, 1989; Rangin *et al.* 1989; Hazebroek & Tan, 1993; Tongkul, 1990, 1994).

General Geology of North Sabah

The northern part of Sabah consists of several rock

units (Fig. 2). The basement rocks comprise ophiolites associated with sedimentary rocks like chert, sandstone and mudstone, representing the oldest rocks. The basement is interpreted as remnants of ancient oceanic crust which formed during the Cretaceous (Tongkul, 1994). This rock unit can be found on the islands of Banggi, Malawali and Balambangan, with several minor occurrences in Kudat and Bengkoka Peninsulas (Wilson, 1960). It has undergone intense tectonic deformation characterised by shearing and brecciation, mostly oriented NW-SE.

Several sedimentary rock units overlie the basement. The deep-water clastic turbidite deposits of the Crocker Formation forms the dominant formation. It comprises a rhythmic alternation of sandstones and mudstones, probably deposited during the Eocene-Oligocene. It has also undergone intense deformation producing a fold-thrust belt oriented NW-SE across Kudat and Bengkoka peninsulas (Tongkul, 1994).

Closely associated with the Crocker Formation is the deep to shallow water Kudat Formation which was probably deposited during the Lower Miocene. This rock unit comprises interbedded sandstones and mudstones with some occurrences of limestone lenses and beds (Stephens, 1956; Tongkul, 1994). It has also undergone intense deformation, which produced complex fold patterns, especially in the Kudat Peninsula (Ibrahim Abdullah *et al.*, 1996).

Chaotic deposits, characterised by dismembered blocks of older rocks inside a clay matrix, occur in the Kudat Peninsula (Tongkul, 1990) and Bengkoka Peninsula (Sanudin *et al.*, 1992). They are interpreted to represent tectonic melange due to major fault movements in this region.

Younger sedimentary rock units of Miocene-Pliocene age, such as the South Banggi, Bongaya and Timohing Formations are mostly shallow marine clastic and carbonate deposits with some occurrence of fluvial deposits. They occur in Bengkoka Peninsula, Jambongan



Figure 1. Tectonic setting of Northern Sabah. The rifted continental margin of China impinging on NW Borneo-Palawan region. Based on Rangin (1989), Hinz *et al.* (1991), Hamilton (1979), Taylor and Hayes (1983) and Briais *et al.* (1993).

Island, Banggi Island and Balambangan Island (Stephens, 1956; Wilson, 1960; Tongkul, 1990, 1991). These rock units have undergone mild tectonic deformation producing open fold structures.

Lithostratigraphy of Kudat Peninsula

The stratigraphy of the Kudat Peninsula is still not clearly understood. Based on available data, the area may be divided into two major sedimentary rock units - the Kudat Formation occupying most of the peninsula and the Crocker Formation occupying the southern part of the peninsula (Fig. 3). The relationship between the two formations is still uncertain - the division adopted here is based on scarce paleontological evidence obtained by Stephens (1956) and on their structural style. The Crocker Formation is interpreted to be of Eocene to Early Miocene age, whereas the Kudat Formation of Lower Miocene age. The Crocker Formation shows characteristics of deep-water depositional environment, whereas the Kudat Formation shows both characteristics of deep-water and shallow-water depositional environments. It is possible that the Kudat Formation was deposited in a shelf-slope environment. Both formations presumably lie on top of the basement rock comprising of Cretaceous-Paleocene ophiolitic sequence.

The Kudat Formation has initially been subdivided into several members (Garau, Tajau, Sikuati, Gomantong, Dudar, Sirar) by Liechti et al. (1960). This has not been followed here due to the confusing nature of the subdivisions. Instead, the Kudat Formation is divided into there major informal unit, a Lower, Middle and Upper, referring to significant changes in the composition of the sediments (see Fig. 3). The Lower Unit comprises mostly sandstone and mudstone, where sandy beds predominate (Fig. 4). It outcrops at the northen tip of Kudat peninsula, coinciding with the Tajau Member of Liechti et al. (1960). The Middle Unit comprises sandstone and mudstone with some occurrences of limestone beds and lenses. Here, mudstones appear to predominate occupying the middle part of the Kudat Peninsula (Figs. 5 & 6). The sequence has been referred to previously as the Sikuati Member. The Upper Unit comprises sandstone and mudstone of various proportions and occupies the southern part of the peninsula and was referred to previously as the Gomantong Member (Fig. 7).

A chaotic deposit showing a linear distribution occurs within the Kudat Formation. It comprises various lithologies in a mixed grey and red mud matrix. It is referred to informally here as a melange deposit, interpreted to have formed sometime after the deposition of the Kudat Formation.

STRUCTURAL ELEMENTS

The Kudat Peninsula shows elongate strike ridges trending in various directions (see Fig. 3). The diverse orientation of strike ridges is due to the presence of largescale folds and faults. The sedimentary sequences in the area generally dip steeply and in places are closely folded and faulted.

Folds

Several large-scale folds occur across the peninsula. A huge fold plunging steeply to the ESE occurs at the northern part of Kudat and affects the Lower and Middle Unit of the Kudat Formation. A Z-shaped drag fold with its axis trending approximately NW-SE affects the Middle Unit of the Kudat Formation near Sikuati (Fig. 8). A W-shaped fold pattern occurs at the southern part of the peninsula and affects the Upper Unit of the Kudat Formation. Within the large-scale folds several outcrop-scale folds occur (Fig. 9,10 & 11). The medium and small-scale folds shows steep plunge and resemble drag folds.

Faults

Several large-scale strike-slip faults trend approximately NW-SE cutting through the strike ridges (see Fig. 3). The most notable strike-slip fault, referred to as the Bangau Fault Zone, extends from Tg. Bangau to Kudat Town. Along its path blocks of the Kudat Formation together with older basement rock units are embedded in



Figure 2. Regional geology of Northern Sabah. Based on Mazlan *et al.*, (1999), Tongkul (1994) and Stephens (1956).



Figure 3. Geological map of Kudat Peninsula showing the distribution of the Lower, Middle and Upper Units of the Kudat Formation. The structural cross-section illustrates the style of folding and the location of three major fault zones.



Figure 4. Steeply dipping sandstone with thin mudstone interbeds near Suangpai, typical of the sandy Lower Unit of the Kudat Formation.



Figure 6. Steeply dipping limestone beds near Dampirit occur within the Middle Unit of the Kudat Formation.



Figure 5. Vertically dipping grey mudstone with thin sandstone interbeds near Sikuati Town typical of the muddy Middle Unit of the Kudat Formation.

a sheared mud matrix, mapped as a melange deposit. The fault shows a dextral sense of movement based on fault plane markings (Fig. 12). Further south another NW-SE trending strike-slip fault, referred to as the Parapat Fault Zone extends from Tg. Terongkongan to Tg. Parapat separating the Z-shaped and W-shaped fold pattern. Blocks of the Kudat sediments inside a sheared mud matrix occur near Kg. Parapat Darat. A NE-SW trending fault, referred to as the Laya-laya Fault Zone separates the Kudat Formation from the Crocker Formation. Along this fault zone, deformed and sheared layers of the Crocker sediments occur. Within the three major fault zones several



Figure 7. Overturned sandstone beds showing sole markings near Indarasan Laut occur within the Upper Unit of the Kudat Formation. Notice the conjugate sets of fractures on the sandstone surface.



Figure 8. Structural sketch map of Sikuati area showing largescale and medium-scale Z-shaped folds.

outcrop-scale thrust faults occur, usually associated with abrupt change in bedding orientations. Small-scale thrust faults associated with drag folds are common (see Fig. 10).

STRUCTURAL EVOLUTION

Deformation Mechanism

The occurrence of steeply plunging folds and refolded folds clearly indicates that Kudat Peninsula experienced polyphase deformation. The presence of Z-shaped drag folds suggests transpressional tectonics may have been involved.

It is envisaged that early N-S directed deformation produced several E-W trending thrust-fold slices on the



Figure 9. Steeply plunging Z-shaped fold cut through by NW-SE trending faults near Sikuati Secondary School.

Kudat sediments and underlying ophiolitic basement. Each slice was between 8-10 km wide and separated by detachment or slip zones. Within each thrust slice, minor folds (F1) and thrust faults developed causing repetition of the Kudat sediments (Fig. 13a).

Later NW-SE directed deformation produced horizontal movement along each of the major detachment zones causing second generation drag folds (F2) to develop within each thrust slice (Fig 13b). The different types of folds within individual thrust slices was possibly related to the competency of the Kudat sedimentary sequence. The occurrence of more competent sandy beds in the Lower Kudat Unit produced a steep plunging fold structure. The development of the huge fold was possibly accompanied by intense shearing along the detachment zone, producing the melange deposit here. In the more muddy Middle and Upper Kudat Units a contorted Z and W-shaped fold pattern developed (Fig. 13c).

Origin of Deformation

It is envisaged that the N-S directed transpressional deformation, originated from the collision of the Dangerous Grounds and Reed Bank with NW Sabah along the NW Borneo Trough during the Middle Miocene (see Fig. 1). As the continental margin of southern China progressively impinged upon northern Sabah an E-W trending fold-thrust belt developed earlier was further shortened and bent south-eastward with a significant dextral strike-slip component (Fig. 14).

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Figure 10. Structural sketch of a small-scale fold near Kg. Lajong. Notice the similarity in its style of folding, faulting and younging of beds to the large-scale structures of Kudat Peninsula.

Figure 11. Steeply plunging fold with associated thrust fault near Kg. Lajong shown in Fig. 10.



Figure 12. Fault plane cutting sandstone showing dextral sense of movement. The fault is a NW-SE strike-slip near the Basel Church, Lau San.

REGIONAL IMPLICATION

The folds and faults seen onshore Kudat Peninsula appear to be part of a larger structural feature in the northern Sabah region. It is quite possible that the style of deformation onshore Kudat Peninsula may well continue offshore (see Fig. 2) and has affected younger structures. This would imply that faults identified to show vertical movement offshore (e.g. Bonanza Fault) may have experienced significant horizontal movement during its early development. Synclines shown to be linear and continuous offshore (e.g. Furious, Pritchard and Bunbury Synclines) may have a more complicated geometry. Reassessment of the structures offshore in this region would therefore benefit from a better understanding of the onshore geology.



Figure 13. Schematic model to show the deformation mechanism of Kudat Peninsula. See text for explanation.



Figure 14. Schematic tectonic model to show how the Paleogene-Neogene fold-thrust belts evolved in North Sabah.

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