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# Layer-Block Tectonics, a New Concept of Plate Tectonics - An Example from Nansha Micro-Plate, Southern South China Sea

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## 1. Introduction

The Layer-block tectonics (LBT) is a new theory describing the layer-slip structure of lithosphere (Liu et al., 2002, 1999; Sun et al., 1991). According to this theory, a lithosphere plate, continental lithosphere plate in particular, is considered a composite of sub-plates connecting with each other horizontally and overlapping with each other vertically. The term "Layer" in the LBT emphasizes the rheological and stratifying characteristics of the lithosphere and the guiding and controlling role of mechanically "soft" layers with different deepness in the layer-slip movement of the lithosphere during the process of tectonic deformation. The term "block", on the other hand, emphasizes the discontinuity of various types of geological bodies segmentalized by dip-slip or strike-slip movement of lithosphere in horizontal direction. We use the concept of the LBT to cover the scientific thoughts of the other tectonic theories such as the gliding of layers (Mandle and Shippan, 1981), the flake tectonics (Oxburgh, 1972), the terrane tectonics (Irwin, 1972), the capped plates (Coleman, 1977), the extensional tectonics (Wernike, 1988, 1981), and so on. The obvious different of the LBT from the these tectonic theories, even from the plate tectonics theory, is that the LBT emphasizes the geotectonic effect of multi-levels of gliding surfaces within lithosphere-upper mantle including rheospheric top surface, Moho surface, mid-crust, top surface of sedimentary basement, and so on, rather than only emphasized singular Moho gliding surface in flake tectonics or the plate tectonics.

The lithosphere can be divided into different layers by the characteristics of material, energy, structure, rheological and chemical stratification at different depths (Su et al., 1996; Song et al., 1996; Wang et al., 1996; Wang, 1992; Rushentsev and Trifonov, 1985; Oxburgh, 1972). These layers interrelate with each other and stack-and-piece together to form an integral lithospheric aggregate. As the manifestation of this nature of stratification, the LBT is the result of bedding layer-slip, dip-slip (both in positive and negative direction) and strike-slip (in slant direction, sinistral or dextral) of geologic bodies under tectonic forces (vertically or horizontally).

All layer-block structures in various scales, whether large as the global lithosphere plate or small as a dislocation structure, have a common slip mechanism, and the "4-dimensional

interrelated-action" faults enclosing them (Liu et al., 2002). The term "4-dimensional interrelated-action" means that dip-slip - layer-slip - strike-slip fault systems consisting of 3-dimensional edge faults which dynamically originated from the same layer-blocks should act jointly and synchronously (three dimensions of space plus one dimension of time), and the layer-blocks would hardly move when lacking any of these dimensions. This leads to the following principle of layer-block partition. Each level of layer-block is defined by slip surface and the "4-dimensional interrelated-action fault system" as boundaries. After each level of layer-block is defined, we will analyze the overlap and joint layer-blocks according to "Overpass-type" movement and the rules of multiple geodynamic systems, and finally draw an outline of the evolution of crust and upper mantle.

According to the depth of layer-slip surface, on which layer-block moves, and the depth of the boundary faults, there are 4 categories: ultra-crustal (incising depth is deeper than the base of lithosphere), crustal (incising depth reaches Moho discontinuity), basemental (incising depth reaches middle crust), and cover (incising depth is above the sedimentary basement) layer-blocks.

Then Nansha Micro-plate is located at the junction of modern Eurasian plate, the Pacific Plate, and the Indo-Australia Plate. Its geological structure is extremely complex. Based on comprehensive analysis of gravity, magnetic, seismic profiles with a total length of about 30,000 km (Yan and Liu, 2004; Liu et al., 2004, 2002, 1999; Schluter et al., 1996; Bai et al., 1996; Hinz et al., 1989; Hinz and Schuler, 1985) and relevant geological data, and in the light of the above-mentioned concepts and principle of partition of the LBT, we divided the Nansha Micro-plate into 6 layer-blocks, i.e., Nansha Ultra-crust Layer-block, Zengmu (Loconia, ZCL in Fig. 1), Nanwei (Riflemam Bank) - Andu (Ardasier Bank) (NCL in Fig. 1), and Liyue (Reed Bank) - North Palawan (LCL in Fig. 1) Crustal Layer-blocks, and Andu - Bisheng (Pearson Reef) (ABL in Fig. 1) and Liyue - Banyue (Half Moon Reef) (LBL in Fig. 1) Basemental Layer-blocks. We also discussed the forming mechanism of these layer-blocks.

Nansha plate is a Cenozoic micro-plate inherited with Mesozoic marine facies strata, magmatic rock and metamorphic rock basement (Liu et al., 2004; Kudrass et al., 1986). It is circled by several large plate-edge basins, such as, Wan'an (west Vanguard bank) basin, Zengmu basin, and Nansha (Borneo-Palawan) trough basin etc., and occupied by a number of intraplate basins. We give their initial division scheme on basal fault system and intra-plate basins in Nanwei - Palawan sea area in the east of Lizhun (Grainger bank)- Tinjar fault (LTf in Fig.1) in Nansha Micro-plate, and present an analysis on the forming mechanism of basal faults controlling the intra-plate basins, on the basis of geological and geophysical data, especially those of seismic profiles, of Nansha area, former research (Liu et al., 2002; Sun et al., 1991).

## **2. Characteristics of layer-block tectonic of the lithosphere of Nansha micro-plate**

### **2.1 Nansha Ultra-crustal Layer-block**

The Nansha Ultra-crustal Layer-block is defined by the ultra-crustal layer-slip surface, i.e. the bottom of Nansha lithosphere, and four boundary fault systems (Liu et al., 2004, 1999) as the controlling boundaries of its overall movement (Tab. 1 and Fig. 1). These boundary fault systems include the Kangtai - Xiongnan (Kangxiong for short, KXf in Fig. 1) ultra-crustal extending and slipping fault zone (in the north), Baxian (southwest Zengmu shoal)-Cuyo (Bacu for short, BCf in Fig. 1) ultra-crustal thrusting fault zone (in the south), Mindoro - Panay ultra-crustal strike-slip fault zone (Minpan for short, which is in the east and serves as

a coordinating role, MPf in Fig.1) in the east, and the Wan'an - Natuna (Wanna for short, WNf in Fig.1) ultra-crustal strike-slip fault zone (in the west).

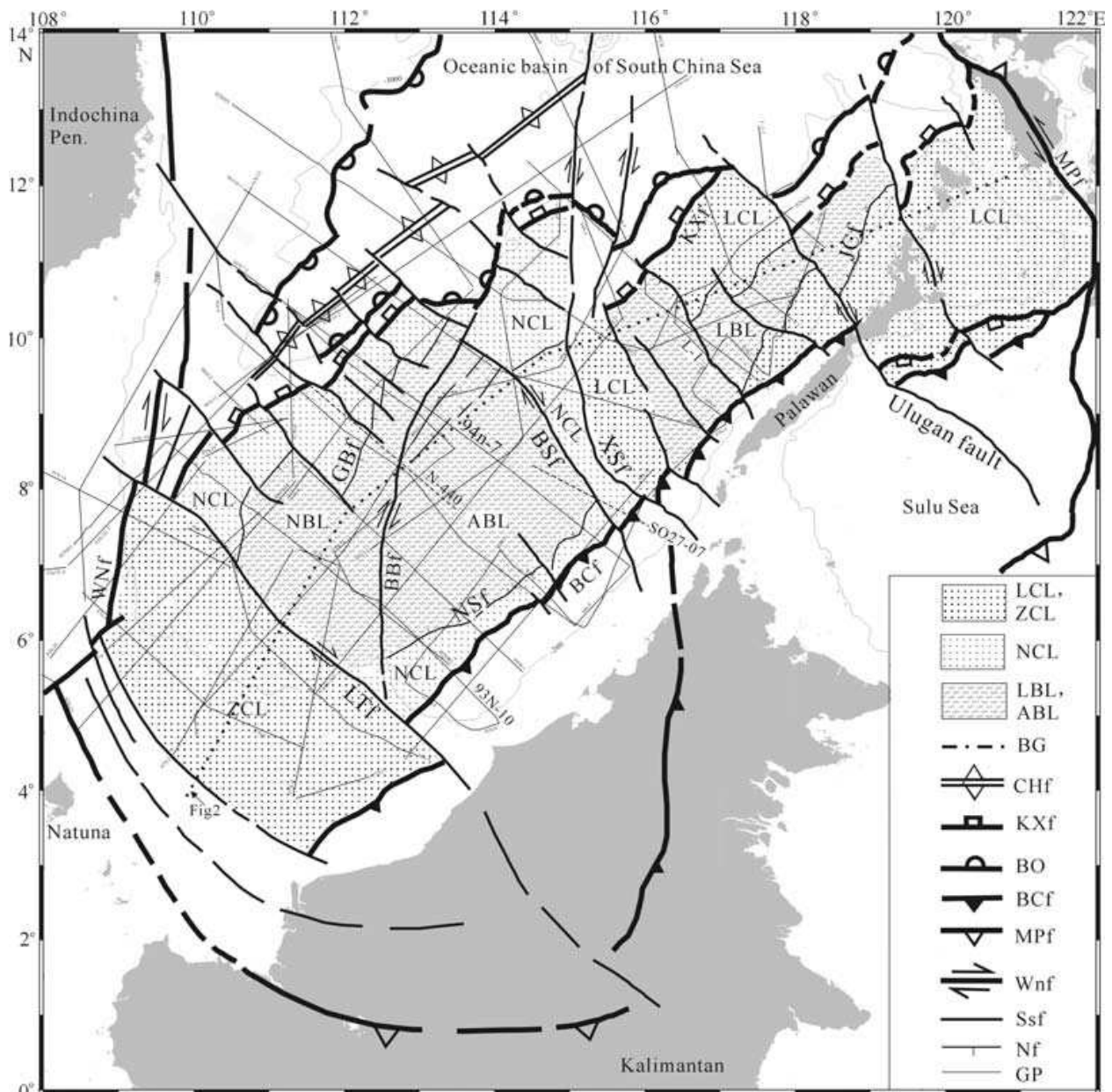


Fig. 1. Layer-block tectonics in Nansha micro-plate.

ABL= Andu - Bisheng basemental layer-block; BBf = Bisheng-Beikang fault zone; BCf = Baxian - Cuyo thrust-nappe fault zone; BO = Boundary of deep oceanic basin; BSf = Bisheng - Siling fault zone; CHf = Changlong - Huangyan (Scarborough Island) sea-floor spreading ridge fault zone; GBf = Guangya - Bisheng fault zone; GP=Geophysical profiles; Jcf = Jianzhang - Calawit fault zone; KXf = Kangtai - Xiongnan extending and gliding fault zone; LBL = Liyue - Banyue Basemental Layer-block; LCL = Liyue - North Palawan Crustal Layer-block; LTf = Lizhun - Tinjar fault zone; MPf = Mindoro - Penay compressive strike-slip fault zone; NCL = Nanwei - Andu Crustal Layer-block; Nf = Normal fault; NSf = Nantong - Siling fault zone; Ssf = Secondary strike-slip fault; Wnf = Wan'an - Natuna strike-slip fault zone; XSf = Xiyue - Siling fault zone; ZCL = Zengmu Crustal Layer-block.



Name of layer-block		Layer-slip – dip-slip – strike-slip 4-dimensional interrelated-action fault system	
Nansha ultra-crustal layer-block		Nansha ultra-crustal layer-slip – fault system	Nansha ultra-crustal layer-slip surface Kangxiong ultra-crustal extending – gliding fault zone Bacu ultra-crustal thrusting – nappe fault zone Wanna ultra-crustal dextral pull-apart strike-slip fault zone Minban ultra-crustal sinistral compression – strike-slip fault zone
Crustal Layer-block	Zengmu crustal block	Zengmu crustal layer-slip – fault system	Zengmu lower-crustal layer-slip surface Wanna ultra-crustal dextral pull-apart strike-slip fault zone Lizhun-Tinjar crustal strike-slip fault zone Bacu ultra-crustal thrusting – nappe fault zone
	Nanwei-Andu crustal layer-block	Nanwei-Andu crustal layer-slip – fault system	Nanwei-Andu lower-crustal layer-slip surface Kangxiong ultra-crustal extending – gliding fault zone Bacu ultra-crustal thrusting – nappe fault zone Lizhu-Tinjar crustal strike-slip fault zone Xiyue-Siling crustal dextral strike-slip fault zone
	Liyue-North Palawan crustal layer-block	Liyue-North Palawan crustal layer-slip – fault system	Liyue-North Palawan lower-crustal layer-slip surface Kangxiong ultra-crustal extending – gliding fault zone Bacu ultra-crustal thrusting – nappe fault zone Xiyue-Siling crustal dextral strike-slip fault zone Minban ultra-crustal sinistral compression – strike-slip fault zone
Basemental Layer-block	Andu-Bisheng basemental layer-block	Andu-Bisheng basemental layer-slip – fault system	Andu-Bisheng middle crustal layer-slip surface Nantong-Siling basemental extending – gliding fault zone Guangya-Bisheng basemental extending – gliding fault zone Lizhun-Tinjia crustal strike-slip fault zone Bisheng-Siling basemental strike-slip fault zone
	Liyue-Banyue basemental layer-block	Liyue-Banyue basemental layer-slip – fault system	Liyue-Banyue middle crustal layer-slip surface Jianzhang-Calawit basemental extending – gliding fault zone Xiyue-Siling crustal dextral strike-slip fault zone Minban ultra-crustal sinistral compression – strike-slip fault zone

Table 1. 4-Dimension Interrelated-Action Fault Systems and Layer-blocks of Nansha Lithosphere

The geometry status of the Nansha ultra-crustal layer-slip surface can be imaged by the low speed layer ( $V_s < 4.7 \text{ km/s}$ ) of transverse wave shown in Fig. 2. The low speed layer of transverse wave can be considered as asthenosphere under Nansha lithosphere and lies in the depth between 58 to 148 km. The depth of the top surface of the low speed layer reaches the maximum value 74 km in the Nanwei bank - Taiping (Itu Aba) island area and rises gradually to the minimum value 58 km in southwest and northwest area i. e. in Borneo and Indochina block. The difference between the maximum and minimum is up to 16 km. The largest gradient is in the northwestern side of the Nansha Micro-plate (Fig. 3). In Nanwei bank - Taiping Island area, the thickness of this low-speed layer is 44 km, and in Borneo area in southwest, the thickness increase to 68 km. The thickness in northwest and Indochina area are up to 90 km. This kind of coupling relation facilitated the southward-southeastward migration of ultra-crustal layer-block of Nansha lithosphere along with the migration of mantle asthenosphere (Liu et al., 1999).

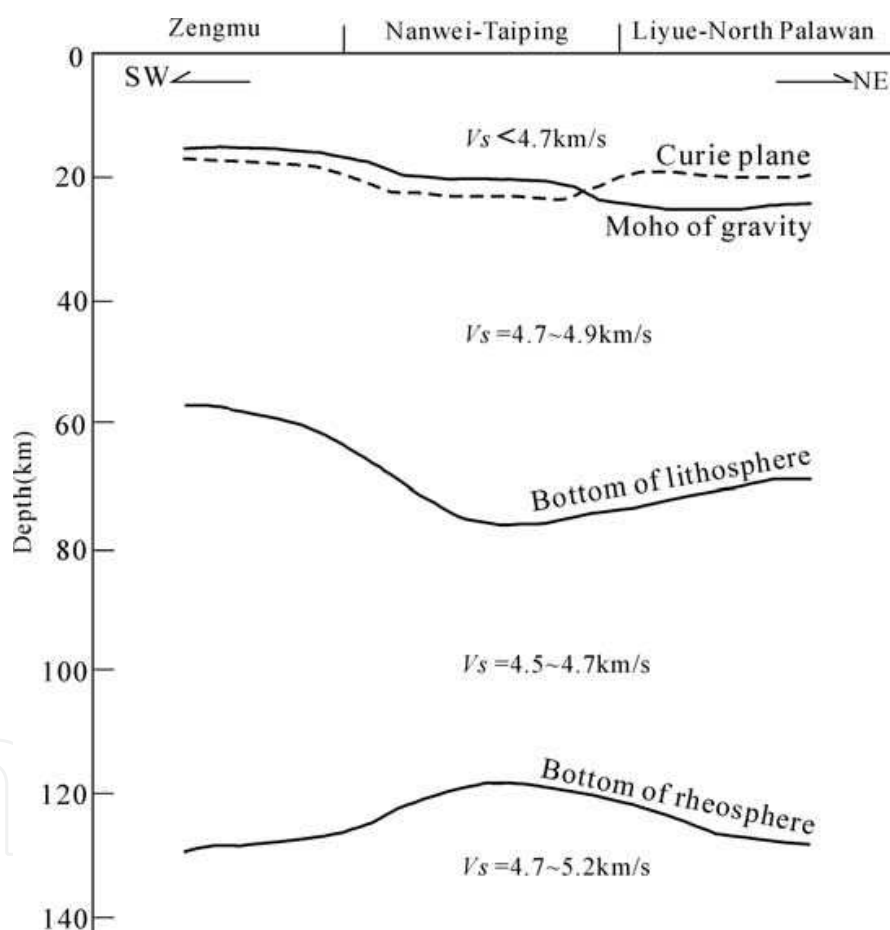


Fig. 2. Sketch map showing structural profile of crust—upper-mantle in southern South China Sea. After Wu et al. (1999), Xia (1997), Zhang et al. (1996), Yao et al. (1994), etc.. See Fig.1 for roughly location.

The above-mentioned 4 groups of dip-slip and strike-slip boundary fault zones, along with the ultra-crustal layer-glide surface, form an spatial and temporal kinematic system. This system constitutes a large-scale 4-dimensional interrelated-action fault system, i.e. the Nansha ultra-crustal layer-slip - dip-slip - strike-slip system, whose movement is unified in the overall southward drift.

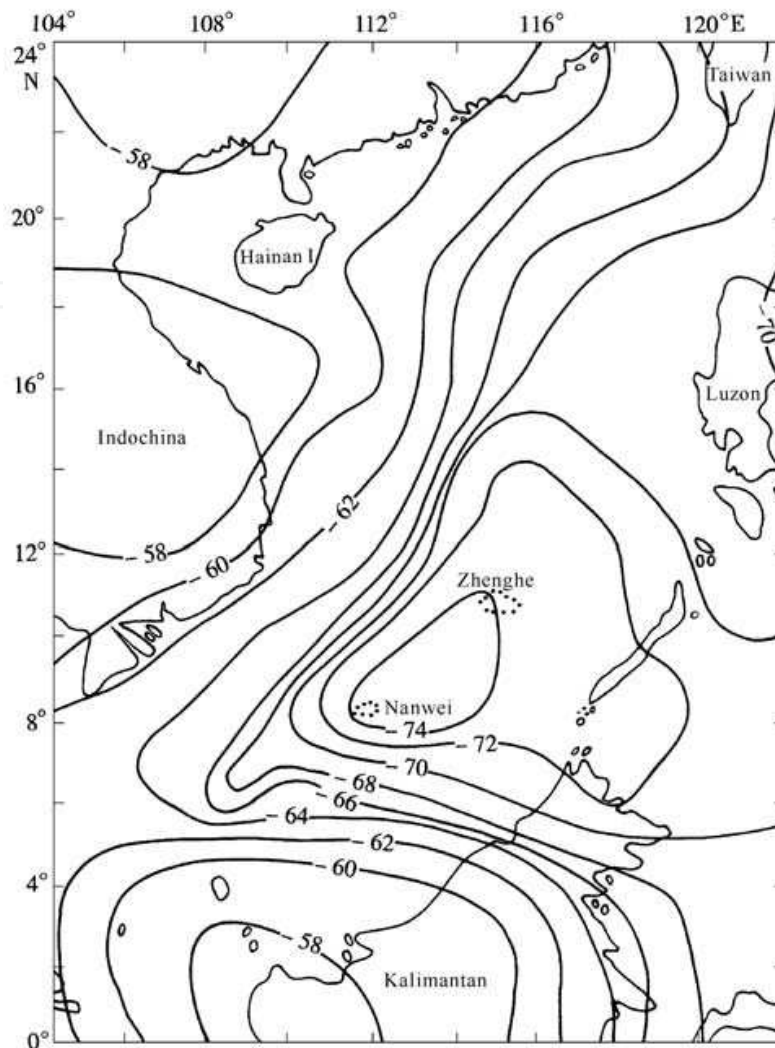


Fig. 3. Isobaths of lower boundary plane of Nansha lithosphere. The curves are drawn according to  $V_s=4.7\text{km/s}$ . The unit of the curves is km. Modified after Zeng et al. (1997).

## 2.2 Crustal layer-blocks in southern South China Sea

The Nansha Ultra-crustal Layer-block can be subdivided into 3 crustal layer-blocks, i.e., the Zengmu, Nanwei - Andu, and Liyue - North Palawan crustal layer-blocks, which are controlled by the lower crustal layer-slip surface and crustal fault systems.

The lower crustal layer-slip surface is the relative gliding plane between crust and upper mantle. Generally, it is a sharp seismic wave velocity interface corresponding Moho discontinuity. Sometimes it can be a transitional thin layer with gradually changing of wave velocity, or an obscuring interface, or a composite layer alternated with high and low velocity fine layers. Considering its property, it can be a chemical interface, or mineral phase changing interface, or even a mechanically non-capable layer, which is the reflection of tensional cracks of rocks extensively developed under super-high static pressure. The depth of Moho is an important parameter to decide the rheological characteristics of lithosphere and intra-plate strain caused by plate boundary forces. It indicates crustal maturity, crustal type, and isostasy degree, and controls the crustal layer-blocks formed by tensional breakup, separating, and downward sliding of crust.

In the southern area of the South China Sea, the depth fluctuating of Moho discontinuity is more complex than the ultra-crustal layer-slip surface. However, its general tendency of change is similar to that of ultra-crustal layer-slip surface as described above, and rises to SW-S. From Liyue bank in the NE, via Nanwei and Andu banks in the middle, to Zengmu basin in the southwest, the Moho changes roughly in three steps, from 24km (Liyue bank in the northeast) to 20km (in the middle) and to 16km (Zengmu basin)(Fig. 2). The magnetic survey (Fig. 4) also reflect the similar characteristics of portioned crustal blocks, which is supported by terrestrial heat flow field (Fig. 2). Each step platform can be considered as an independent layer-slip plane. In this way, we can think that there are three lower crustal layer-slip planes, the Liyue - North Palawan, Nanwei - Andu, and Zengmu lower crustal layer-slip planes, from northeast to southwest. The transitional slope zones are the fault zones, i.e. Xiyue (Yiyue or West York Island)- Siling (Commodore reef) (XSf in Fig.1) and Lihun - Tinjar (LTf in Fig. 1) crustal strike-slip fault zones incising the crust. These fault zones separate the three crustal layer-blocks above-mentioned.

### **2.3 Basemental layer-blocks in the southern area of the South China Sea**

Generally, basemental layer-blocks are partitioned by middle crustal layer-slip surface and dip-slip or strike-slip boundary fault zones that incise only to middle crustal layer-slip surface. The middle crustal layer-slip surface generally develops in middle-crustal layer. The middle crust is usually consisted of granite and dioritoid rocks, and is 8~20km in thickness and 10~15km in buried depth (Huang et al., 1994). Under normal geothermal conditions, this depth is adaptable for greenschist metamorphic process of quartz deformed from ductility to plasticity. In addition, since there are abundant of radioactive elements concentrated in this depth, local melting may occur. Therefore, it behaves plastically and rheologically. Above this layer-slip surface, there is the relatively brittle rigid layer of upper-crustal crystalline basement, which is consisted of granitoid intrusive rocks and metamorphic rocks; and below this layer-slip surface, there is the lower-crust consisted of relatively strong gabbroic rocks. The middle crust layer-slip plane can provide a space for the concentrated releasing of gravity energy and horizontal stress energy, downsiding, and inner-crust diving of upper crust. Because of the existence of this surface, the upper crust loses its tectonic deformation energy during the plastic flow process and becomes too weak to dive into lower crust due to insufficient energy. Most thick-skinned tectonics, such as Basin - Range Province and thrust-superimposed orogenic zone, are controlled by this layer-slip surface (Li et al., 1996).

Some signs of sliding of middle crust layer-slip surfaces have been revealed in the southern area of the South China Sea. By upward extrapolation of magnetic data with the steps of 5km, 10km, and 15km, respectively. We analyze the space characteristics of middle crustal layer-slip surface. As shown in Fig. 4, in the south of the area of Lihun (Grainger) bank - Yinqing (London) reefs - Feixin (Flat) island, the zero-contours of upward extrapolation of magnetic data show a SE-migration tendency of increasing with the step of upward extrapolation. According to this result, it can be concluded that there is a detachment surface with depth comparable to that of middle crust (about 10km in depth). The Andu-Bisheng and Liyue-Banyue basemental layer-blocks slid and tilted prominently into southeast direction along this surface.



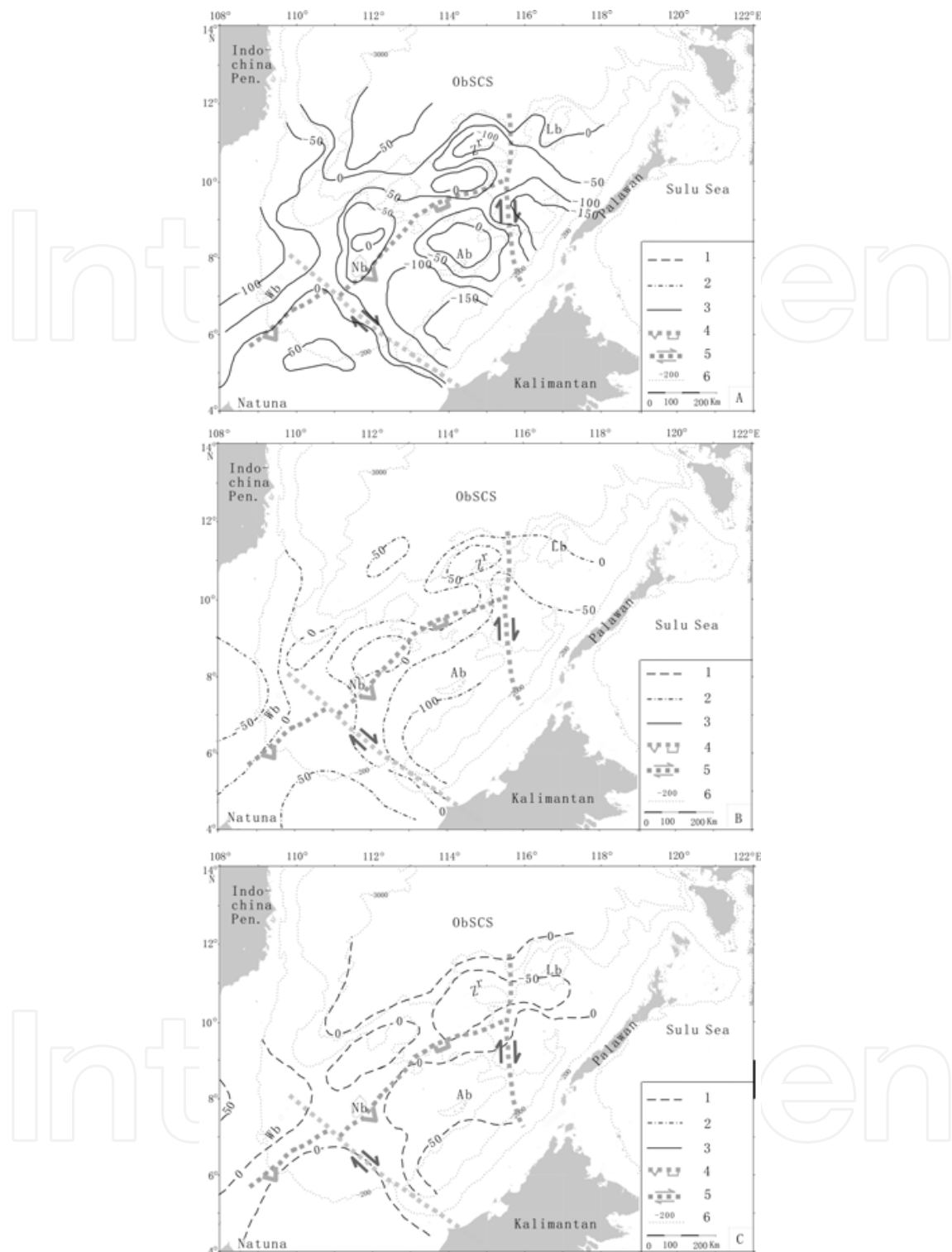


Fig. 4. Map showing magnetic anomaly curves of upward extrapolation for steps of 5, 10 and 15km in turn in southern South China Sea. A is for the step of 5 km, B is for 10km, and C is for 15km. 1=magnetic anomaly curves of upward extrapolation for the step of 15km; 2=magnetic anomaly curves of upward extrapolation for the step of 10km; 3=magnetic anomaly curves of upward extrapolation for the step of 5km; 4=Mid-crustal layer-slip plane; 5=Strike-slip fault zone; 6=Water isobaths; Ab=Andu bank; Lb=Liyue bank; Nb=Nanwei bank; OBSCS=Oceanic basin of South China Sea; Wb=WanAn bank; TP=Taiping island.

### 3. Characteristics of main intra-plate basins in Nansha area

Most basins, in particular those featuring of stretching, are caused by tilting or subsiding of the basement. This requires the existence of a “4-dimensional interrelated-action” (Liu et al., 2002) between boundary faults. Basemental layer-blocks control the formation of intra-plate basins. As shown in Fig. 5, we recognized 3 basin groups controlled by the basemental layer-blocks, i.e., Nanwei–Andu basin group (NBG in Fig. 5) in southwest, Liyue–Palawan basin group (LBG in Fig. 5) in east, and the Feixin–Nanhua (Cornwallis South Reef) basin group (FBG in Fig. 5) in between. The Nanwei–Andu basin group includes the well-know west Nanwei, east Nanwei, Beikang, and Andu basins etc. (Adb, Bkb, Wnb, and Enb in Fig. 5, in turn). The Liyue – Palawan basin group includes north Palawan, west Palawan and Liyue basins etc. (Npb, Wpb, and Lyb in Fig. 5, in turn) The Feixin–Nanhua basin group is a large-scale strike-slip basin in a whole. From Fig. 5, we can see that all these basin groups developed in different crustal layer-blocks, and are directly controlled by their basal layer-blocks respectively.

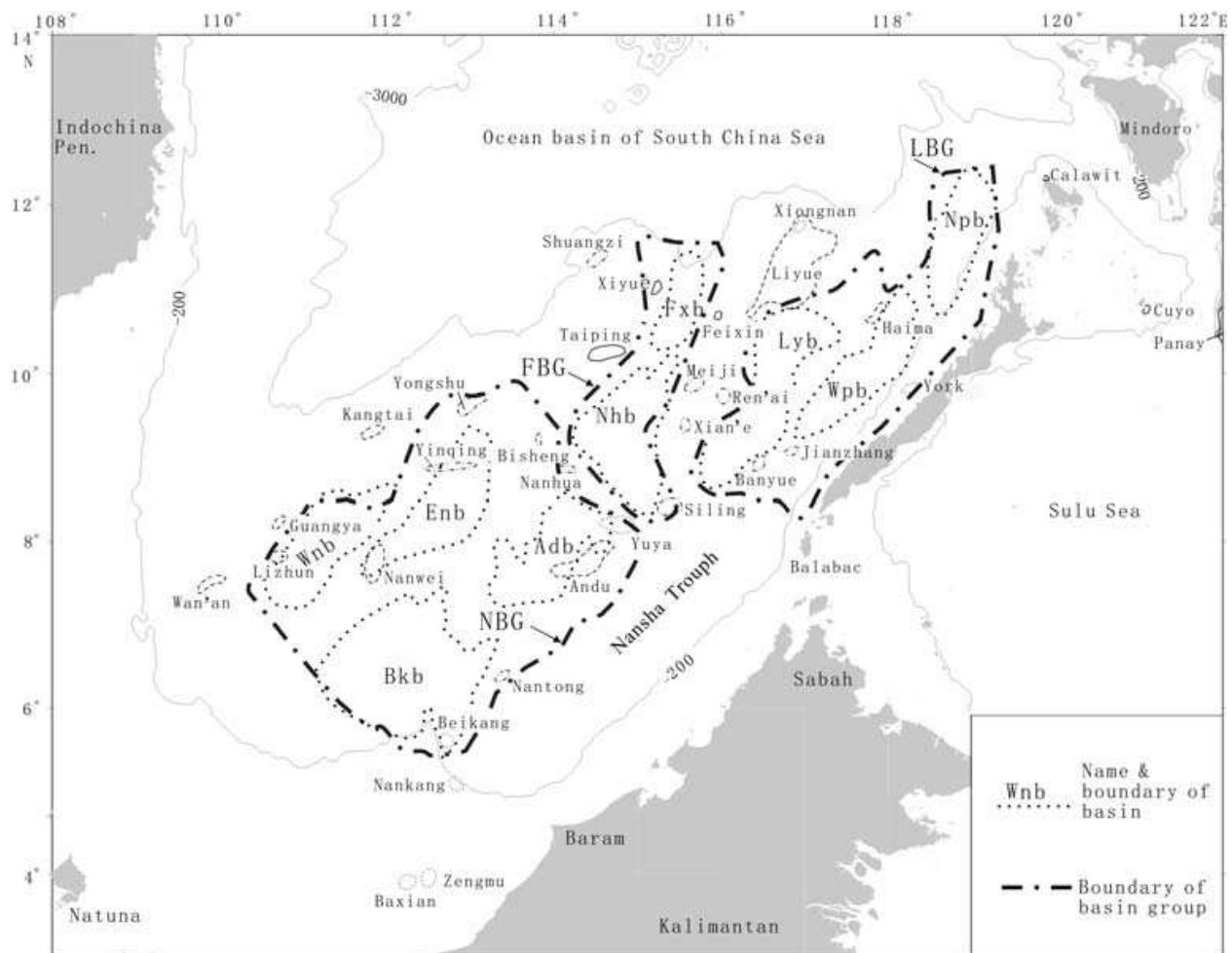


Fig. 5. Distribution of intra-plate basins in Nansha micro-plate.

Adb = Andu basin; Bkb = Beikang basin; Enb = East Nanwei basin; FBG = Feixin–Siling basin group; Fxb = Feixin basin; Lyb = Liyue basin; NBG = Nanwei–Andu basin group; Nhb = Nanhua basin; Wnb = West Nanwei basin; Wpb = West Palawan basin; Npb = North Palawan basin; LBG = Liyue–Palawan basin group.

### 3.1 Characteristics of Nanwei–Andu basin group and its basin-controlled faults

Nanwei–Andu basin group was developed in Nanwei – Andu crustal layer-block, and is controlled by the movement of Nanwei – Andu basemental layer-block. It is enclosed by Bisheng – Siling strike-slip fault zone (BSf in Fig. 1) in the northeast and Lizhun – Tinjar strike-slip fault zone (LTf in Fig. 1) in the southwest, and Nantong – Siling fault zone (NSf in Fig. 1) in the southeast and Guangya – Bisheng fault zone (GBf in Fig. 1) in the northwest. These fault zones share the Nanwei – Andu upper-crust layer-sliding surface, form a dip-slip – layer-slip – strike-slip system with “4-dimensional interrelated-action”, and control the formation of Nanwei – Andu basin group.

#### 3.1.1 Lizhun – Tinjar fault zone

It is a major NW-strike deformation zone in Nansha Islands. It is an apparent boundary line for both topography and geophysics. The magnetic field (Zhang et al., 1996), gravity field (Su et al., 1996a), and geothermal field (Ru and Pigott, 1986) across this line show great differences. It is a crustal fault deep through Moho. In Early Miocene, it was a dextral fault zone, with 100km horizontal offset (Young, 1976). In Late Miocene, it became sinistral. And from the Quaternary Period, it became dextral again. Its activities influenced the formation of the Andu–Bisheng crustal layer-block, and the Nanwei – Andu basin group.

#### 3.1.2 Bisheng – Siling basal strike-slip fault zone

The northwestern section of this NW direction fault zone passes the east of Bisheng Island, and its southeastern section runs to the east of Siling Reef, where it can be traced by observing the activities of Xiyue – Siling fault in its later period. It is located largely in Nanhua (Pigeon) waterway, and is consisted of several nearly parallel faults. Seismic profile shows a negative flower structure (Liu et al., 2002).

#### 3.1.3 Nantong – Siling basal extensional sliding fault zone

Basically, this zone is an extensional fault zone developed along the southeast of Nantong Reef – Siling Reef and the northern edge of Nansha Trough. It is consisted of several nearly parallel normal faults (Liu et al., 2002). Most of these faults are dip NW direction, except that the southwestern section runs in NEE-strike direction and the northeastern section runs in NE-strike direction. Its middle section is cut by several NW-strike translation faults. In the half graben formed through activities of this fault zone, the sedimentary covers started to develop in Paleocene Epoch. The half graben is filled with Paleocene to Early Oligocene clastic deposit. The activity of the faults was stronger during Late Oligocene to Early Miocene. From gravity and magnetism profile (Cui, 1996), it can be seen that this fault zone only disturbed into middle crust with the depth of 6~8km,. Its detachment surface is near ductile bed in the middle crust. The rock density above this depth is extremely inhomogenous but rather homogenous at 2.7 g/cm<sup>3</sup> in deep (see Fig. 6).

#### 3.1.4 Guangya – Bisheng basemental extending dip-slip fault zone

This fault zone controls the northwestern edge of Nanwei – Andu basin group. It dip to SSE or SE direction, and is intersected into sections by several NW strike-slip faults. In magnetic field map, this fault zone is located right at the transitional zone between a dome and a depression of the top-interface of the magnetic basement. The Nanwei – Andu basin group developed in the depression in the southeast of Guangya – Bisheng basemental extensional dip-slip fault zone.

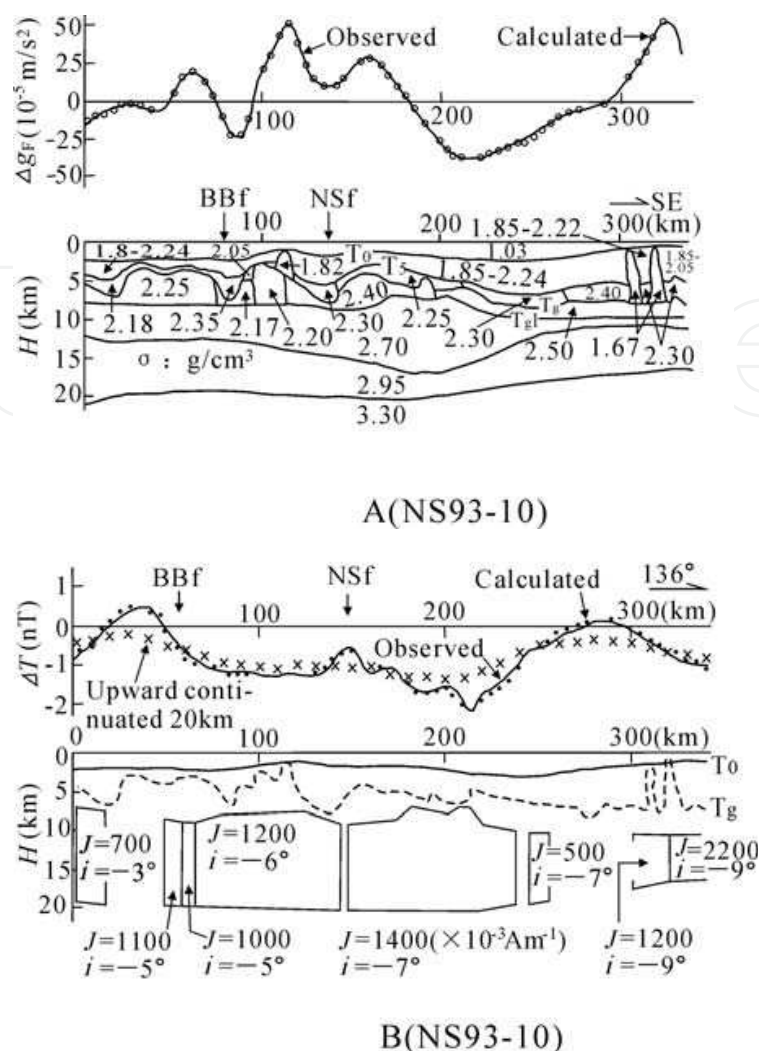


Fig. 6. Gravity and magnetic profiles crossing Nantong-Siling basemental extension fault zone. A = Gravity profile; B = Magnetic profile. BBf = Bisheng-Beikang fault zone; NSf = Nantong - Siling fault zone; Packed up from Cui (1996). See NS93-10 of Fig.1 for location of the profile.

### 3.1.5 Andu-Bisheng upper crust layer-slide surface

In the middle of Nansha Micro-plate and in the south side of Lizhun bank - Yinqing reefs - Feixin reef line, the zero contours of upward extrapolation of magnetic anomaly shows a tendency of southeastward drifting with increasing of the upward extrapolation steps (Liu et al., 2002). From this, it can be presumed that there exists a detachment surface extending along the layer in deep, which is called Andu-Bisheng upper crustal layer-slide surface, in the middle crust (about 10km in depth). Andu-Bisheng upper crustal block (i.e. Andu-Bisheng basemental layer-block) slips and tilts along this surface southeastward, and formed a series of NE basemental depressions in the northwestern edge. The aerial magnetometer measurement conducted by Aero-Geophysical Prospecting and Remote Sensing Center of Chinese Ministry of Geology and Mineral Resources, also revealed the basemental depressions and shows that the central basement of the depressions is 2~4km deeper than that of the two sides (Liu et al., 2002).



### 3.1.6 Nanwei – Andu Basin Group

From seismic profiles (Fig. 7), this group can be easily seen a complex, a face-to-face dip-slip faulted-block group, and is consisted of multiple half grabens and horsts controlled by primary face-to-face tilting boundary faults. Two primary boundary-controlled faults, Guangya - Bisheng and Nantong - Siling positive dip-slip - extending faults (Fig. 7, 8), extend into depth, decouple, flatten gradually, and merged into the Andu-Bisheng middle crustal layer-slide surface. The main activities of the faults happened between Early Tertiary and Early Miocene. They started to subside in late Early Paleocene, earlier than that in Zengmu basin (Zhong et al., 1996, 1991). Among the basins, the Beikang and West Nanwei basins reached their peaks of tectonic subsidence at middle Eocene period, with 0.2~0.3km/Ma and 0.6km/Ma subsidence rate respectively. The extension coefficient of the Beikang basin is 1.4~1.72. In Late Eocene, the thermal subsidence became stronger, and steep tectonic subsidence appeared in Pliocene.

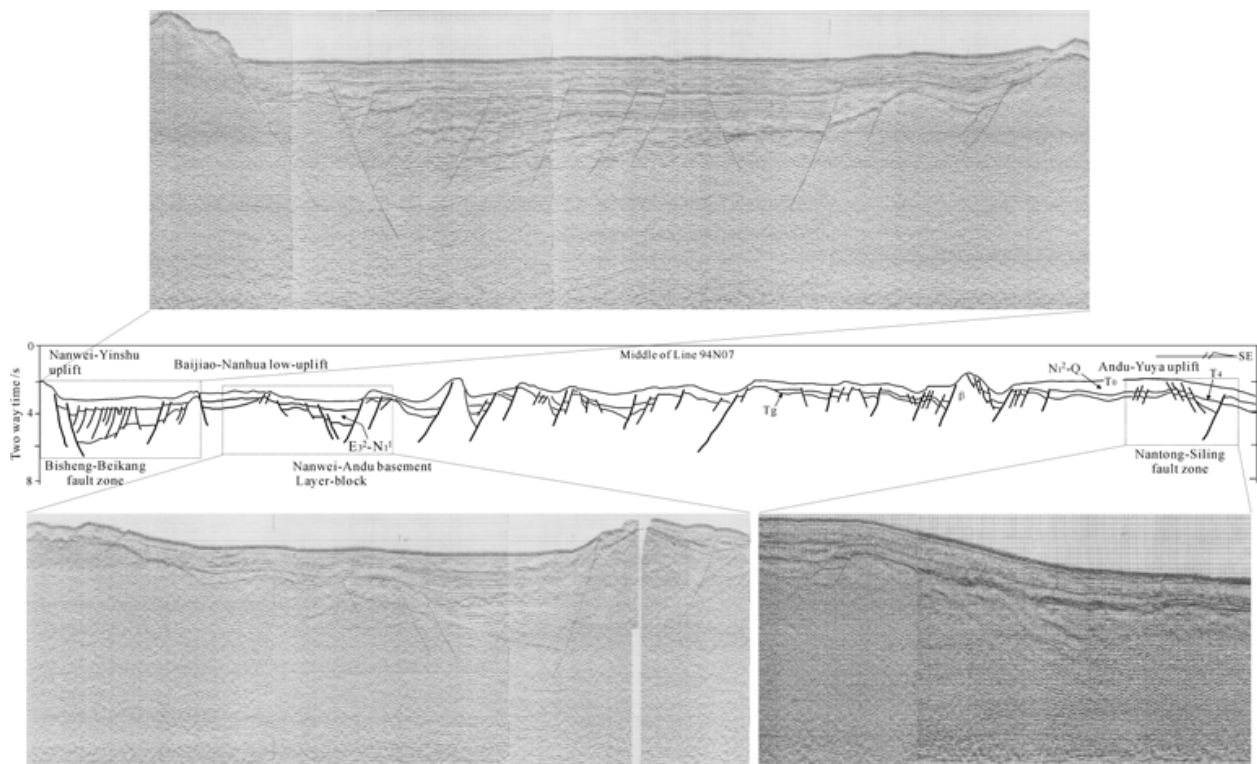


Fig. 7. Interpreted seismic profile 94N07 transecting Nanwei-Andu basemental layer-block. See Fig.1 for the location of the profile.

### 3.2 Basic characteristics of Liyue – Palawan basin group and its basin-controlling faults

Liyue – Palawan basin group developed in Liyue – North Palawan crustal layer-block, and is controlled by Liyue – Banyue basemental layer-block. The dip-slip – layer-slip – strike-slip “4-dimensional interrelated-action” fault system, which encloses the basemental layer-block and controls the formation of this basin group, is consisted of Minpan ultra-crustal sinistral compression and strike-slip zone in east and Xiyue-Siling crustal dextral strike-slip zone (XSf in Fig. 1) in west, Jianzhang (Royal Captain Shoal) – Calawit (Island) basemental extending positive fault zone (JCf in Fig. 1) in south, and Liyue – Banyue middle crustal layer-slide surface.

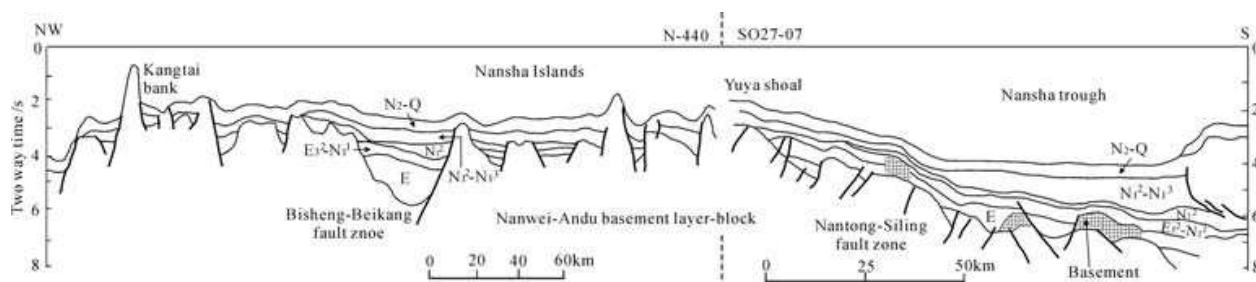


Fig. 8. Interpreted seismic profiles transecting Nanwei-Andu basemental layer-block A = profile transecting eastern part (SO27-07) and western part (N-440) of Nanwei-Andu basemental layer-block. See Fig.1 for locations of the profiles.

### 3.2.1 Minpan ultra-crustal sinistral compression – strike-slip zone

This zone connects northwards with the passive subduction zone in the east of South China Sea oceanic crust (i.e. Manila trench), and extends to Taiwan Island. In the south, it extends to Negros and Cotabato trenches, subduction zones of Sulu and Sulawesi oceanic crusts. These two trenches started their arc activities in Late Miocene (7Ma) and Early Pliocene (Pubellier et al., 1991). From Taiwan Longitudinal Valley to Cotabato trench, the entire fault zone becomes the boundary between Eurasian Plate and West Philippine Oceanic Plate. It is obvious that this fault zone has been active for a long time. It is a ultra-crust strike-slip fault zone cutting deep into lithosphere, and significantly influenced the development of Nansha Micro-plate.

### 3.2.2 Xiyue – Siling crustal dextral strike-slip fault zone

This fault runs along a NS-strike trough to the west of Liyue Bank. Its southern section is merged into the southeastern section of NW-strike Nanhua waterway and turned into SE direction. The Xiyue – Siling crustal strike-slip fault zone starts from the southern edge of the oceanic basin of the South China Sea, passing through the west of Liyue Bank and east of Siling Reef, and enters into the lowest section of Nansha Trough (water depth is larger than 3300m). Southward, it extends into Sabah area, and separates the EW-strike structure of northeastern Sabah and NE-strike structure of southwestern Sabah (Yao, 1995; Tongkul, 1990). This fault zone is reflected on both magnetic and gravity fields. Together with Lizhun – Tinjar crust strike-slip fault, it cut into Nansha lower crust layer-slide surface and made it a three-level step-like structure. The southern section of this fault zone is rather steep, with deeper sections inclining to the east and converging into the layer-slide surface of Liyue – North Palawan lower crust.

The strata on each side of the fault are different. The lower structural layer in the east is Early Jurassic delta –shallow-marine facies sandstone-mudstone to Early Cretaceous littoral to shallow-marine facies coal-bearing clastic rock series (Kudrass et al., 1986; Taylor and Hayes, 1980). In the west, the lower structural layer of northwest part of Nansha Islands is even older, and may be the Triassic marine sedimentation. The strata of the middle structural layer in the east are thin in Ren'ai (Second Thomas) Reef – Liyue Reef area, to less than 1km mostly. They are a set of unmetamorphic Paleocene – Eocene delta facies and open shallow sea – half deep-marine facies clastic deposit. The age of strata filling in the bottom of half grabens lasted into Late Cretaceous. The middle structural layers in the west, however, are rather thick to 1~3km. The thickest layer appears near Nankang (South Luconia) shoal, to 4.5km in thickness, with half graben deposits filled in its lower part, and sheet-like

draping layers in its upper part (Liu et al, 2007). The Late Oligocene to Early Miocene shallow-sea platform layered carbonate rock of the upper structural layer just distributes evenly in the areas on the two sides of Xiyue – Siling fault zone.

There are at least two apparent tectonic events. The earlier one cut into lower Miocene series, and the later one cut into Pliocene series to Quaternary system (Hinz and Schuler, 1985). From seismic profiles (Hinz and Schuler, 1985), it can be seen that strike-slip and extension events cause the formation of apparent half graben structures, and the throw of the faults are 1.7~3.0s (two way time). The events of the north part stopped at the end of middle Miocene; the south part, however, continued till Recent due to the Sabah thrust (Yao, 1995). Its activity is directly related to the formation of Nanwei – Andu and Liyue – North Palawan crustal layer-blocks, Liyue – Banyue basemental layer-block, Liyue – Palawan basin group, and the Feixin – Nanhua basin group.

### **3.2.3 Jianzhang – Calawit extending – dip-slipping fault zone**

This fault zone starts from the northwest of Calawit Island of Calamian Islands (Fig.5). In the north, it extends to Minpan ultra-crustal sinistral trans-compression – strike-slip zone. To the east of Jianzhang shoal in southwest, it submerges under the progressive thrusting and mélangé wedge of South Palawan. The fault zone ends at Balabac – Balukelo regional shear fault, which is out of the eastern beach of Sabah. This fault zone is cut into several sections by a series of NW or near NS-strike transcurrent faults. The major transcurrent faults include the Ulugan dextral strike-slip fault (Fig.1). Numerous profiles show that the extension – detachment actions of this fault zone occurred from the Late Cretaceous to early Early Tertiary, and these tectonic activities caused the formation of asymmetrical half graben sedimentary basin (which is deep in southeast and shallow in northwest). The extension fault developed in Pre-Oligocene stratum sequence. Only a few faults in southwestern sections cut into the overlapping carbonate sequence (Late Oligocene-to-Early Miocene Nido formation) or Quaternary system. The extension – detachment surface, which dips in NW direction, is steep at upper part and gentle at lower part. It converges into the plastic layer-slide surface in middle crust, and extends to Moho at some extremely thin sectors (Schluter et al., 1996). It seems that there were at least twice compressive thrusts occurred in the northeast of the fault zone. The earlier one was in about Paleocene-to-Middle Eocene ( $E_1 - E_2^2$ ) and the later was after Early Miocene, caused an extensive faulting in northeast of Liyue – North Palawan area and in the Pre-Oligocene sedimentary delta wedge in the south of Liyue bank.

One of the results of the event of this fault zone is the formation of a complex half graben structure in NE-SW-strike direction, with its southeastern part subsided and northwestern part uplift (i.e. deep in southeast and shallow in northwest). This makes the platform-like top of Liyue – Banyue basal layer-block inclines to southeast as a whole, and deepens gradually as it runs into Palawan trough (Fig. 9).

### **3.2.4 Liyue – Palawan basin group**

It includes North Palawan, West Palawan and Liyue basins etc. It developed in the middle-south of Liyue – Banyue basal layer-block, and its long-axis is generally in NE direction. It began to subside as Nanwei – Andu basin group (Zhong et al., 1991; Ru and Pigott, 1986) at the Late Paleocene (B. P. 55Ma). In Early Eocene, it subsided rapidly to 1.1km, and then subsiding process slowed down (Zhong et al., 1991).



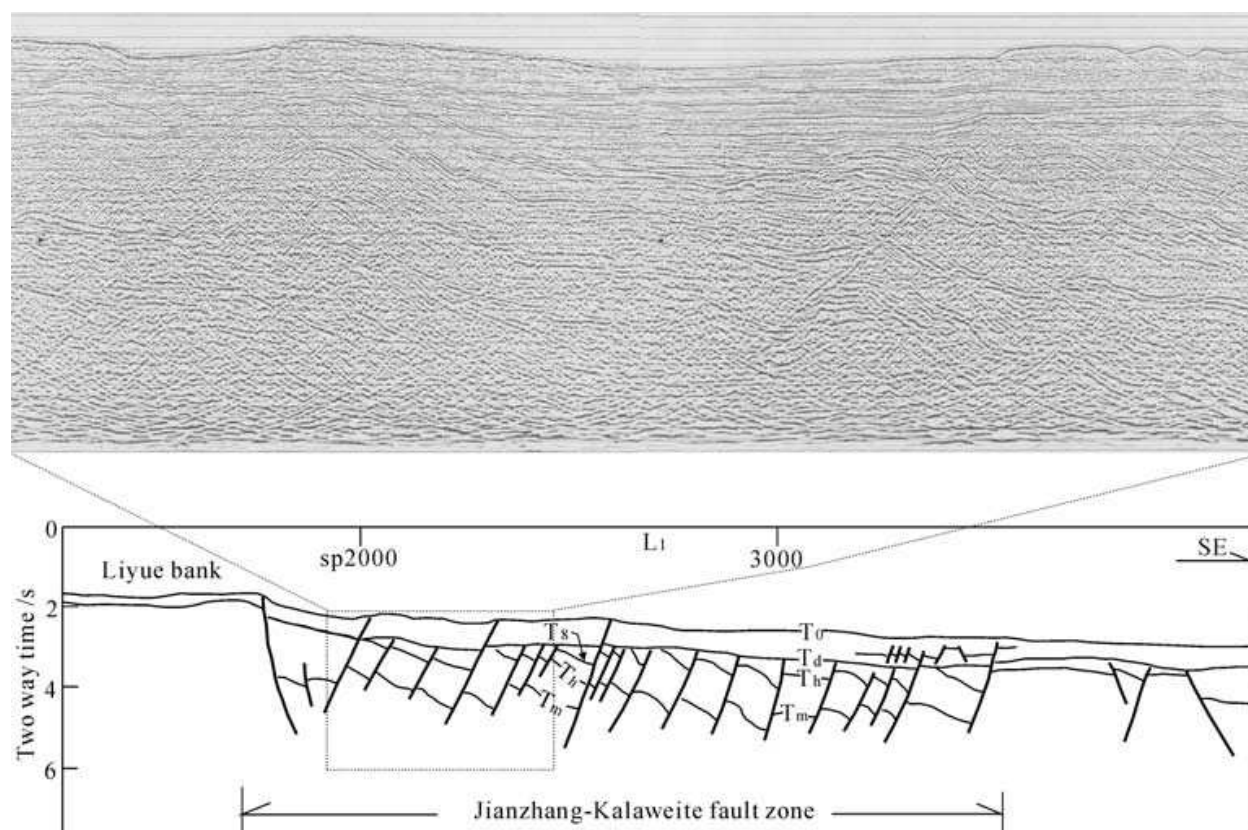


Fig. 9. Seismic profile  $L_1$  transecting western Liyue-Banyue basemental layer-block (See Fig.1 for location) .  $T_d$ ,  $T_8$ ,  $T_h$ ,  $T_m$  are the reflect horizons between lower Miocene and mid-Miocene, upper Eocene and upper Cretaceous, lower and lower Cretaceous, and lower Cretaceous and pre-Cretaceous, respectively.

### 3.3 Feixin – Nanhua basin group

This strike-slip and pull-apart basin group is mainly controlled by Bisheng – Siling basal strike-slip fault zone and Xiyue – Siling crust strike-slip fault zone. It is formed as the result of relative dextral strike-slip between Nanwei – Andu crustal layer-block and Liyue – North Palawan crustal layer-block, which are located in the east and west sides of the basins. It is formed mainly in Eocene and Miocene Epoch.

## 4. Forming mechanisms of the main cenozoic sedimentary basins within Nansha Micro-plate

The key condition for the movement and migration of a layer-block is the formation of a transformation mechanism that controls the three-dimensional boundary fault system of a layer-block. Layer-blocks in geodynamical system will show the tendency of overall movement when they are applied with sufficient tectonic forces. The system transition and conversion between three-dimensional boundary faults interrelating with the whole layer-block but with different properties of movement, is the prerequisite for realizing the movement of the whole layer-block. According to the multiple dynamics principles, the formation of layer-block structure is controlled by multiple-geodynamics, and the driving mechanism for layer-block of diverse levels is distinct.



There is a direct genetic relation between basemental layer-blocks and intra-plate basins in Nansha Micro-plate. The genesis of intra-plate basin is different from that of plate-edge basin which energy comes from mantle convection. The genesis of intra-plate basin, however, is not only influenced by movement of plate, but also by intra-plate force. The basins inside Nansha Micro-plate mainly received its energy from rheomorphism of middle crust. Depending on different ways of action of basin-forming force, the basins can be divided into three types as mentioned above: Feixin - Nanhua basal strike-slip - pull-apart basin, Andu - Bisheng basemental face-to-face dip-slip - detachment basin, and Liyue - Banyue basemental unidirectional dip-slip - detachment basin. Since the first type has the same strike-slip - pull-apart mechanism as that of ordinary strike-slip fault, we will not give further discussion. In the following paragraphs, we will focus on the basin-forming model of the other two types.

The genesis of Andu-Bisheng basal block is in the following procedure: The thermal uplift of mantle of South China Sea in late Mesozoic caused the lithosphere pure shear extension of South China Sea. As a result, the lithosphere mantle and lower crust of Nansha occurred extension and rheomorphism, and caused the destabilization of gravity of upper crust. The upper crust then used middle crust layer as the layer-slide surface, and started dip-slip - tilting movement along the pre-existed NE-strike Guangya - Bisheng fault and NE-strike Nantong - Siling fault. As the face-to-face dip-slip of the two faults continued, the strata near fault-side along northern and southern boundaries of hanging walls kept descending. The underlying plastic substances were squeezed to the bottom of upper crust of lower walls, and caused the uplifting and denudation of upper crusts of lower walls. Meanwhile, some plastic substances in middle crust were squeezed to the bottom of middle hanging walls, which enhanced the low-uplifting effects of internal part of Nanwei - Andu basemental layer-block, and caused the formation of complex graben structure (Fig. 10A). This procedure, if considering its mechanics of deformation, has a mechanism very similar to the mechanism of cantilever beam on elastic foundation (Li et al., 1995) (Fig. 10C).

The other type of basemental layer-block is the Liyue - Banyue basal layer-block. Its main structural feature is concurrent-direction tilting and uplifting fault block group (Fig. 10B). The extending - dip-slip movement of the NE-strike Jianzhang - Calawit extending - gliding fault zone caused the tilting-sliding of the layer-block along the underlying middle crustal layer-slide surface. As a result, there formed the North Palawan, West Palawan and other fault basins, whose main axes are all in NE direction, in the southeast of the Liyue-Banyue basal layer-block; and the Liyue bank - Haima (Seahorse) bank area in the northwest of the Liyue - Banyue basal layer-block began to rise.

The cause why the upper crust can easily slide on the middle crust surface is that there are nano-sized particle layers developed between the upper-crust and mid-crust. The nano-particles are characterized by higher density, higher strength, and lower rolling friction force ( $f_2$  in Fig.11); and exist in almostly all faults and layer-slip surfaces in natural world. In the case with nano-particles, the friction is rolling friction. Under the same normal pressure force ( $P$  in Fig.11), the rolling friction force is far less than the sliding friction force ( $f_1/f_2$  can be up to 18) ( $f_1$  in Fig.11). So, the upper crust can easily move along the mid-crust layer.

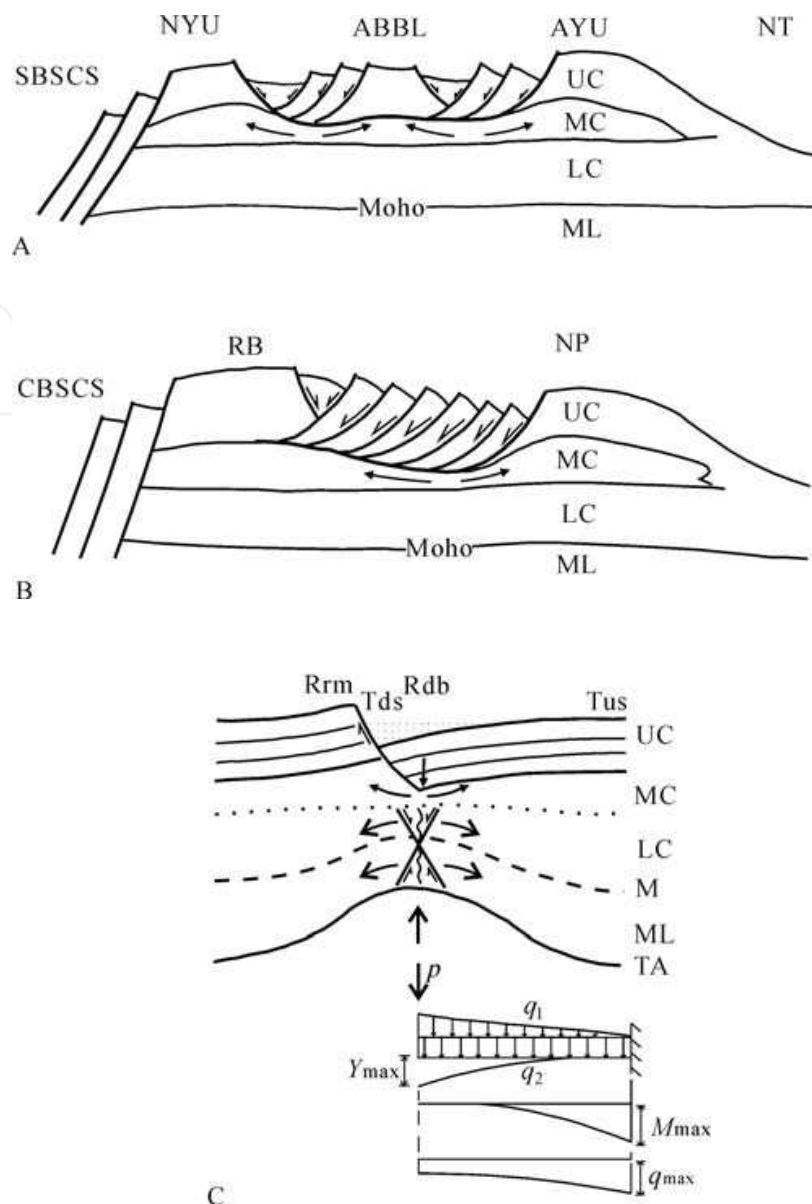


Fig. 10. Major forming mechanism types of intralate basins in Nansha micro-plate. A = Opposite-dip slip-detachment; B = Unilateral-dip slip-detachment; C = The flexural model of elastic basement cantilever (Li et al., 1996). Maxima of bending moment ( $M_{max}$ ) and shear stress ( $q_{max}$ ) occur at the tilting uplifted side of rift downcast basin. Maxima of deflection ( $Y_{max}$ ) and subsidence range occur at the tilting descending side of the rift downcast basin. The  $P$  is the gravity concentrating load of triangular prism covering above the plane of fault. The  $q_1$  is the distribution load of filling above the basement of basin. The  $q_2$  is the uniformity distribution load of hanging wall self-gravity of fault. Both  $M$  and  $Q$  positively correlate with the length and gravity of girder. ABBL = Andu-Bisheng basemental layer-block; AYU = Andu-Yuya (Investigation shoal) uplift; CBSCS = Central basin of South China Sea; LC = lower crust; M=Moho; MC = mid-crust; NP = North Palawan; NT = Nansha trough; NYU = Nanwei-Yongshu (Fiery Cross or N. W. Investigator reef) uplift; RB = Reed bank; Rdb = Rift downcast basin; Rrm = Rift rising mountain; SBSCS = Southwest basin of South China Sea; TA = top of asthenosphere; Tds = Tilting descending side; Tus = tilting uplifted side; UC = upper crust.

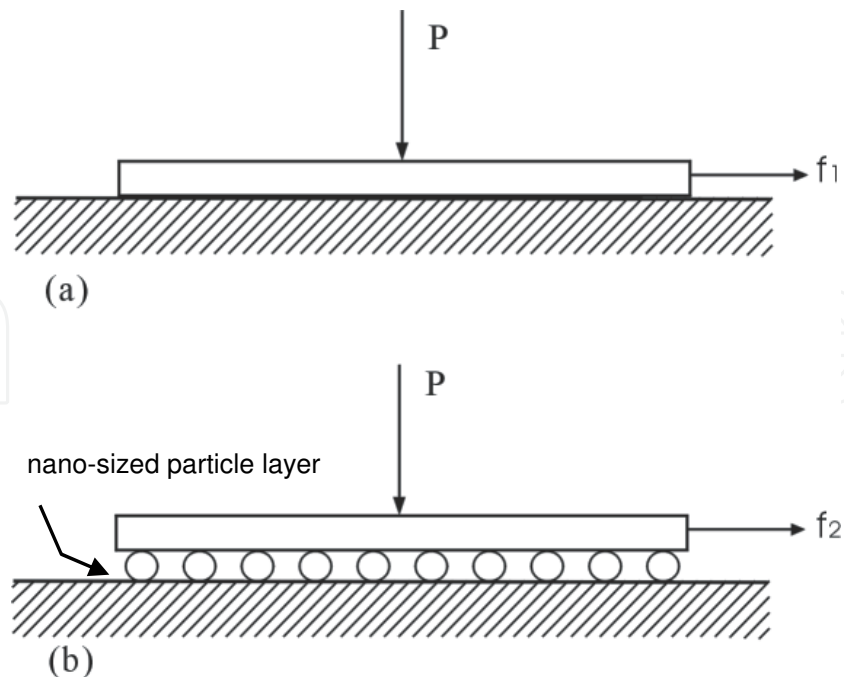


Fig. 11. Rolling friction comparing with sliding friction. (a)  $f_1$ : sliding friction force in the case without nano-particles; (b)  $f_2$ : rolling friction force in the case with nano-particles. Generally, the  $f_2$  is far smaller than the  $f_1$ .

## 5. Conclusions and discussions

The geological and geophysical data from Nansha area show the characteristics of the LBT. From the data, we identify the Nansha ultra-crustal layer-block, Zengmu, Nanwei - Andu, Liyue - North Palawan crustal layer-blocks, and Andu - Bisheng and Liyue - Banyue basemental layer-blocks. They are products of multiple geodynamic systems.

The fault structure of Cenozoic sedimentary basement inside Nansha Micro-plate is a dip-slip - layer-slip - strike-slip "4-dimensional interrelated-action" fault system. The Nanwei - Andu and Liyue - Banyue basal dip-slip - layer-slip - strike-slip fault systems controlled the development of Nanwei - Andu, Liyue - North Palawan, and Feixin - Nanhua basin groups in Nansha Micro-plate. The formation of basins in Nansha Micro-plate is the result of multiple dynamical forces. It is influenced by the tectonic evolution of Nansha Micro-plate since Cenozoic era, but most importantly, it is directly controlled by the plastic rheomorphism effect of middle crust. The basin-forming mechanism of basins in Nansha Micro-plate shows a great diversity. The Nanwei - Andu basin group has a uniformed basemental face-to-face dip-slip - detachment mode, while a basemental single-direction dip-slip - detachment model is applicable for Liyue - North Palawan basin group.

The proposal of these models for the forming mechanism of the intra-plate basins is provided with guiding implication for the exploration of oil and gas or gas hydrate resources inside Nansha Micro-plate. They should give us some elicitation as follows: zones which are in the hanging walls of basin-controlled boundary faults and near the faults, should be remunerative for oil-gas exploration. Along these zones, with the gliding - tilting movement of these basin-controlled growth boundary faults, not only some

conditions of “generation – movement – reservoir – preservation” of oil-gas resources could be formed in the neonatal Cenozoic sedimentary strata, but also possible oil-gas within the pre-Cenozoic marine-facies strata overlaid the Cenozoic Erafthem could remove upwards along neonatal faults and form oil-gas accumulations. In the concrete, the secondary structures, such as rolling anticlines and tilted fault blocks, which developed on the hanging walls of Nantong – Siling and Guangya – Bisheng faults in Nanwei – Andu basin group, as well as paleo-buried hills structures developed around low uplifts between these two fault zones should be advantaged zones for oil-gas accumulations in Nanwei – Andu basin group, while the zone along southern side of the Jianzhang – Calawit Extending – Dipping Fault Zone i.e. the northwestern shelf of Palawan Island should be regarded as better belt for oil-gas accumulations in Liyue – Palawan basin group. Some oil-gas fields discovered in above-mentioned advantageous belts, such as the Crestone exploration area of China in Beikang basin, Thanh Long or Blue Dragon oil-and-gas fields in west Nanwei basin and active gas/oil fields or new discovered fields in northwest Palawan basin, and so on, are very good exemplifications.

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The term tectonics refers to the study dealing with the forces and displacements that have operated to create structures within the lithosphere. The deformations affecting the Earth's crust are result of the release and the redistribution of energy from Earth's core. The concept of plate tectonics is the chief working principle. Tectonics has application to lunar and planetary studies, whether or not those bodies have active tectonic plate systems. Petroleum and mineral prospecting uses this branch of knowledge as guide. The present book is restricted to the structure and evolution of the terrestrial lithosphere with dominant emphasis on the continents. Thirteen original scientific contributions highlight most recent developments in seven relevant domains: Gondwana history, the tectonics of Europe and the Near East; the tectonics of Siberia; the tectonics of China and its neighbourhood; advanced concepts on plate tectonics are discussed in two articles; in the frame of neotectonics, two investigation techniques are examined; finally, the relation between tectonics and petroleum researches is illustrated in one chapter.

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