CHAPTER II

GEOLOGY OF THE PHITSANULOK BASIN

2.1 INTRODUCTION

Geologically, Sirikit oil field is a part of the Phitsanulok basin which is underlain by Mesozoic basement. Phitsanulok basin is the largest onshore Tertiary basin of Thailand. This basin is closely related to structural framework (Figure 2.1)which directly effects thickness of sediment. The thick sediments in the basin is considered to be the kitchen areas, that generate hydrocarbons and supply to the Sirikit oil field. This chapter will report general information of structure, evolution, stratigraphy and environment of the basin before focusing on detail of the Lan Krabu Formation (LKU FM.).

2.2 STRUCTURAL SETTING

Phitsanulok basin is apparently contributed by geological structures, particularly rifting and faulting which are related to the movement of Malayan peninsula and Indochina. Rift basins set along north south trends that is similar to suture zone between Shan Thai and Indochina microcontinents. Basin is subsequently developed by several fault systems around the basin. Structural configuration of the Phitsanulok basin is constrained by four major fault systems including Western boundary fault, Uttaradit fault, Mae Ping fault and Petchabun fault (Figures 2.2 and 2.3).

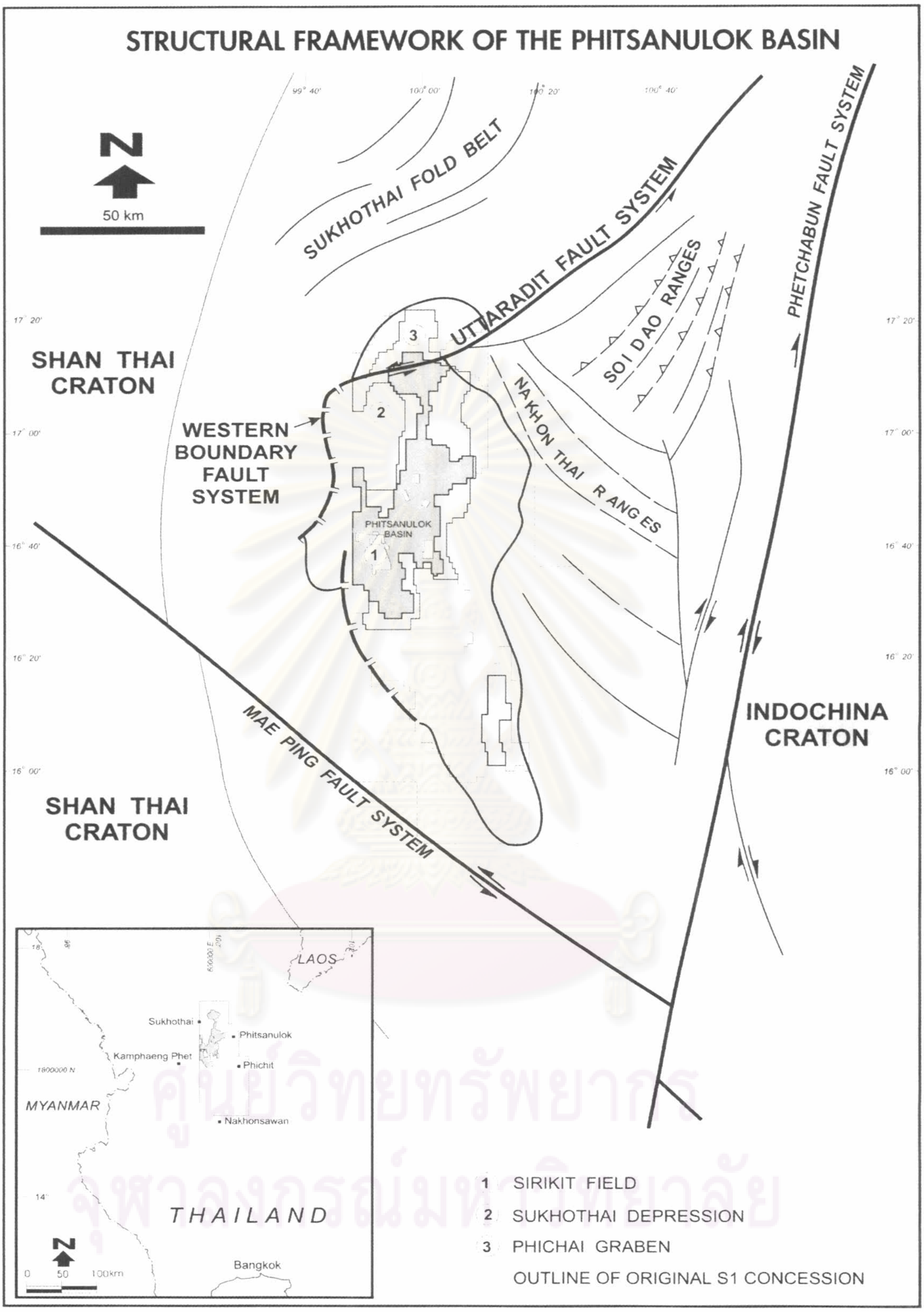

Figure 2.1 Structural framework of the Phitsanulok basin (Mäkel et al., 1997).

2.3 BASIN EVOLUTION

Structure of the Phitsanulok basin is effected by movements of four major faults; therefore basin development is directly involved by those events. Burgisser (1995) divided evolution of the Phitsanulok basin into four periods as below.

Phase I (Extensional) : Extension occurs along the western boundary fault system in WSW-ENE direction. The Uttaradit fault acts as the northern basin edge and accommodates the extension with sinistral slip of the basement. In addition, dextral movement along the Phetchabun fault in the Indochina block leads to compression in Soi Dao area. Combination between sinistral movement along the Mae Ping fault and dextral movement along the Phetchabun fault causes divergence nearby junction of both faults (Figure 2.2).

Phase II (Extension and Transtension) : This phase (Figure 2.2) begins with extensional movement along the Mae Ping fault. This affects inversion in the southern area which leads to continuous movement along the Petchabun fault. Divergence during Phase I compensated for the compression in the northeast disappears, consequently, the compression in the Soi Dao area is increasing.

Phase III (Transtension and Transpression) : This phase is revealed in Figure 2.3. The northern part of the basin accomplishes extension process, however, compression still continues, while overthrusting develops in the Soi Dao area. Block of the fault systems (Uttaradit fault and northern Petchabun fault) in the northeast leads to development of a hinge zone the eastern up throwing flank and Nakhon Thai area with increment of downthrow along the western boundary fault system. In the north, developments of Phichai graben along with maximum downthrow occur along Uttaradit fault; in addition, Sukhothai depression, already started in Phase II, still carries on. In the south, extension continues and leads to anti-clockwise rotation in the southern Phitsanulok basin. This rotation is compensated by dextral displacement along NW-SE trending faults.

Phase IV (Transpression) : This phase starts when extension in the southern part of the area is blocked. This event leads to increasing of compressional stresses and inversion features with dextral wrench faulting parallel to the Petchabun faultwhichthe later affects pre-existing structures (Figure 2.3).

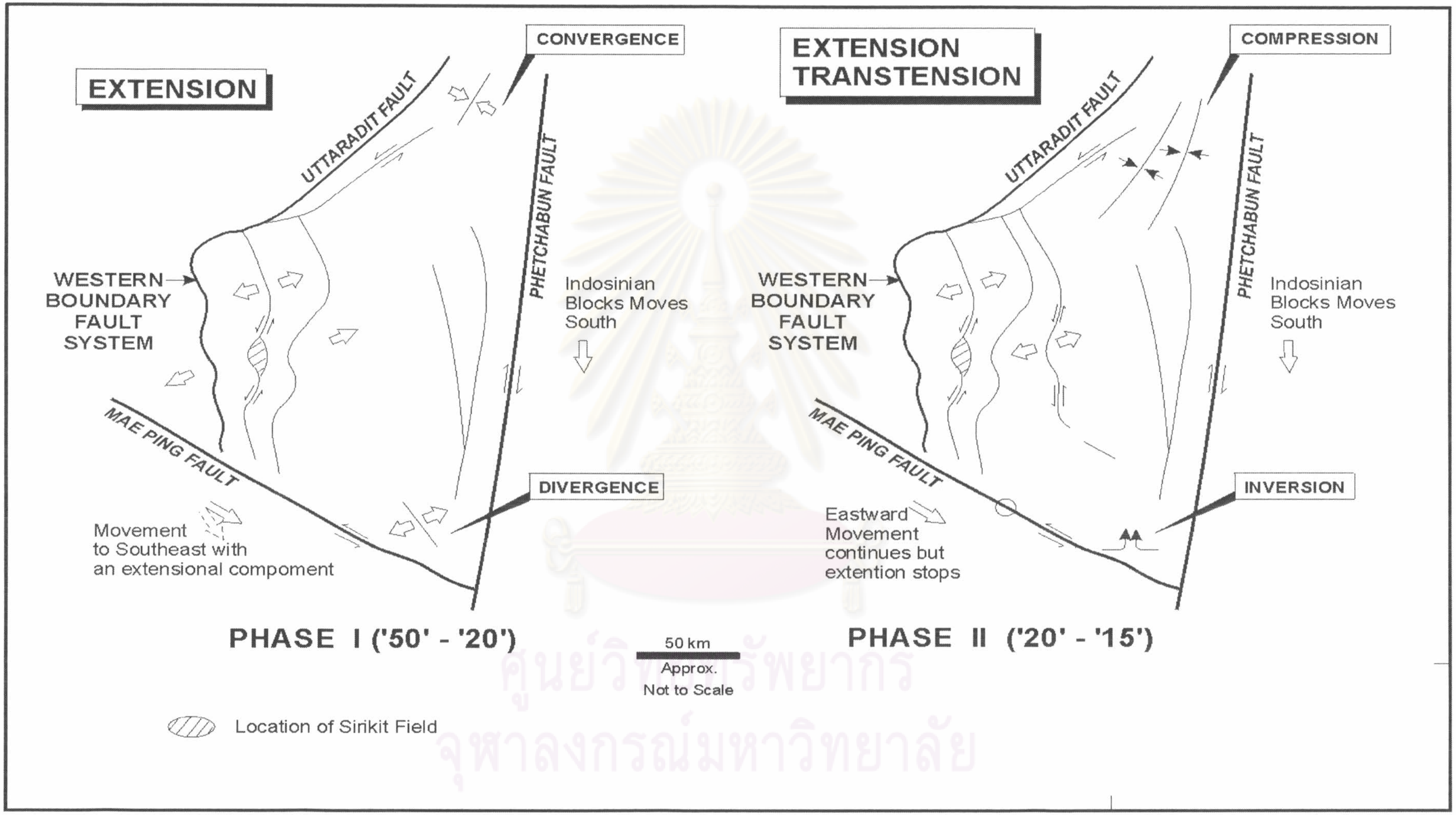

Figure 2.2 Structural model of the Phitsanulok basin in phase I and phase II (Mäkel et al., 1997).

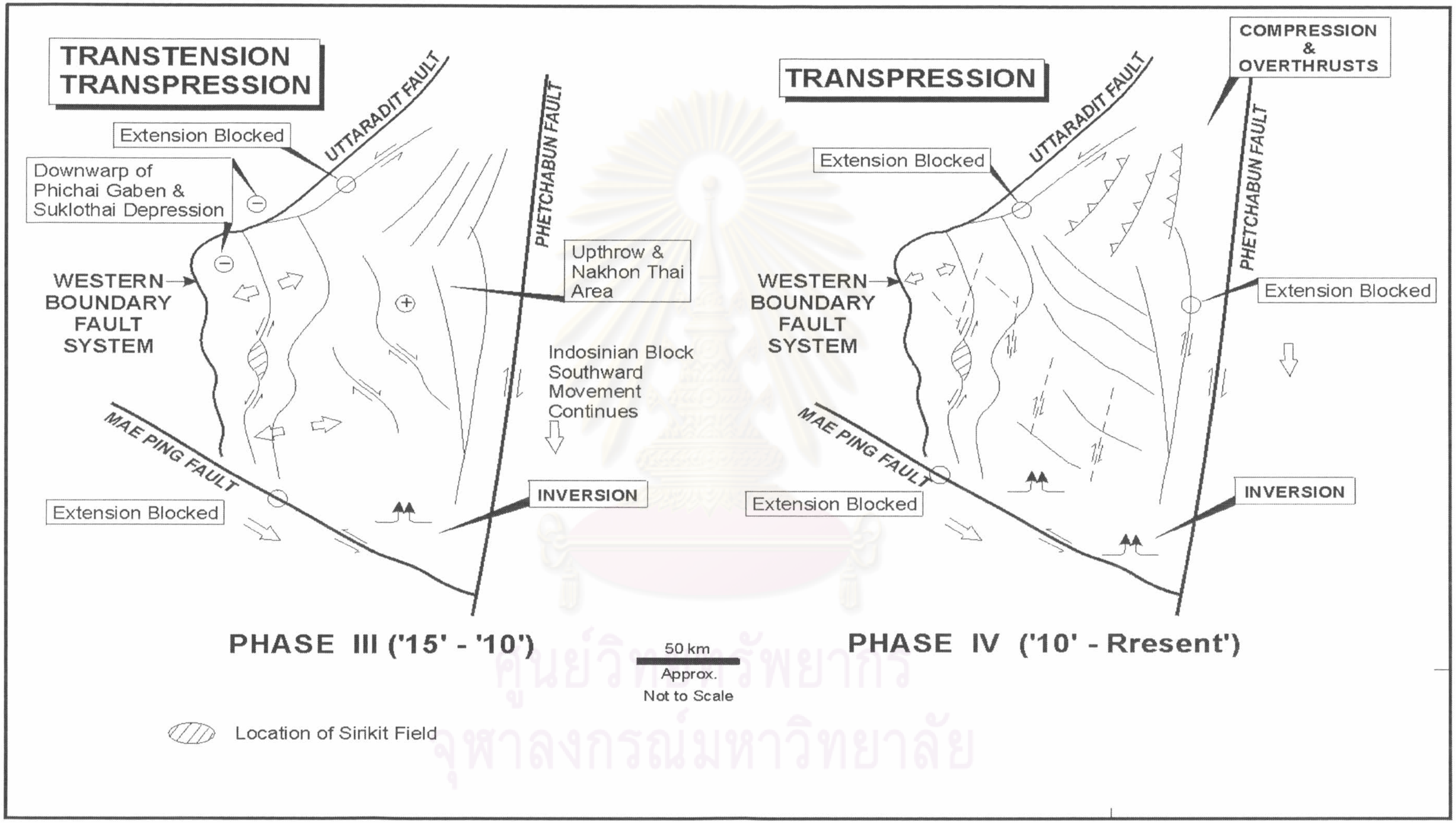

Figure 2.3 Structural model of the Phitsanulok basin in phase III and phase IV (Mäkel et al., 1997).

2.4 STRATIGRAPHY

Sedimentation in the Phitsanulok basin has taken place since Late Oligocene when the Sarabop Formation started its deposition. This formation overlies Mesozoic basement; that implies the oldest Tertiary clastics in the basin. This sedimentary sequence contains sandstone, conglomerate, siltstone and mottled claystone. They likely indicate high-energy alluvial fan environment. It is estimated that sands have an average extent of 200-300 meters with a maximum of 600 meters (Goesten et al.,1991). The Sarabop Formation is particularly covered by lower energy lacustrine and fluviatile sequences of the Lan Krabu and Chum Saeng Formations; both formations are in Miocene age. The Lan Krabu Formation is characterized by sequence of mouthbar sandstone and channel sandstone; details of this formation will be described in the next section. The Chum Saeng Formation composes of soft lacustrine claystone. Subsequently, the Chum Saeng Formation is covered by the Pratu Tao Formation, containing channel sandstone. Individual sands range in thickness from 1 to 25 meters (Phuthithammakul, 1993). Finally, these older formations are overlain by sequences of the Yom and Ping Formations, respectively. The Yom Formation lies above a variable thick shale (5 to 30 meters)whichseparates it from the Pratu Tao Formation. The Yom Formation has an average of 300 meters thick. Individual sands range in thickness from 1 to 30 meters. (Phuthithammakul,1993). Their ages range from about 17 Ma up to recent. The youngest Ping Formation is characterized by sand with interbedded shale (Figure 2.4).

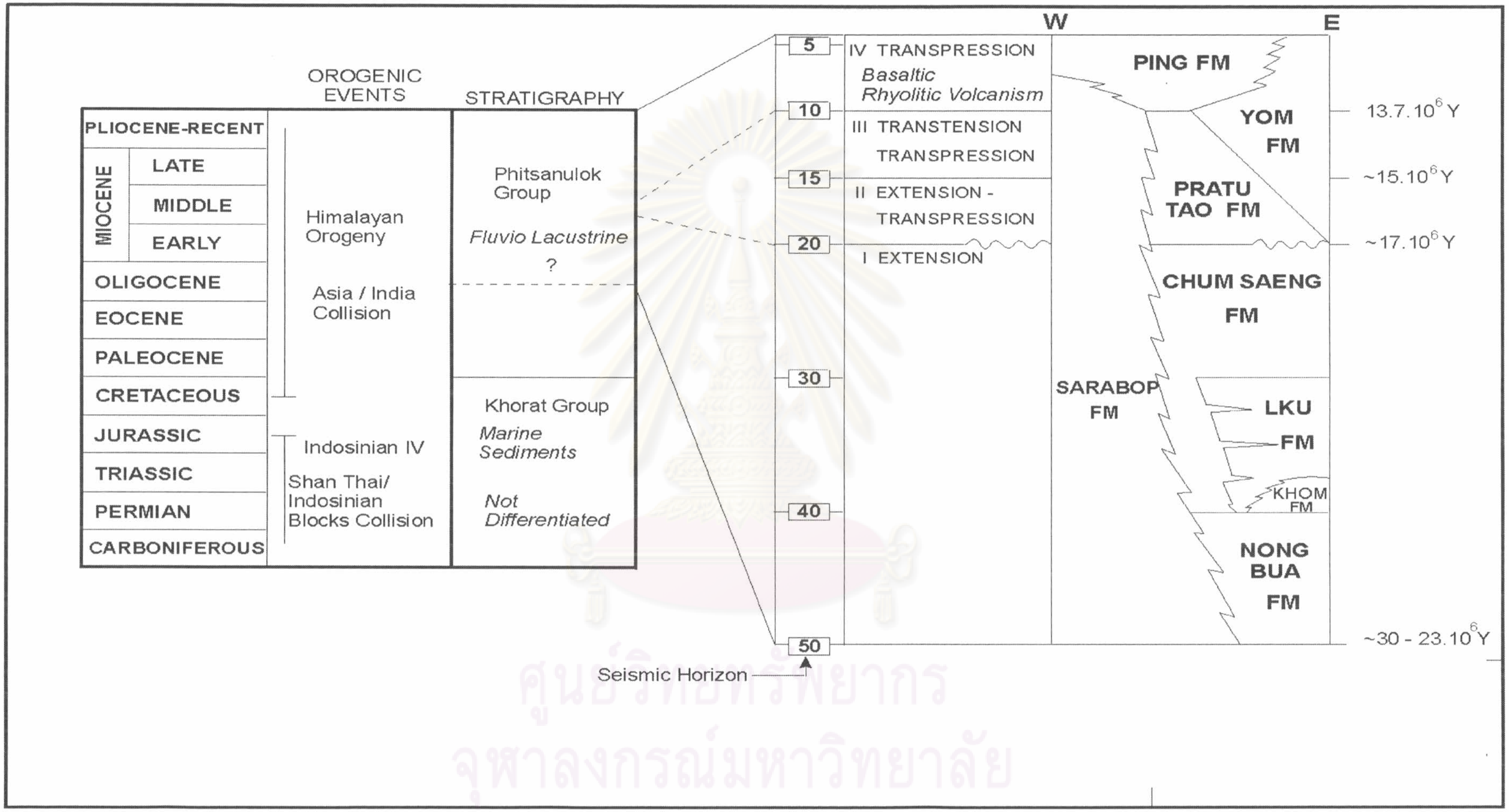

Figure 2.4 Stratigraphic column of sedimentary sequences in the Phitsanulok basin in correlation with regional tectonic events (Mäkel et al., 1997).

2.5 SEDIMENTARY TRANSPORTATION

The main orientation of basin is in north-south direction which is apparently significant source of the depositional system. Sedimentation in the Phitsanulok basin can be subdivided, base on lake level, into highstand cycle and lowstand cycle. During high lake level period, water may fill up lake the basin, then sediments are potentially supplied from all directions (Figure 2.5a). Sirikit field, which is located far away from paleoshoreline should therefore obtain only fine-particle sediments such clay deposits during this period. On the other hand, the channel from the north would develop into the central of the basin during period of low lake level (Figure 2.5b). Consequently, most north-south trending channels in the basin, including Sirikit area, appear to be the main influence of sedimentation during this period.

2.6 DEPOSTIONAL ENVIRONMENT

Depositional environment of the Phitsanulok basin is clearly related to structural evolution in this area. Therefore depositional environment is reasonably discussed in correlation with structure of the basin. Goesten and Coutts (1989) divided depositional environments in this basin into 3 stages: including 1) alluvial fan and alluvial plain deposits in the lowest section during Oligocene age; 2) lacustrine and alluvial plain deposits in the middle section during Lower Miocene age; and 3) alluvial plain and alluvial fan deposits in the upper part of the basin during Middle Miocene age to recent.

The sedimentary deposits under stages 1 and 2 have taken place within Phase I of the structural history. Sediments occurred in this stages are represented by clastics of the Sarabop Formation, which is composed of fluvial, alluvial fan and fan delta deposits. Sediments are derived from the west of western boundary fault system; that leads to occurrences of the younger sediments progressively along the eastern part of the area.

In Miocene, sediments appear to have deposited during subsiding of the basin, in which depositional environment changes to open lacustrine deposits of the Chum

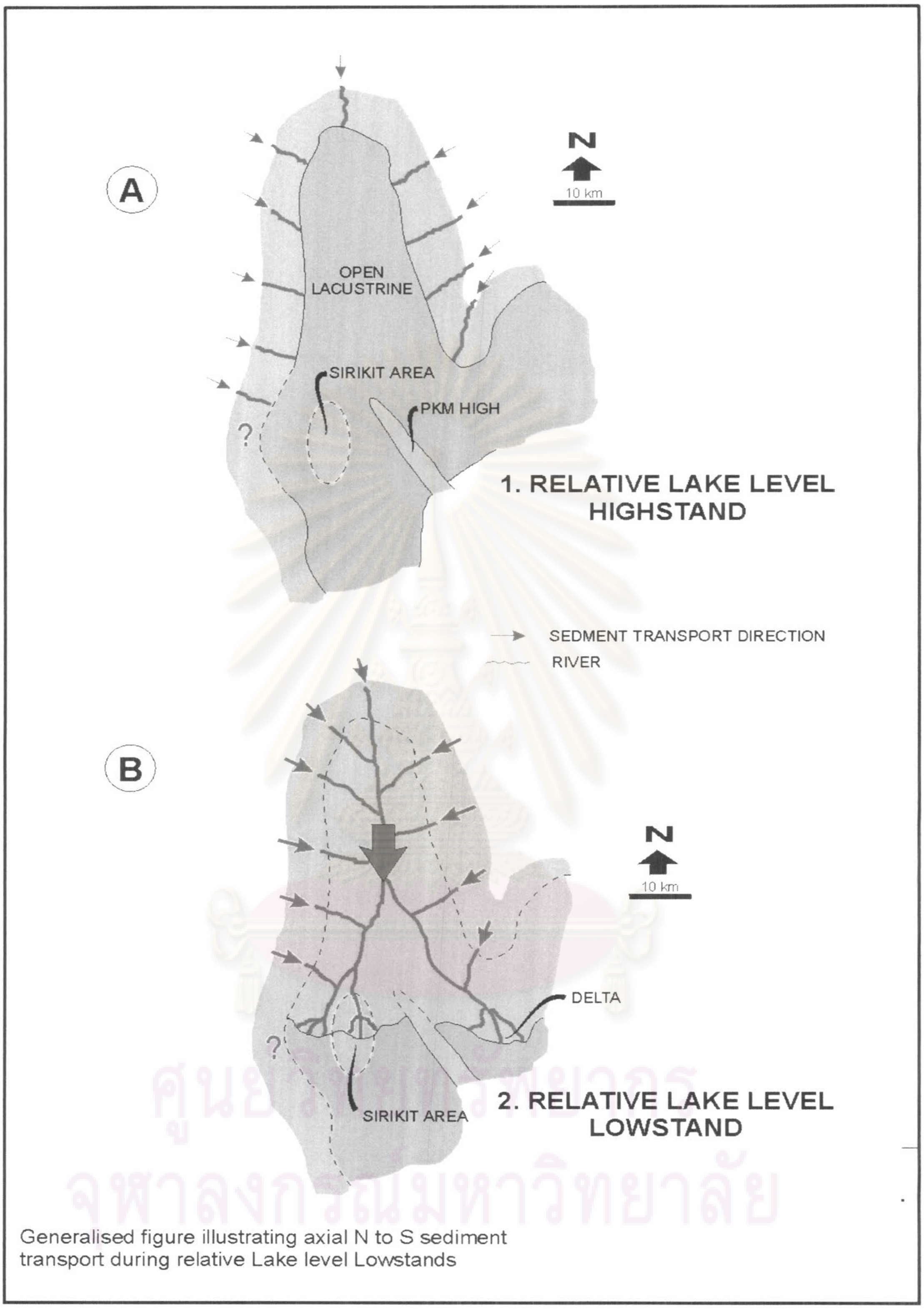

Figure 2.5 Schematic models of directional sedimentary transportation in ancient Phitsanulok lake, containing cycles of high lake level (a) and low lake level (b) (Mäkel et al.,1997).

Saeng Formation and Fluvio-deltaic deposits of the Lan Krabu Formation along the central and eastern parts.

Depositional environment then changes abruptly in Middle Miocene, that is equivalent to Phase II of structural history. Extension of movement in the basin is decreasing whereas major tectonic is dominated by transtension. This tectonic changing therefore affects sedimentation which consequently causes deposits of the Phatu Tao Formation and the Yom Formation. Environments of those deposits are described as braided and meandering river systems (Phuthithammakul, 1993).

During tectonic changing period, rate of subsidence is decreasing and more uniform throughout the basin. This event leads to tectonic changing from transtension to transpression of structural history Phase III, which is beginning of the Ping Formation's deposits. Regarding depositional environments, they are likely derived from meandering fluvial deposits of the Yom Formation to alluvial fan and braided stream deposits of the Ping Formation.

2.7 LAN KRABU FORMATION

The Lan Krabu Formation begins to have deposited in Lower Miocene age. Thickness of 600-700 meters has accumulated throughout whole sequences of the formation, consisting of progradational deltaic tongues. These tongues are separated by the open lacustrine shale of the Chum Saeng Formation (Figure 2.6). The interbedded Chum Saeng sequences indicate periods of relative high lake levels when Sirikit area is flooded. These cycles represent progradation of a lobate delta system into a very shallow lake. Each progradational cycle consists of coarsening-upwards sand and shale beds with thickness average ranging from a few centimetres to several meters. Flint et al. (1988) studied the core facies analysis. Their results present that deltaic sandstone in the Sirikit oil field are overall sheet rather than bar-finger geometries

The Lan Krabu Formation is a main reservoir in Sirikit oil field, which can be subdivided, base on correlation techniques, into several members including K, L and M members (Jahn *et al.*, 1989). K member is able to be splited into four sub-members (e.g. K1, K2, K3 and K4), as well as, L member contains four sub-members (e.g. L1,

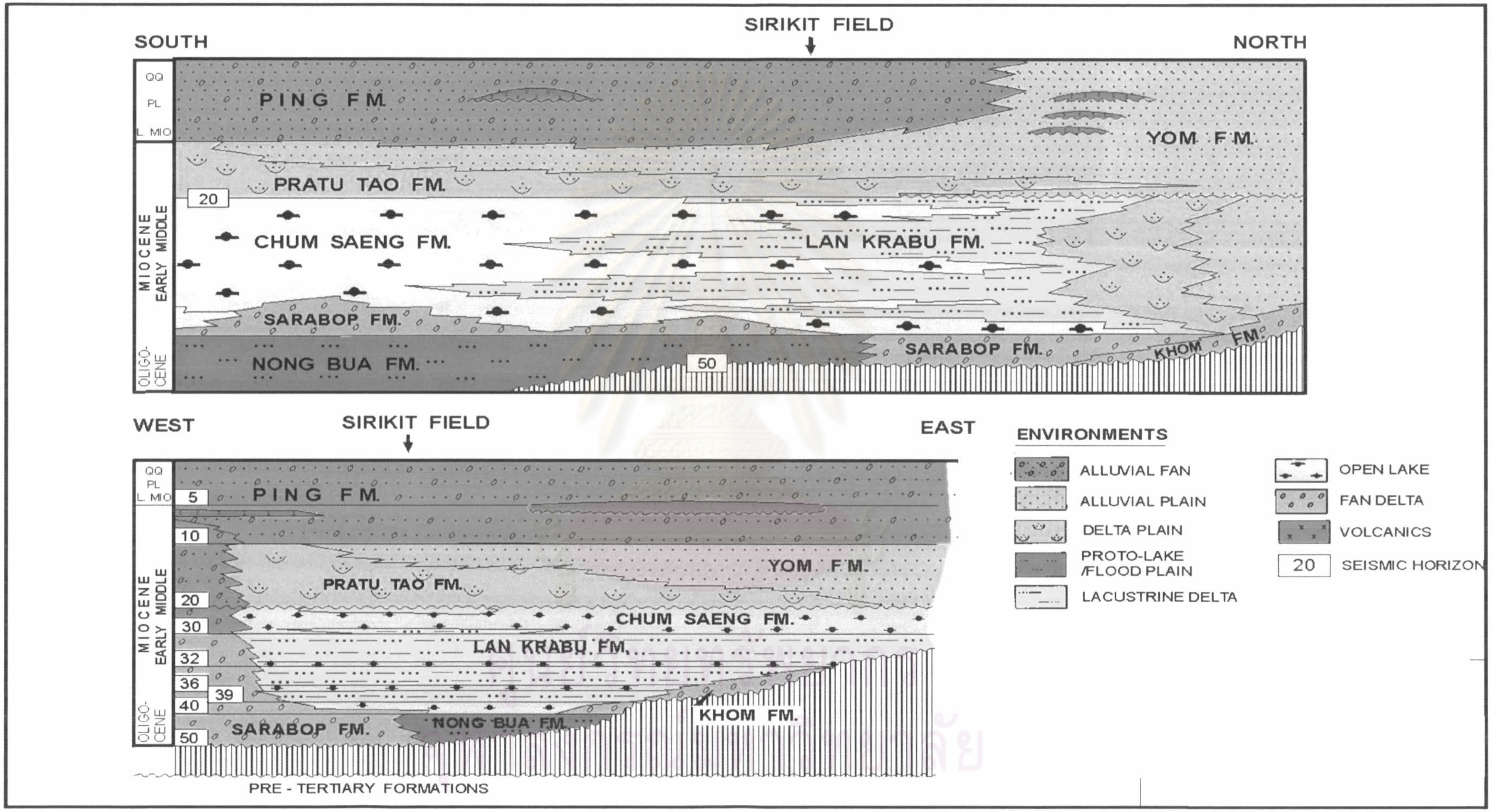

Figure 2.6 Schematic Tertiary chronostratigraphy of the Phitsanulok basin (Mäkel et al.,1997).

L2, L3 and L4). For the M member, it is more homogeneous and could not be categorized to sub-member.

There are four facies of main reservoir of the Lan Krabu Formation in Sirikit area (Ainsworth et al., 1997). They are mouthbar facies, channel facies, heterolithics facies and crevasse-splay facies.

Kennaird (1988) suggested that heterolithics approximately 20 % of net sands found in core can not be recognized from geophysical log.

Jahn et al. (1989) have discovered crevasse-splay facies formed as very thin beds. In general, crevasse-splay is interbedded with hard floodplain shales, whereas mouthbar sands are frequency interbedded with soft shales.

Goesten (1992) suggested that the most dominant sand facies in the Sirikit area is mouthbar facies. Thickness of individual sub-member cycle is often ranging from10 to 15 meters. Moreover, Goesten also recognized that only 10% sands are present in the Lan Krabu Formation. Thickness of interpreted channels varies from 3 to 14 meters. Channel orientation is along north-south trend with north to south flowing direction.

2.8 LAN KRABU RESERVOIR GEOMETRY

Historically, the reservoir geometry and dimension of each facies were estimated using calculation of approximate width and thickness (Table 2.1). Result of calculation from this study generally show excessive lateral extension of the lower sandbody, this is a result of lithostratigraphic correlation technique. In fact, sandbodies estimated from well information are generally smaller than those expected by this technique.

Recently, reservoir geometry of the Lan Krabu Formation is studied from reservoir modeling of Sirikit oil field (Table 2.2). The model is especially focused on mouthbar and channel geometries. Lithostratigraphic correlation and Repeat Formation Testing

(RFT) are additional tools, which may be used to check geometry size and to indicate connection between sandbodies.

Table 2.1 Geometrical size and sand volume of reservoir body estimated from width and thickness of the formation (Mäkel et al.,1997).

	Mouth-bar sand		**Crevasse sand**		**Channel sand**	
Unit	**Size m**	**% total net sand**	**Meter**	**% total net sand**	**Meter**	**% total net sand**
K2	900 - 2700	75	450 - 2100	20	500 - 1500	5
K3	900 - 2500	25	450 - 3500	60	400 - 900	15
K4	1450 - 2600	55	600 - 1600	35	450 - 900	10
LU	1450 - 2500	90	600 - 900	5	400 - 1300	5
LL	1200 - 2600	55	750 - 1200	25	400 - 700	20

Table 2.2 Currently geometries of reservoir body yielded by modeling as present in Figure 2.7 (Mäkel et al.,1997).

Sub-Member	**Mouthbar**		**Mouthbar Sand**		**Channel**	
	Width (km)	Length (km)	Width (km)	Length (km_	W/T ratio	Max. width (m)
D, K & L 1, 2, 4, M	1.5 to 2	Km	1.5 to 2	0.5 km	20	100
L3 & K3	1.5 to 2	Km	1.5 to 2	0.5 km	20	280

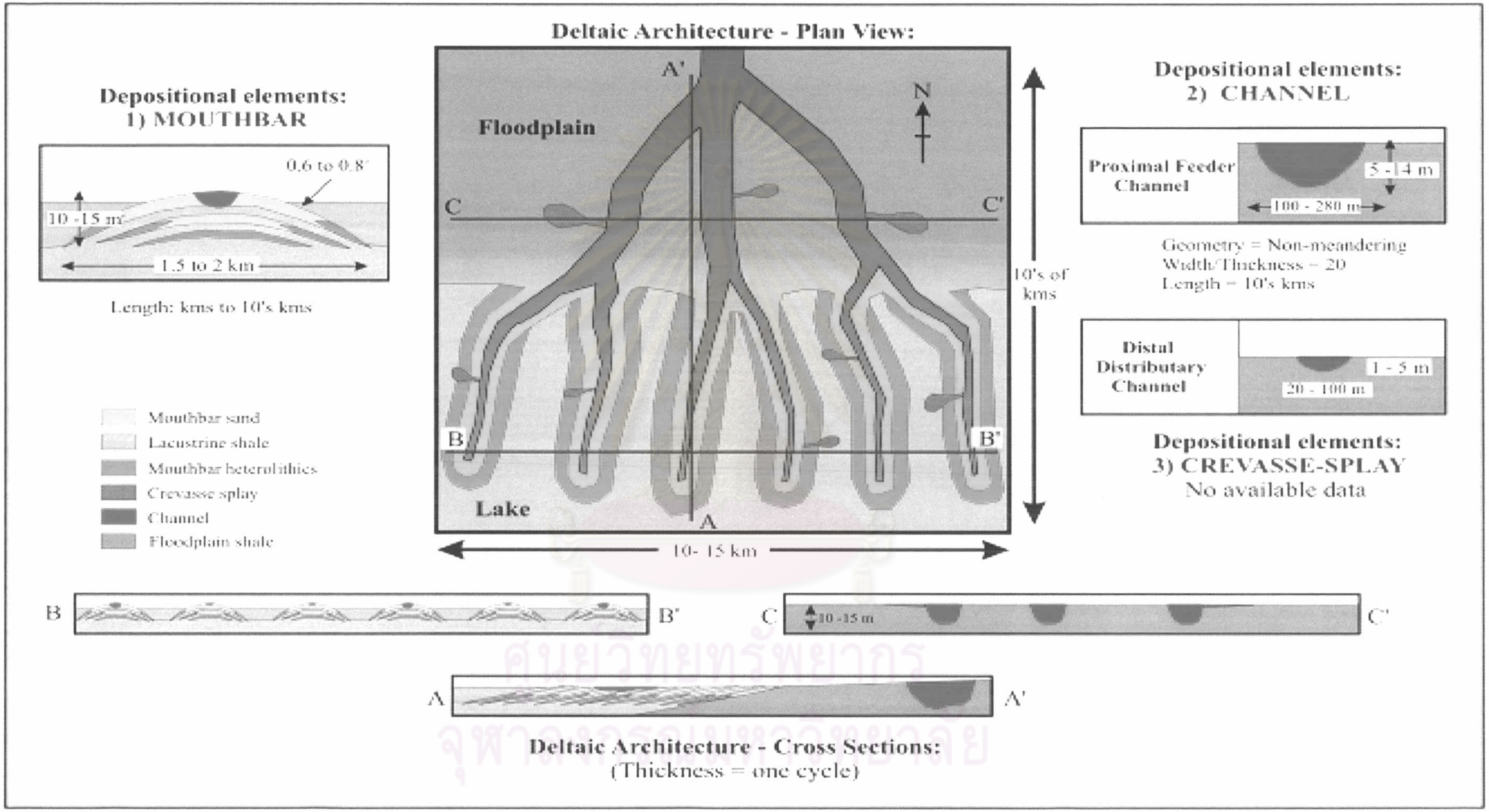

Figure 2.7 Depositional elements and architecture of Lake Phitsanulok reviewing fluvially dominated deltaic complex (Mäkel et al.,1997).