

Stratigraphic Correlation and Isopach Maps of the Western Taiwan Basin

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ABSTRACT

Subsurface geologic reports, paleontological data and stratigraphic correlation studies of the 88 onshore and offshore exploration wells of the western Taiwan Basin completed by earlier researchers were incorporated. Six regional stratigraphic profiles and the isopach maps of each formation above the Wuchihshan Formation were constructed in this study. During the Oligocene, the depositional center was located to the east of the Hsinchu-Taoyuan-Taipei belt, and the thickness of the Oligocene strata increased from the west to the east. During the Miocene, the depositional center was situated to the east of the Miaoli-Hsinchu belt and the sediments were mainly from the northwest of Taiwan although part of the sediments was also derived from the Peikang basement high in the early Miocene. The configuration of the sedimentary basin and the source of sediment during the deposition of the Kueichulin and Chinshui Formations were not too different from those in the Miocene. However, during the late Pliocene, the sediments were from the east and with quite thick clastic sequence deposited in western Taiwan. The depositional center of the Cholan Formation is located to the east of the Taichung-Miaoli-Hsinchu belt. In the Toukoshan stage of the Pleistocene the sediments were also from the east and very thick clastic strata were deposited in western Taiwan.

(Key words: Stratigraphic correlation, Isopach maps, Western Taiwan basin)

1. INTRODUCTION

The purpose of this study is to describe the stratigraphy of the late Cenozoic clastic sequence in western Taiwan and elucidate the sources of the sediment, the depositional center of the basin as well as the coastline during the highest sea level of this region during that time.

Tertiary sedimentary basins in western Taiwan have been the main targets for petroleum exploration, with hundreds of deep exploration wells being drilled onshore and offshore in those areas. Abundant subsurface geological data are now available, and some of the exploration wells have reached the Pre-Miocene "economic basement". Most of the "basement" rocks encountered are comprised of sedimentary rocks, ranging in age from the Paleogene to Mesozoic.

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Previous studies involving the stratigraphic analyses of the Western Taiwan Basin have mainly been focused within onshore or offshore. Two examples include, "Geological and geochemical studies for the exploration of hydrocarbon in the Peikang area, Taiwan" (Hu *et al.*, 1981) and "Stratigraphic correlation of the Tertiary formations, the Chia-Nan Plain in the southern Taiwan area" (Hsu, 1979), though there are others. The only study encompassing every basin in western Taiwan is "Tertiary sedimentary basins in Taiwan" (Ho, 1971), the result of which suggests that the Neogene formations in central-southern Taiwan thin out from the east to the west in a wedge-shape, while the formations also pinch out toward and onlap the lithologic units in the west. Bosum *et al.* (1970) suggested that the Peikang basement high located in the central part of western Taiwan extends for only a short distance to the east and then terminates or is truncated. The whole western Coastal Plain has been affected by the Kuanyin basement high in the north and the Peikang basement high in the central south, and the formations between the highs show slight undulation. In his study on the evolution of the tertiary basins, Sun (1982) proposed nomenclature for various structural units. He suggested that the Paleogene basins had been initiated by a series of horst and graben structures and included the Tungyintao Basin, South Penchiayu Basin, Nanjehtao Basin, Taihsi Basin, Taichung Basin, Tungyintao Ridge, Kuanyin basement high, Penghu basement high and the Peikang Ridge. He also postulated a possible extension of the Peikang ridge to the north. The structural mechanisms for the formation of the Neogene basins were very different from those of the Paleogene basins, according to Sun (1982), who also noted that the Penghu platform divided the Neogene sedimentary basins into southern and northern basins, which are named the Tainan Basin and the Taihsi-Taichung Basin, respectively.

Three distinct cycles of sedimentation are recognized in the Oligocene and Miocene clastic sequences of western Taiwan. The first cycle consists of the Wuchihshan and Mushan Formations, the Kungkuan Tuff and the Taliao Formation; the second of the Shihti, Tsouho, and Nankang Formations; and the third of the Nanchuang and Kueichulin Formations. The Wuchihshan, Mushan, Shihti and Nanchuang Formations, all of continental-paralic-neritic deposits, are mainly composed of well winnowed protoquartzite, subgraywacke and shale, intercalated with several thin coal seams. These formations are mainly of stable shelf sediments. The Taliao, Tsouho, Nankang and Kueichulin Formations, all of a neritic-shallow bathyal environment, consist chiefly of less winnowed subgraywacke and lithic graywacke units interbedded with siltstone and shale and yielded marine fossils (Chou, 1976, 1980).

Four major structural movements have been identified in the Tertiary Basins (Sun, 1982), and they are: the Crustal movement at the end of the Cretaceous which uplifted the area, and was then subjected to folding and erosion. The subsequent advance of the sea and volcanic activities in the Paleogene resulted in the deposition of the Paleogene sediments. A second uplift caused the Paleogene deposits in the high areas to be eroded, and the subsidence in other areas, such as the Penghu area, initiated the deposition of the Eocene sediments. Growth faults, which are in the trend of the Taiwan Strait, developed and extended from the southeast toward the northwest during this period. The third crustal activity developed in the early Oligocene, and the rejuvenated uplift resulted in the erosion of most of the upper Eocene and part of the middle Eocene sediments. The period from the middle of the Miocene to the Pliocene in western Taiwan experienced the fourth structural movement which was characterized by a vertical

uplift and normal faulting. In contrary, intensive folding and metamorphism took place in the eastern part of Taiwan island. Owing to this significant difference in geological history, there is a striking change of stratigraphy across the boundary of the western and the eastern Taiwan Basins.

2. MATERIALS AND METHODS

This study is to investigate the stratigraphy and sedimentation of the Western Taiwan Basins, and the information used is mainly derived from hydrocarbon exploration wells. In order to cover the area to be studied extensively, 35 exploration wells located onshore of the Western Taiwan Basins were selected for investigation: KY-1, HK-4, CT-8, YHS-10, CS-73, PST-2, TCS-28, HL-2, PKS-1, WG-1, PC-1, TC-1, PK-3, LC-1, PCC-1, CLI-1, HP-1, PT-1, YM-1, KT-2, CTH-15, CT-1, KH-1, PS-3, CN-1, YHS-5, CS-69, PKL-4, CHK-119, HL-3, PKS-2, THS-1, SU-1, PH-1 and YC-1. A total of 53 offshore wells were examined, and they included 27 exploration wells: YTP-1, YKL-1, YKL-4, FK-1, YKL-2, YKL-5, YKL-6, YKL-3, TCN-1A, YSS-1, YSS-2, YSS-3, YTC-3, YTC-4, YTH-1, YTH-2, YPH-3, YPH-4, TL-1, YCI-3, YCI-4, YTJ-1, YTN-1, YTN-5, YTG-1, YPT-1 and YPT-2, as well as another 26 offshore wells.

The geological reports and relevant paleontological data of the above wells, the nannofossil information of Huang (1977, 1978, 1979, and 1980) and Chi (1978, 1979, 1980, and 1981), the palynological information of Shaw (1984a, 1984b, 1984c, 1985, 1990), the stratigraphic correlation chart of the offshore Taiwan exploration wells (Lin, 1982), the stratigraphic correlation charts of the Penghu Basin and the Taihsi Basin (Ting, 1984) and the table of formation tops of exploration wells in the Chia-Nan Plain area (Kuang, 1987) were utilized (Table 1), and the information in these reports was integrated to construct six stratigraphic profiles in this study. Profiles A and B observe the south-north trend, while Profiles C, D, E, and F follow the east-west trend. The locations of the profiles are shown in Figure 1. The isopach maps of the Oligocene, Mushan, Taliao, Shihti, Peiliao and the Talu Formations, the Kuanyinshan Sandstone and the Nanchuang, Kueichulin, Chinshui, Cholan and Toukoshan Formations in western Taiwan were constructed.

3. RESULTS

3.1 Stratigraphic Correlations

The stratigraphic correlation Profile A (Figure 2) was constructed based on the subsurface geological and paleontological data of the following wells: YKL-6, YKL-3, YKL-1, YPT-1, CBS-3, YSS-2, YSS-3, YTC-1, YTH-1, YCI-3, YTJ-1, YTN-1, YTG-1 and YPT-1.

The stratigraphic correlation Profile B (Figure 3) was constructed using the subsurface geological and paleontological data of the following wells: KY-1, HK-4, CT-8, YHS-10, CS-73, TCS-28, HL-2, PKS-1, WG-1, PC-1, PK-3, LC-1, PCC-1, and CLI-1.

The stratigraphic correlation Profile C (Figure 4) was constructed on the basis of the subsurface geological and paleontological data of the following wells: YPT-1, YKL-1, YKL-4, FK-1, YKL-2, and YKL-5.

Table 1. Calcareous nannoplankton datum, biochronozone and stratigraphic correlations of the Neogene sequence in Taiwan. (Lin, 1982; Huang et al., 1979; Chi, 1980)

CALCAREOUS NANNOFOSSIL DATUM	FORMATION IN NORTHERN TAIWAN	STANDARD NANNO ZONES	EPOCH	SERIES
<i>E. huxleyi</i> (F)	Toukoshan Fm.	NN21		PLEISTOCENE
<i>P. lacunosa</i> (L)		NN20		
<i>G. oceanica</i> (F*)		NN19		
<i>G. oceanica</i> (L*)	Cholan Fm.	NN18	LATE	PLIOCENE
<i>G. oceanica</i> (F)		NN17	MIDDLE	
<i>D. pentaradiatus</i> (L)		NN16		
<i>R. minutulus</i> (L)	Chinshui Fm.	NN15	EARLY	PLIOCENE
<i>S. abies</i> (L)	Kueichulin Fm.			
<i>Gephyrocapsa spp.</i> (F)		NN12		
<i>D. quinquerarius</i> (L)	Nanchuang Fm.	NN11	LATE	MIOCENE
<i>D. q.</i> (F); <i>D. surc.</i> (F)		NN10		
<i>D. hamatus</i> (L)		NN9		
<i>C. coalitus</i> (F)	Kuanyinshan Ss.	NN8	MIDDLE	MIOCENE
<i>C. floridanus</i> (L)		NN7		
<i>S. heteromorphus</i> (L)		NN6		
<i>H. ampliaperta</i> (L)	Talu Fm.	NN5	EARLY	MIOCENE
<i>S. heteromorphus</i> (F)	Peiliao Fm.	NN4		
<i>S. belemnus</i> (L)		NN3		
<i>S. belemnus</i> (F)	Shihti Fm.	NN2		
<i>H. carteri</i> (F)	Taliao Fin			
<i>S. ciperensis</i> (L)	Mushan Fm.	NN1	LATE	OLIGOCENE
<i>S. distentus</i> (L)	TTS Fm.	NP25		
<i>S. ciperensis</i> (F)	TSK Ss.	NP24		
<i>R. hillae</i> ; <i>R. umb.</i> (L)	KK Fm.	NP23	EARLY	
<i>C. formosus</i> (L)		Wuchihshan Fm.	NP22	
<i>D. barbadiensis</i> (L)	SL. Ss.	NP21	EARLY	

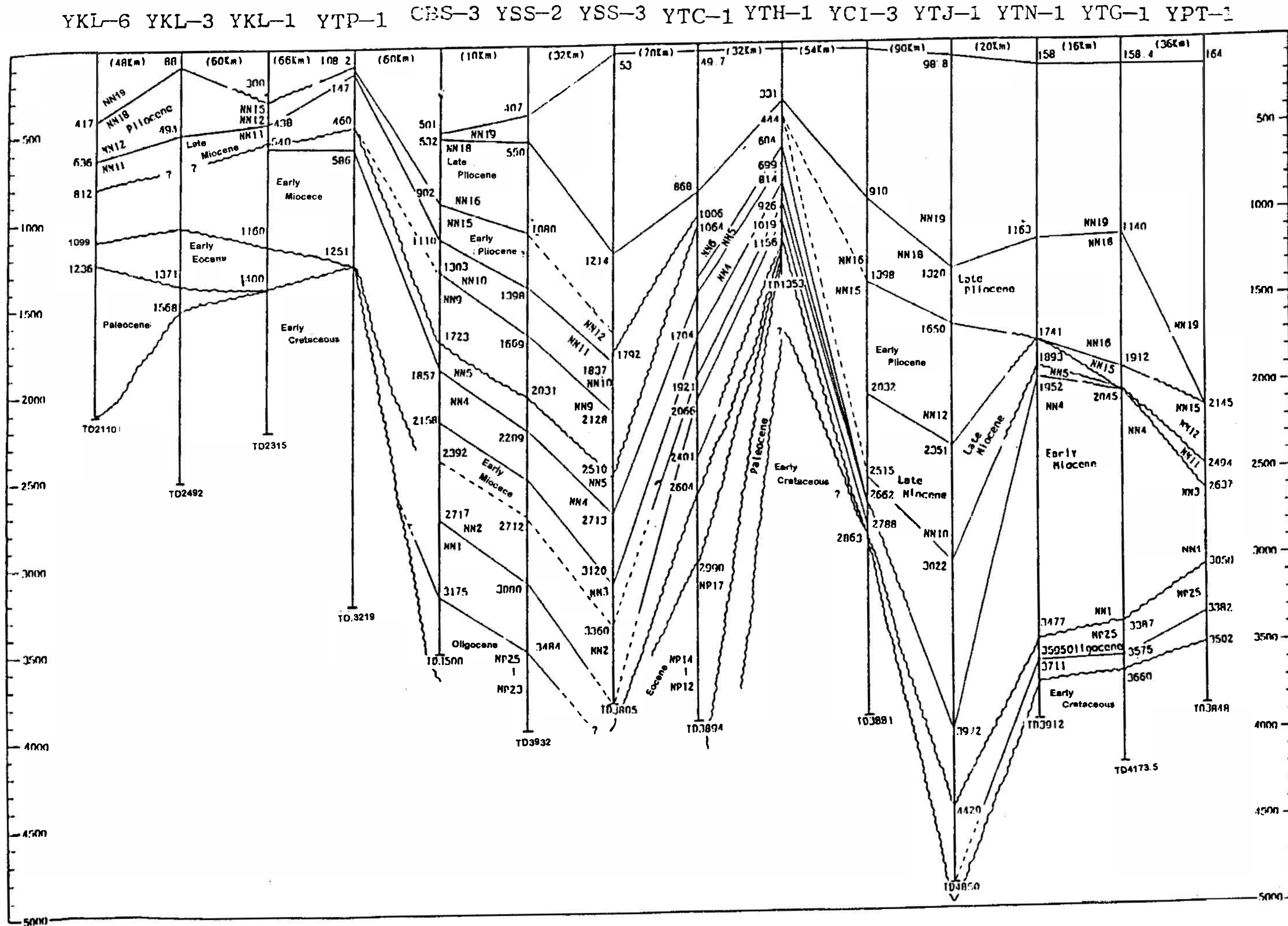


Fig. 2. Stratigraphic correlation Profile A and the names of the 14 wells used in the construction of the profile, offshore Western Taiwan Basin. (From Shaw *et al.*, 1990)

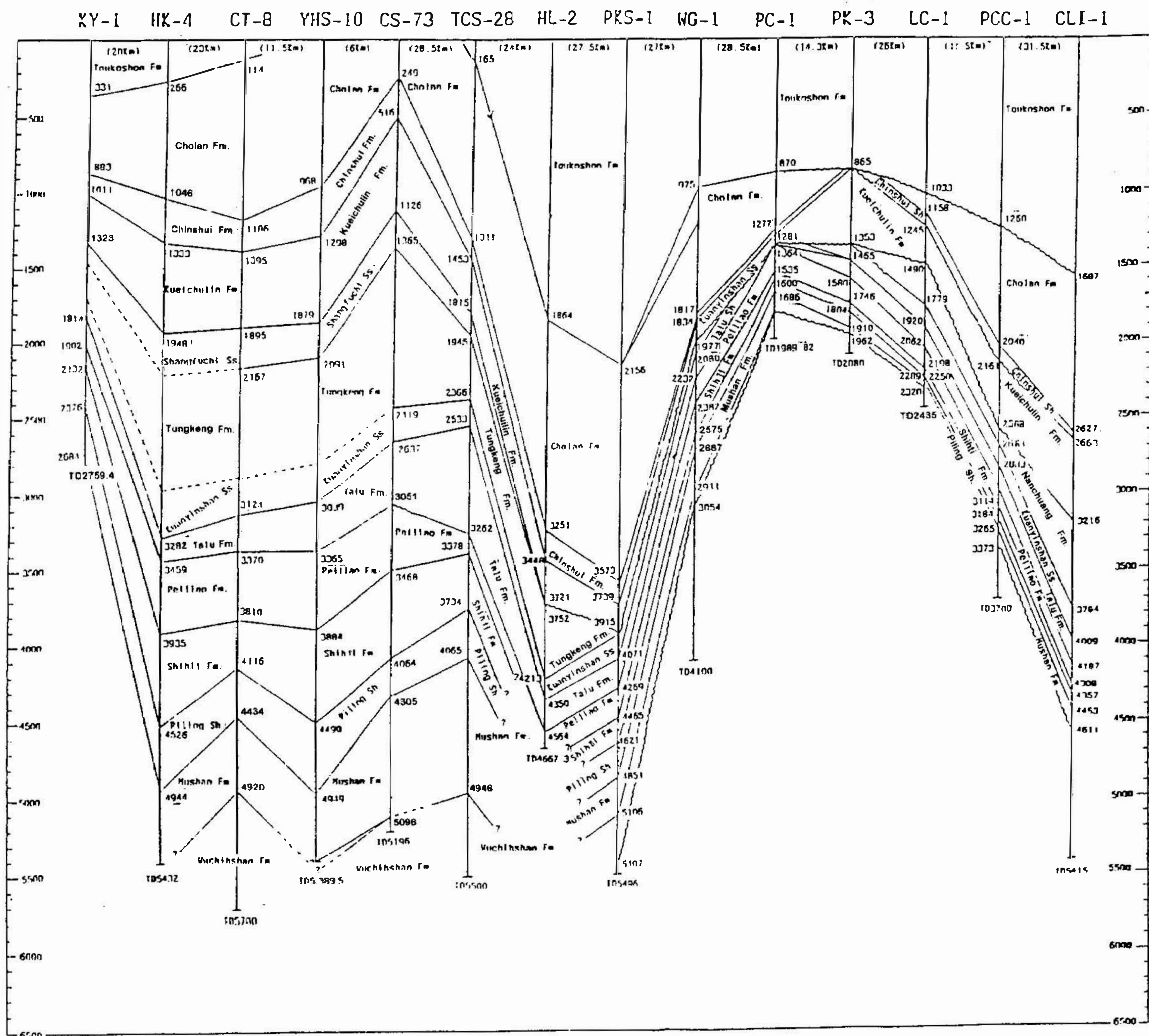


Fig. 3. Stratigraphic correlation Profile B and the names of the 14 wells used in the construction of the profile, onshore western Taiwan Basin. (From Shaw *et al.*, 1990)

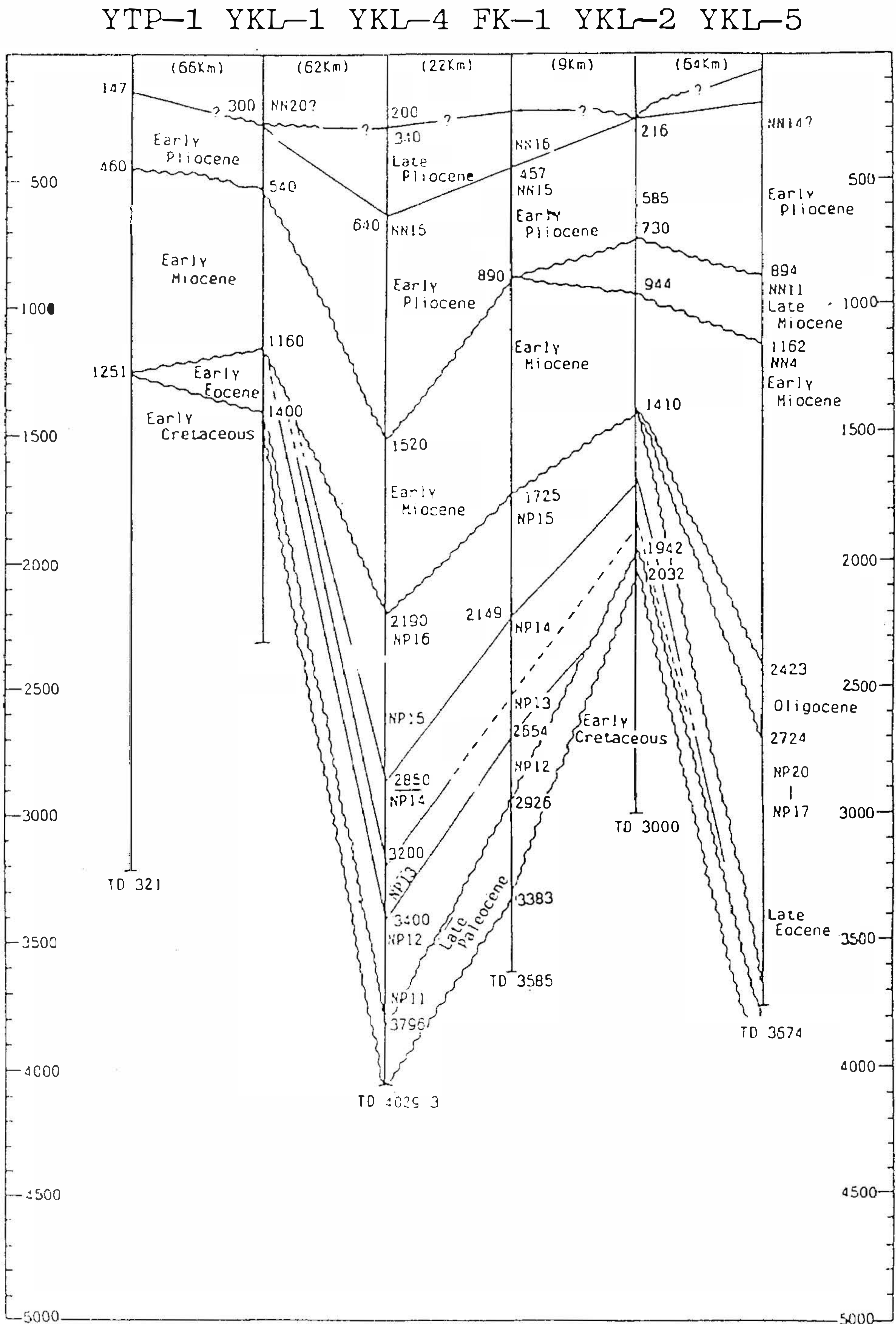


Fig. 4. Stratigraphic correlation Profile C and the names of the 6 wells used in the construction of the east-west profile, northern offshore Taiwan. (From Shaw *et al.*, 1990)

The stratigraphic correlation Profile D (Figure 5) was constructed in accordance with the subsurface geological and paleontological data of the following wells: CBS-3, YSS-2, TCN-1A, PST-2, YHS-10, and PKL-4.

The stratigraphic correlation Profile E (Figure 6) was constructed on the basis of the subsurface geological and paleontological data of the following wells: YPH-4, YPH-3, TL-1, YTH-1, YTH-2, YTC-3, YTC-4, WG-1, and TC-1.

The stratigraphic correlation Profile F (Figure 7) was constructed from the subsurface geological and paleontological data of the following wells: YPT-2, YPT-1, YTG-1, YTN-1, YTN-5, YTJ-1, YCI-4, YCI-3, PCC-1, and HP-1.

3.2 Isopach Maps and Discussion

The locations of the wells used in this study are shown in Figure 8. The correlation of the stratigraphic divisions in Taiwan (after Lin, 1982; Huang *et al.*, 1979; Chi, 1980) is shown in Table 1.

3.2.1 Pre-Oligocene

Most of the exploration wells were not deep enough to encounter Paleocene formations and, in fact, the paleontological evidence indicates that the Paleocene formations were only present locally in the northern offshore of Taiwan and the Wangkung- Taihsi-YTH region. The Eocene formations are also present in the above mentioned areas as well as in the Penghu Basin. Data is not sufficient to enable the construction of the regional Oligocene and Eocene isopach maps.

3.2.2 Wuchihshan Formation

The Oligocene formations are generally absent in the offshore, the west of YKL-1, YTP-1 and YML-1 and north of Block E areas; they are also absent in the YIT-1 and YA-1 regions. The Peikang basement high was gradually formed during this stage, and it extended to the Paochung-Tienchung area in the north and to Chiali in the south. This basement high separated the Western Taiwan Basin into two parts: the Northern and Southern Basins. The depocenter of the Wuchihshan Formation (Figure 9) in the Northern Basin was in the Hsinchu-Taoyuen-Eastern Taipei belt, and the thickness of the sediment increases from the northwest to the southeast and from the south (north of the Peikang basement high) to the north. The maximum thickness of the Wuchihshan Formation in the basin reaches to more than 1000m in the depositional center, and it was derived mainly from the northwest of Taiwan but also partly from the Peikang basement high.

3.2.3 Mushan Formation

The Mushan Formation (Figure 10) is absent in the offshore areas, west of YTP-1, YML-1, YCI-5 and YIT-1, and in the onshore PC-1 and TC-1 wells. Its thickness is generally under 100m in the Peikang basement high but may reach to nearly 800m in the depocenter of the Northern Basin to the east of Miaoli. The sediment was derived from the northwest and southwest of Taiwan.

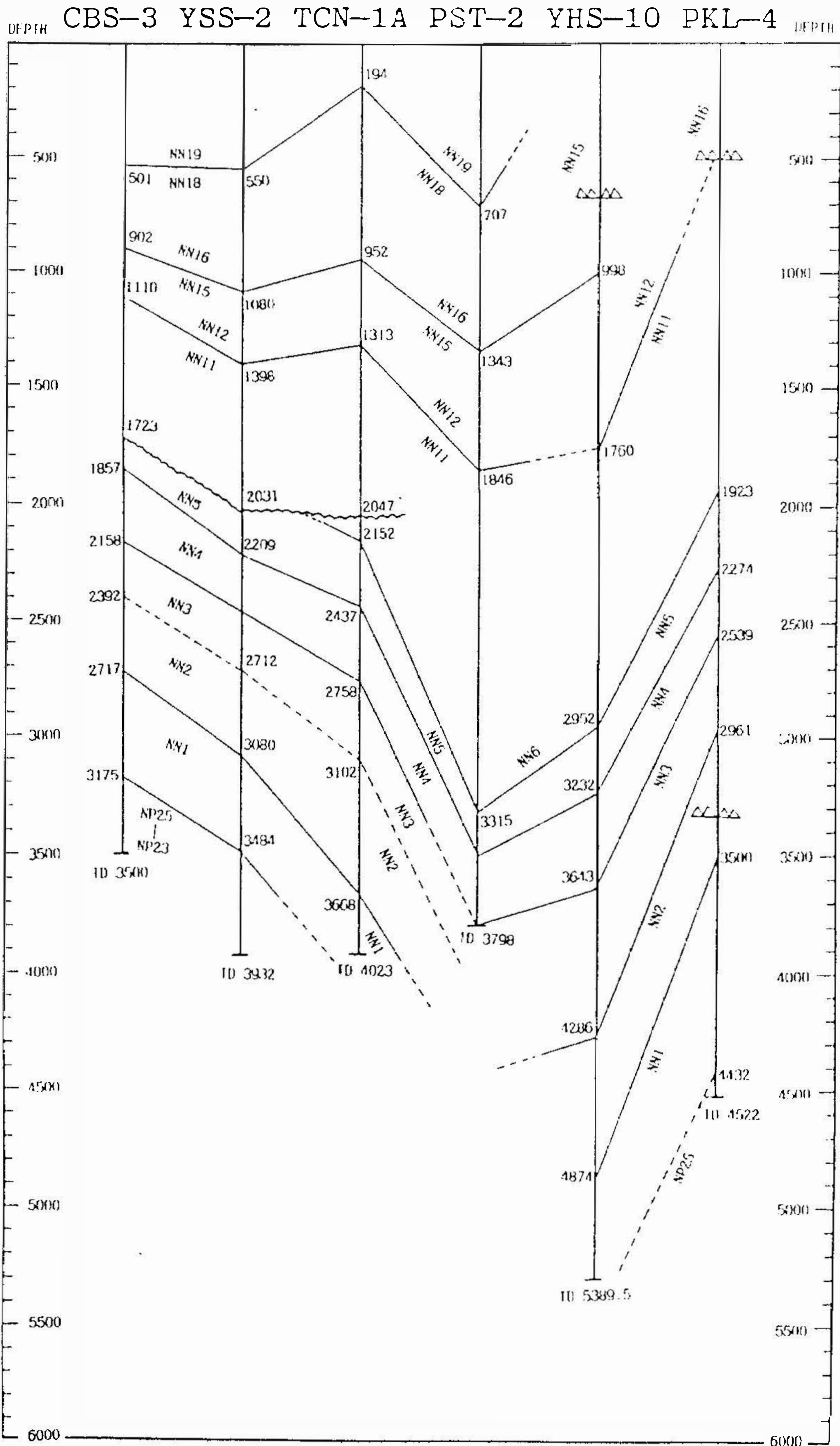


Fig. 5. Stratigraphic correlation Profile D and the names of the 6 wells used in the construction of the profile extending from the northwest offshore to on-shore Taiwan. (From Shaw et al., 1990)

YPT-2 YPT-1 YTG-1 YTC-1 YTN-5 YTJ-1 YCI-4 YCI-3 YKL-1 HP-1

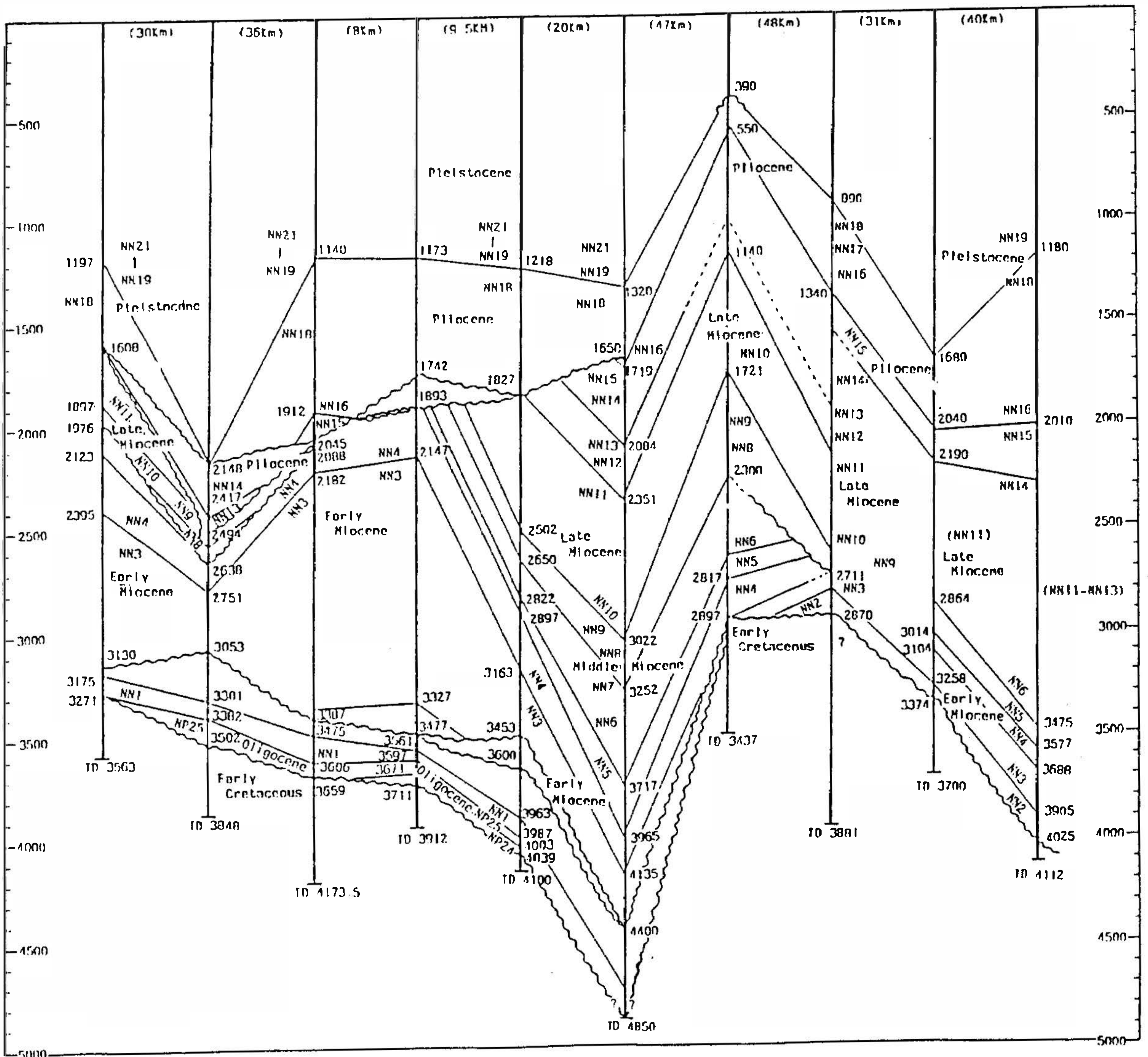


Fig. 7. Stratigraphic correlation Profile F and the names of the 10 wells used in the construction of the profile, southern offshore Taiwan. (From Shaw *et al.*, 1990)

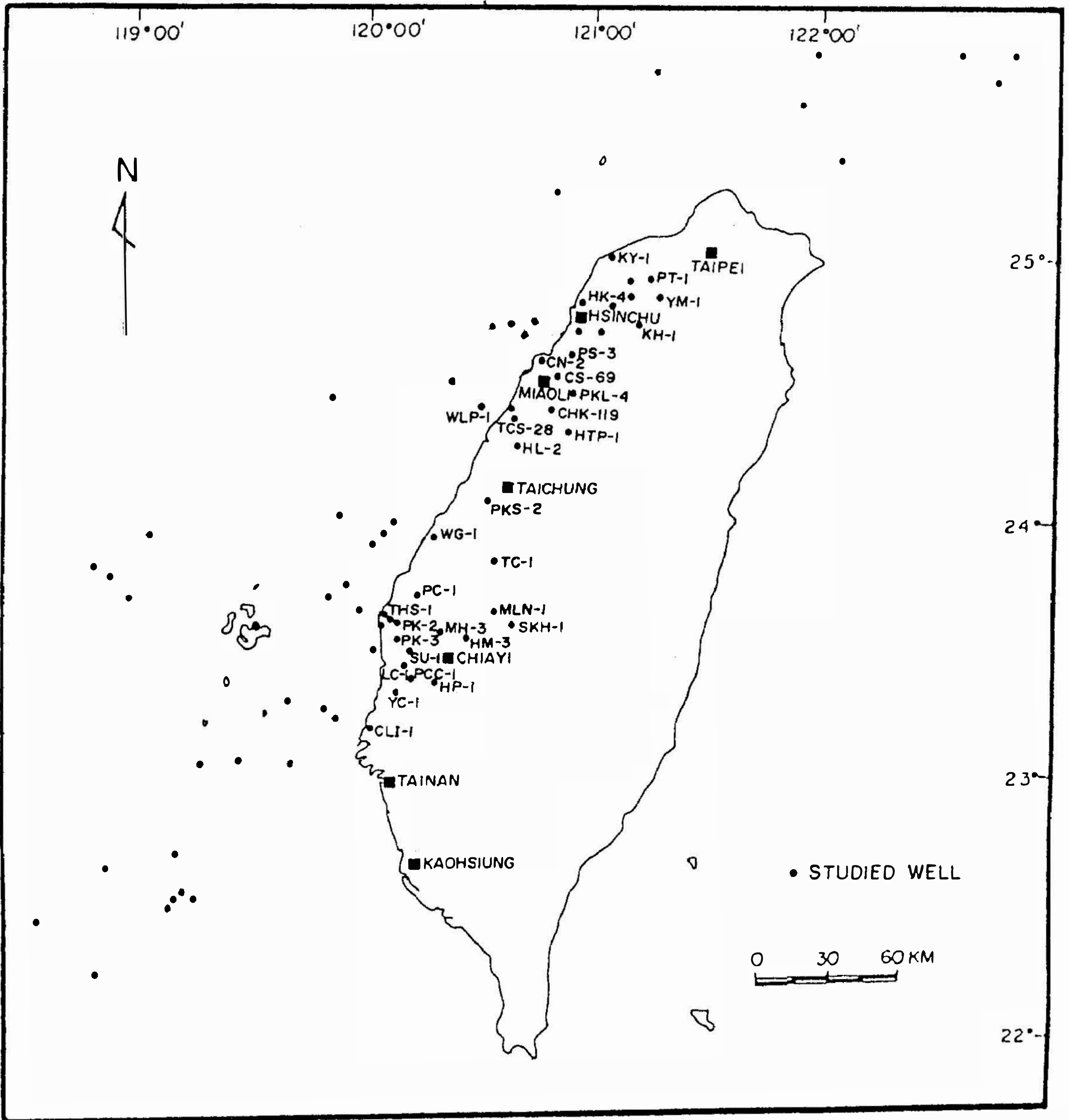


Fig. 8. Location map of the wells used in the construction of the isopach maps, Western Taiwan Basin.

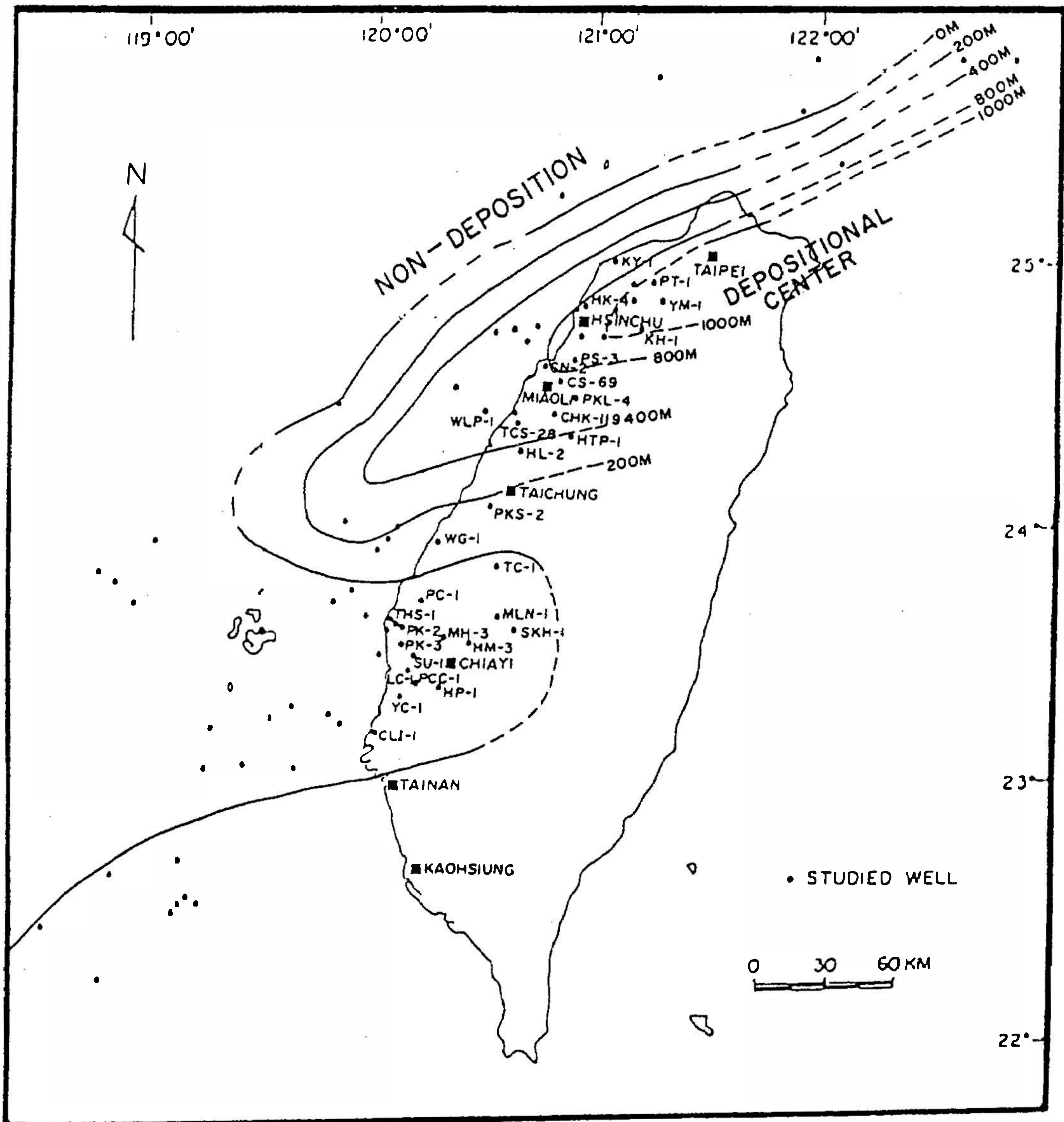


Fig. 9. Isopach map of the Wuchihsan Formation, Western Taiwan Basin.

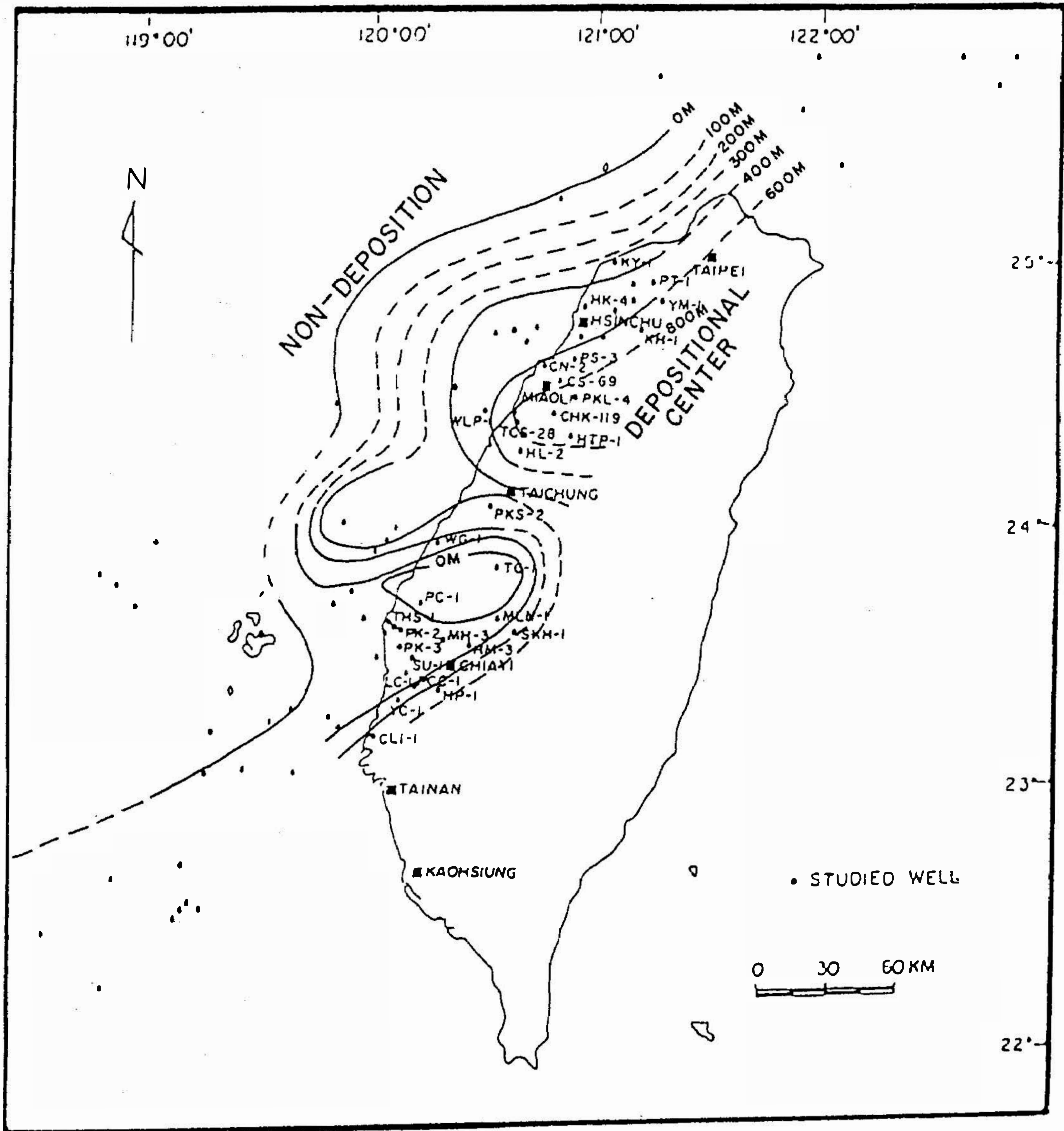


Fig. 10. Isopach map of the Mushan Formation, Western Taiwan Basin.

3.2.4 Taliao Formation

The Taliao Formation (Figure 11) is virtually absent from the offshore areas, west of the YCI-1.4.5 and YIT-1 wells. The thickness of this formation is about 100m in the Peikang basement high but may reach to about 600m in the depocenter of the Northern Basin in the east of the Miaoli-Hsinchu belt. The sediments were mainly from the northwest of Taiwan, and the Peikang basement high became a prominent barrier separating the Northern and Southern Basins.

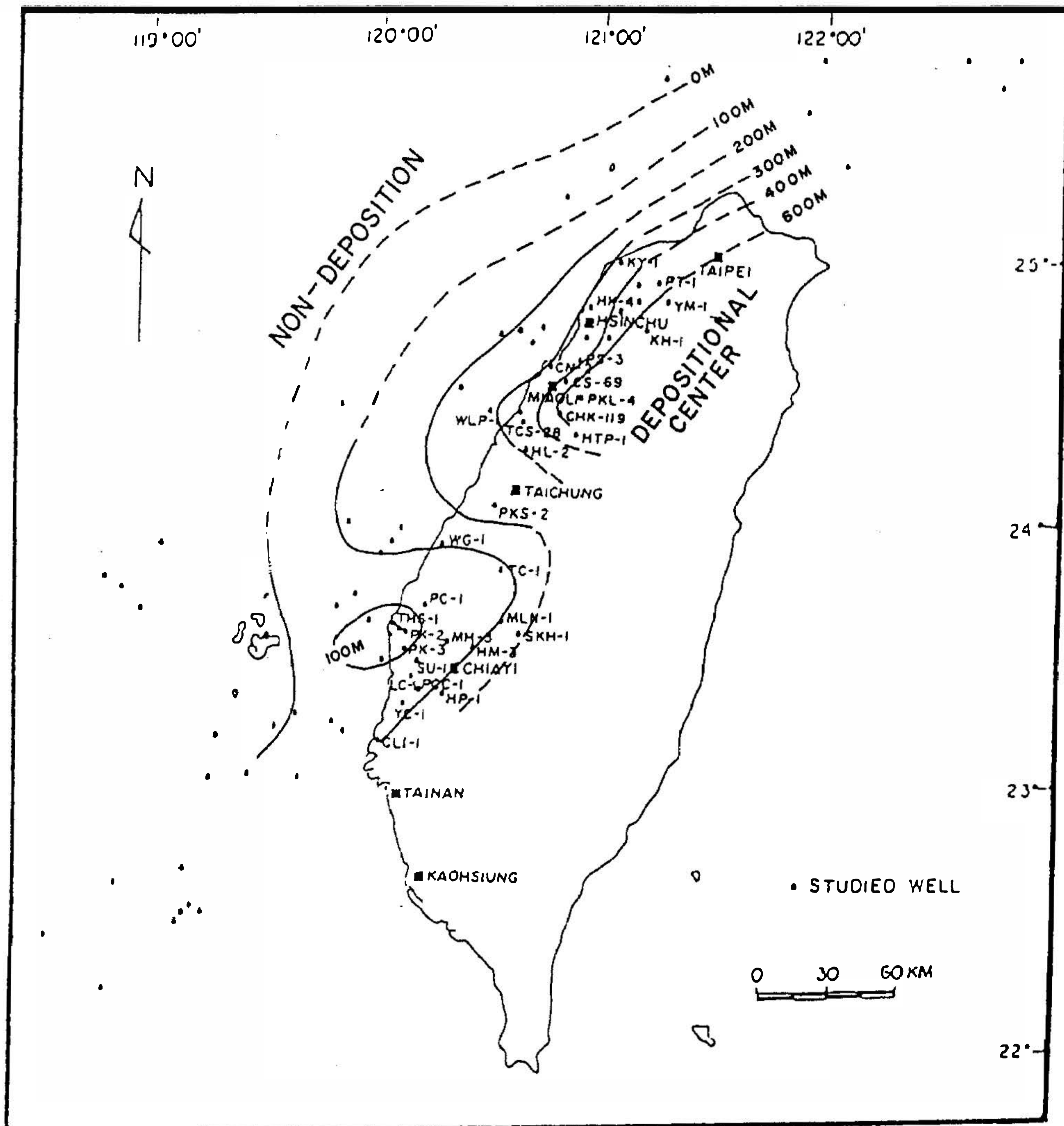


Fig. 11. Isopach map of the Taliao Formation, Western Taiwan Basin.

3.2.5 Shihti Formation

The thickness of the Shihti Formation (Figure 12) is about 200 m in the YSS and YTH areas, while that in the Peikang basement high is under 100m. This phenomenon indicates that the Peikang basement high (extending from Paochung-Tienchung to Chiali) was still a barrier between the Northern and Southern Basins. About 700m thick, the Shihti Formation (684 m at CS-69) was deposited in the depocenter located in the east of the Miaoli-Hsinchu belt, with its sources in the west and northwest of Taiwan.

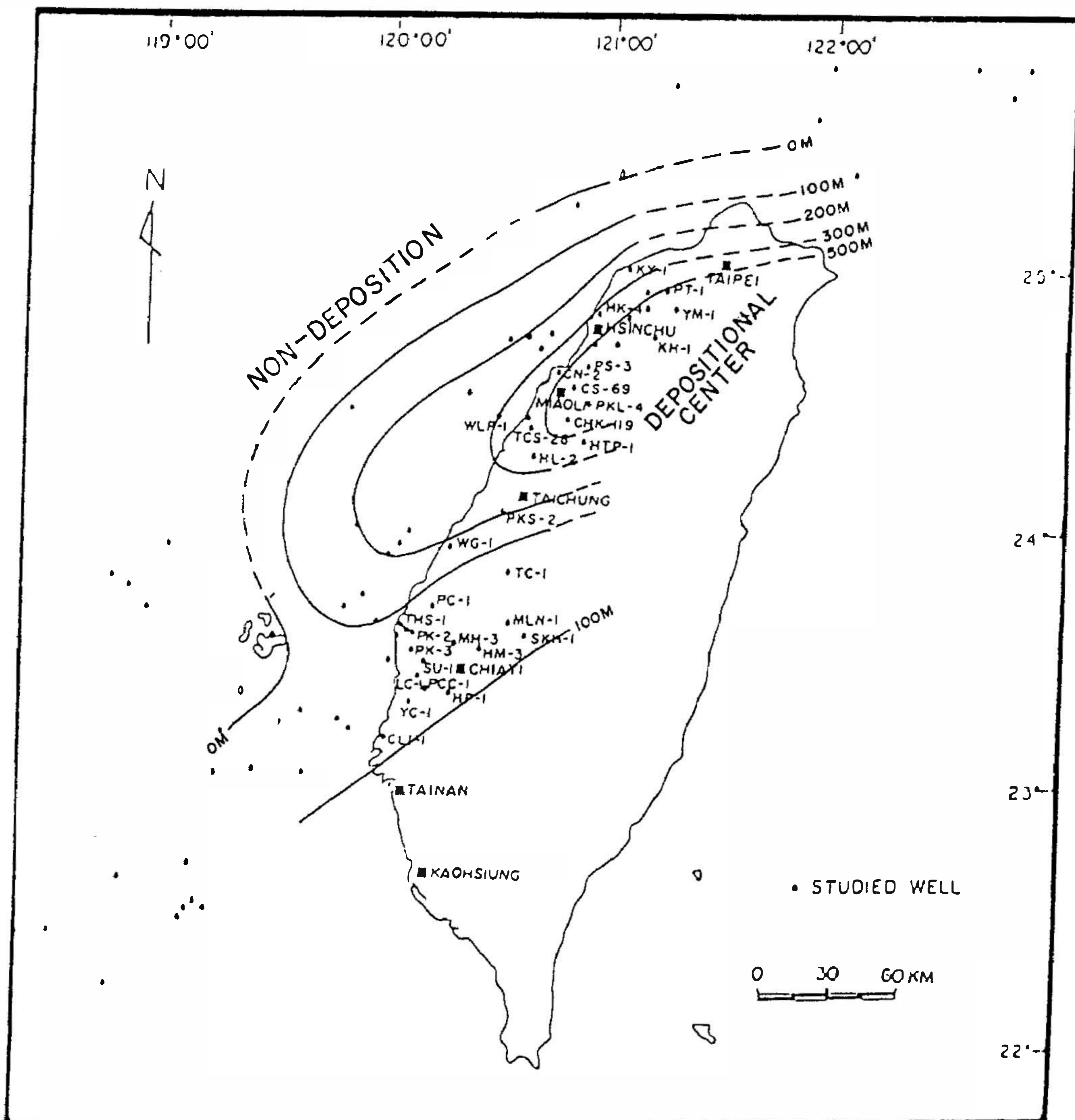


Fig. 12. Isopach map of the Shihti Formation, Western Taiwan Basin.

3.2.6 Peiliao Formation

The average thickness of the Peiliao Formation (Figure 13) in the KY-1, YSS and HL areas is 200 to 300 m but increases toward the east and may reach up to 800-900 m in thickness in the depocenter in the east of the Miaoli-Hsinchu-Taoyuan belt. The sediment was derived from the west and northwest of Taiwan, and the effect barrier of the Peikang basement high has diminished gradually.

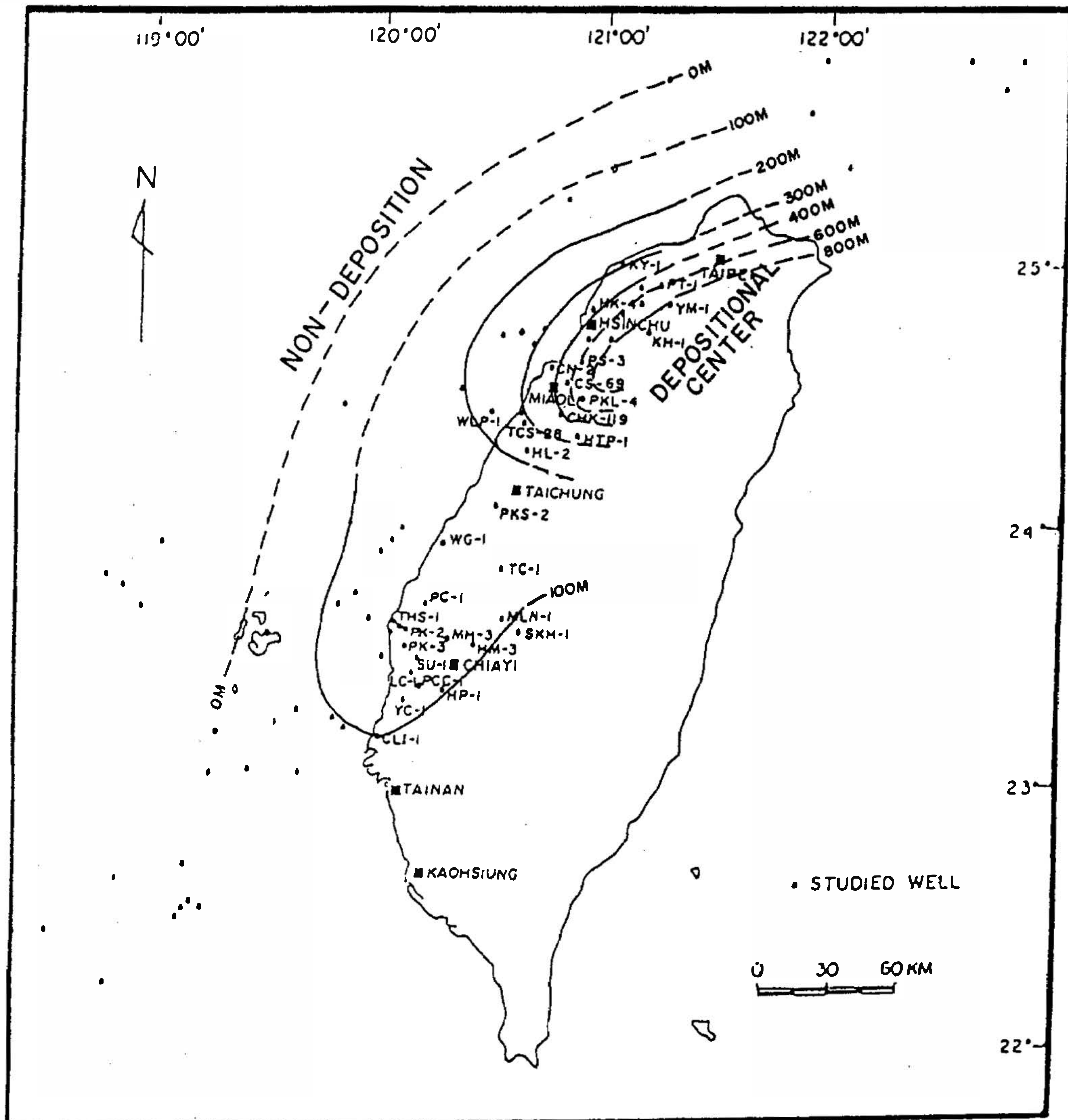


Fig. 13. Isopach map of the Peiliao Formation, Western Taiwan Basin.

3.2.7 Talu Formation

The isopach map of the Talu Formation (Figure 14) reveals that the thickness of the formation maximizes in the YSS and TCS areas where the thickness ranges from 400 to 500m and decreases toward the east, the south and the north. Based on the distribution of the Talu Formation, it may be interpreted that the formation represents a large fan delta.

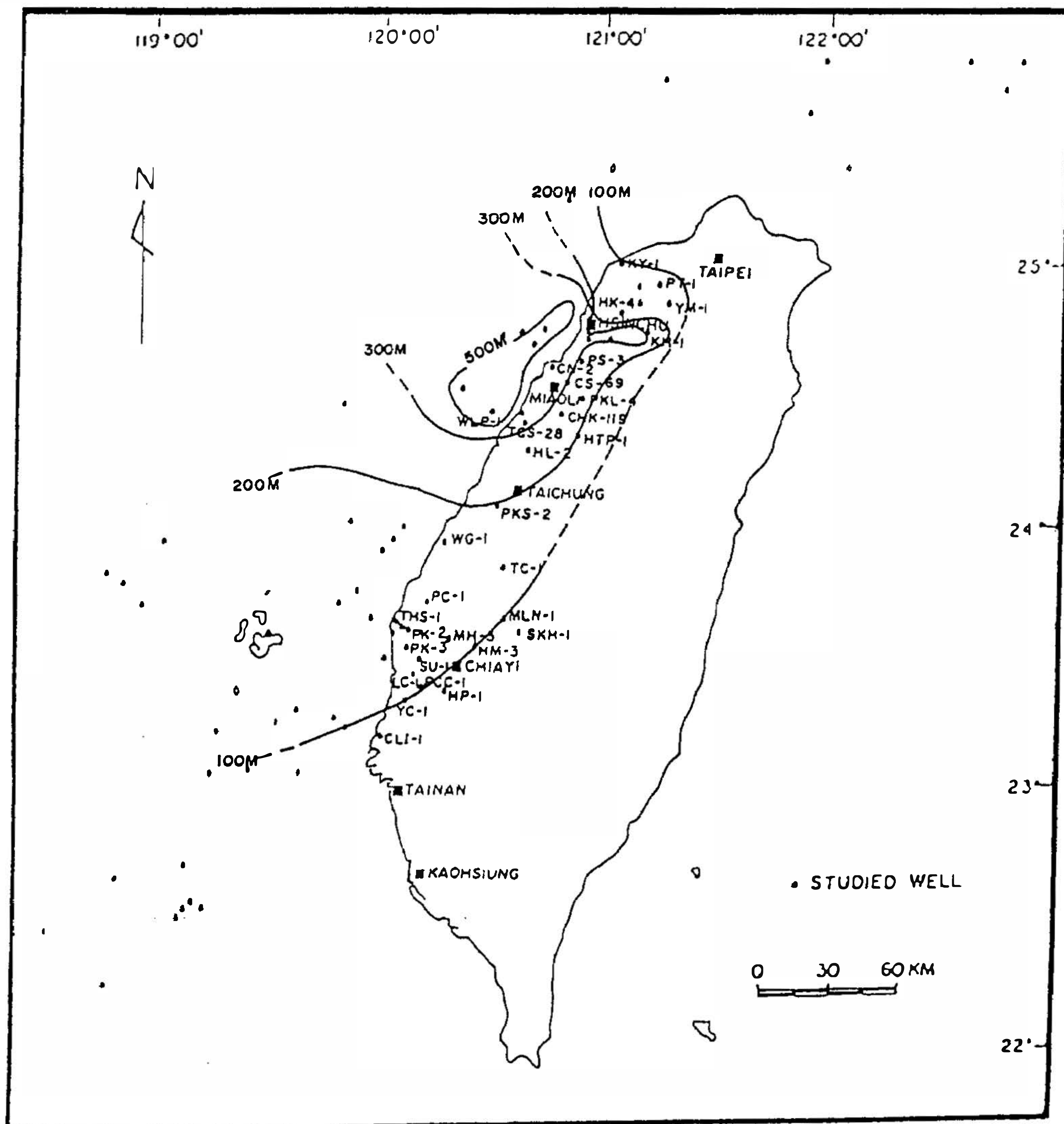


Fig. 14. Isopach map of the Talu Formation, Western Taiwan Basin.

3.2.8 Kuanyinshan Sandstone and Nanchuang Formation

As it is difficult to differentiate these two formations (Figure 15), they are discussed here as one unit. The thickness of these two formations in the Taichung-Pachanghsi area is below 250 m, but this gradually increases in the direction the Northern and Southern Basins. The thickness in the YSS to TCS areas is between 500 m and 700 m and increases toward the depocenter located to the east of the Hsinchu area where the thickness may reach up to nearly 1500 m. The Kuanyinshan Sandstone and Nanchuang Formation were derived from the west and northwest of Taiwan.

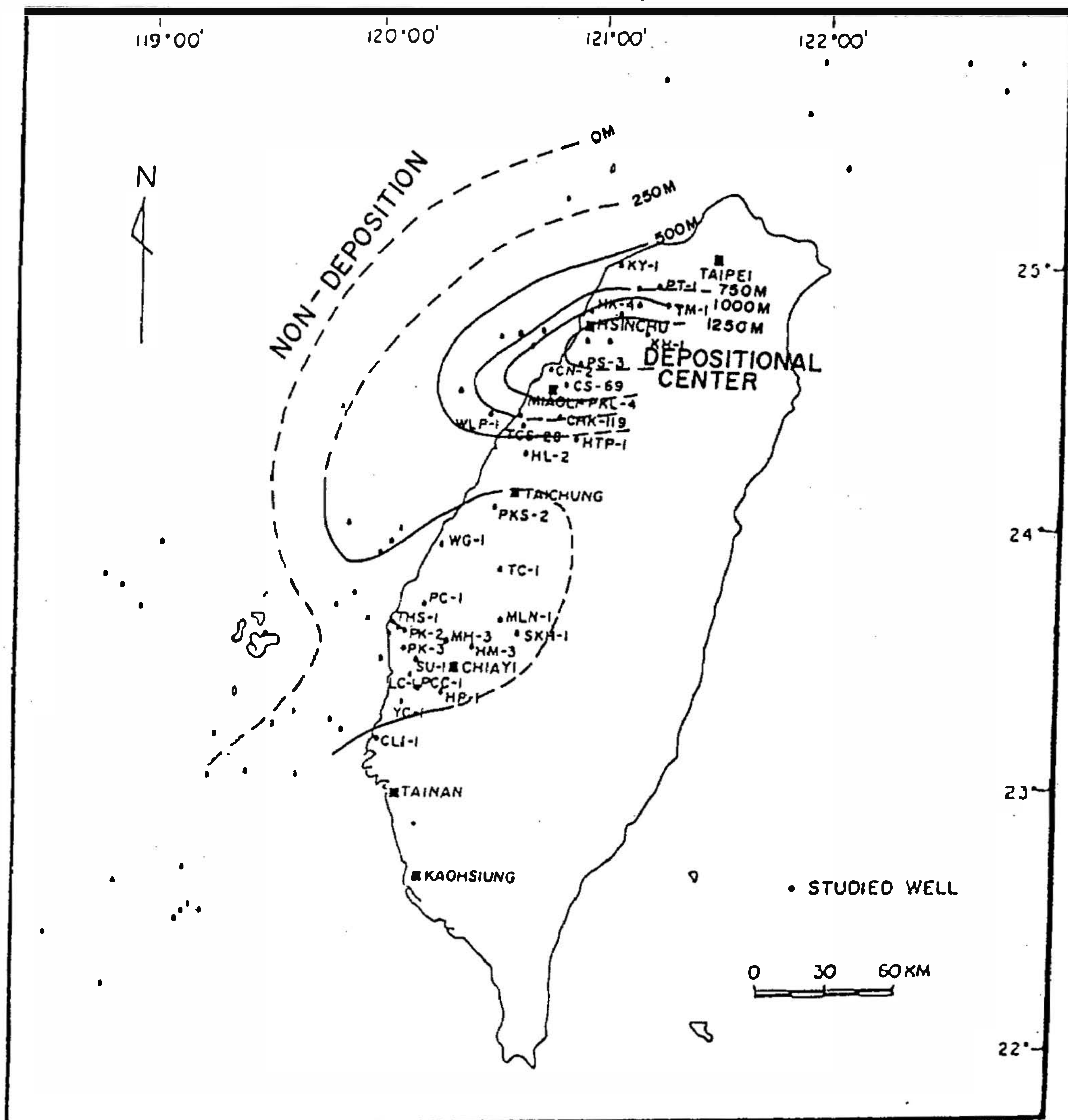


Fig. 15. Isopach map of the Kuanyinshan Sandstone and Nanchuang Formation, Western Taiwan Basin.

3.2.9 Kueichulin Formation

The isopach map of the Kueichulin Formation (Figure 16) shows that the sediment thickness in the KY-1, YSS to TCS areas is 200-400 m. It then increases toward the northeast and may reach more than 800 m in the depocenter in the east of the Hsinchu-Taoyuan area. The sediments were derived from the west and northwest of Taiwan.

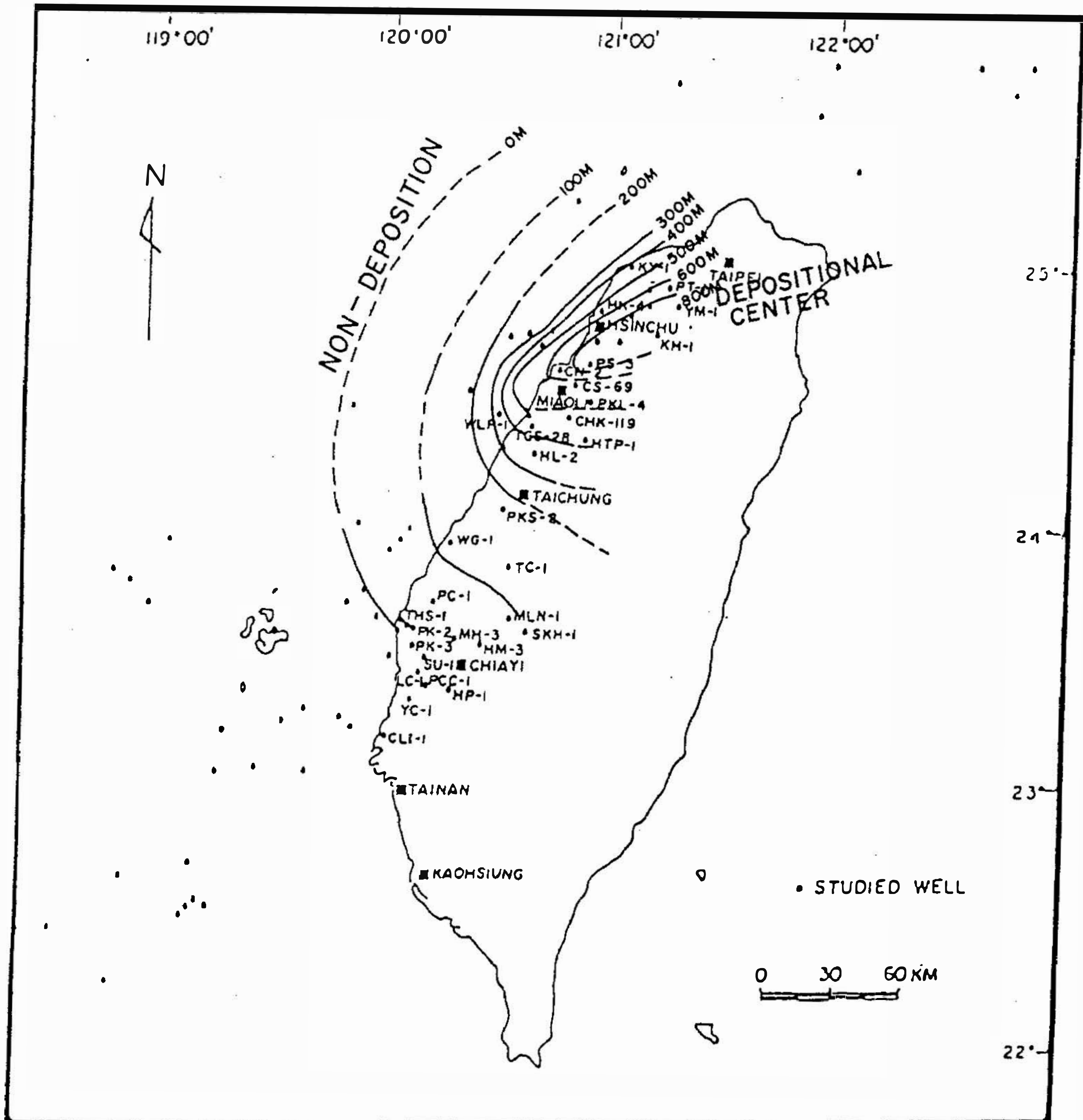


Fig. 16. Isopach map of the Kueichulin Formation, Western Taiwan Basin.

3.2.11 Cholan Formation

Mountain building movements were active during the Cholan stage, on uplifting the Central Range and subjecting it to erosion. As a result, a tremendous amount of sediment (thicker than 1500 m) derived from the uplifted Central Range was deposited in western Taiwan (Figure 18). The thickness of the sediment gradually decreases to the west, and in the present coastal area its thickness is about 750 m. Further to the west in the area west of the YSS and THS-6 wells, its thickness decreases abruptly to under 250 m. As stated, the sediment was obviously from the east, and the depocenter was located in the Miaoli-Taichung belt.

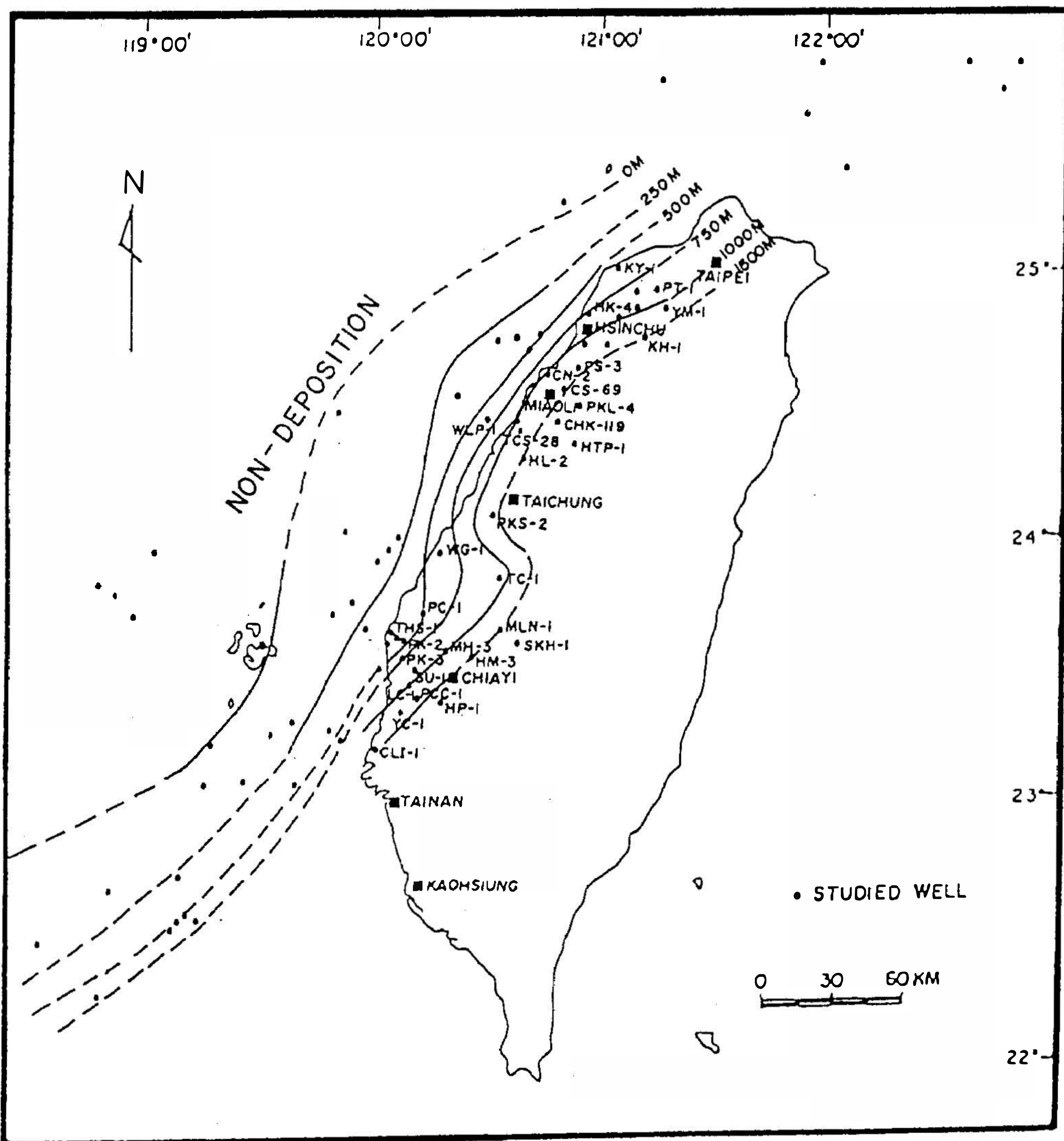


Fig. 18. Isopach map of the Cholan Formation, Western Taiwan Basin.

3.2.12 Toukoshan Formation

Mountain building on the island of Taiwan continued in the Toukoshan stage and has resulted in the deposition of huge amounts of sediment in western Taiwan (over 3000 m thick in the east of the Taichung area). Sediment thickness, however, decreases abruptly to the west, and in the YSS and YTH-3 and 4 areas, the formation is less than 500 m in thickness (Figure 19). The Toukoshan Formation in the Taiwan Strait was deposited in a stable environment and had little impact of the thrust faulting initiated by the mountain building process. Again, the sediment was from the east, and the thickest place shifted to the Taichung-Nantou areas.

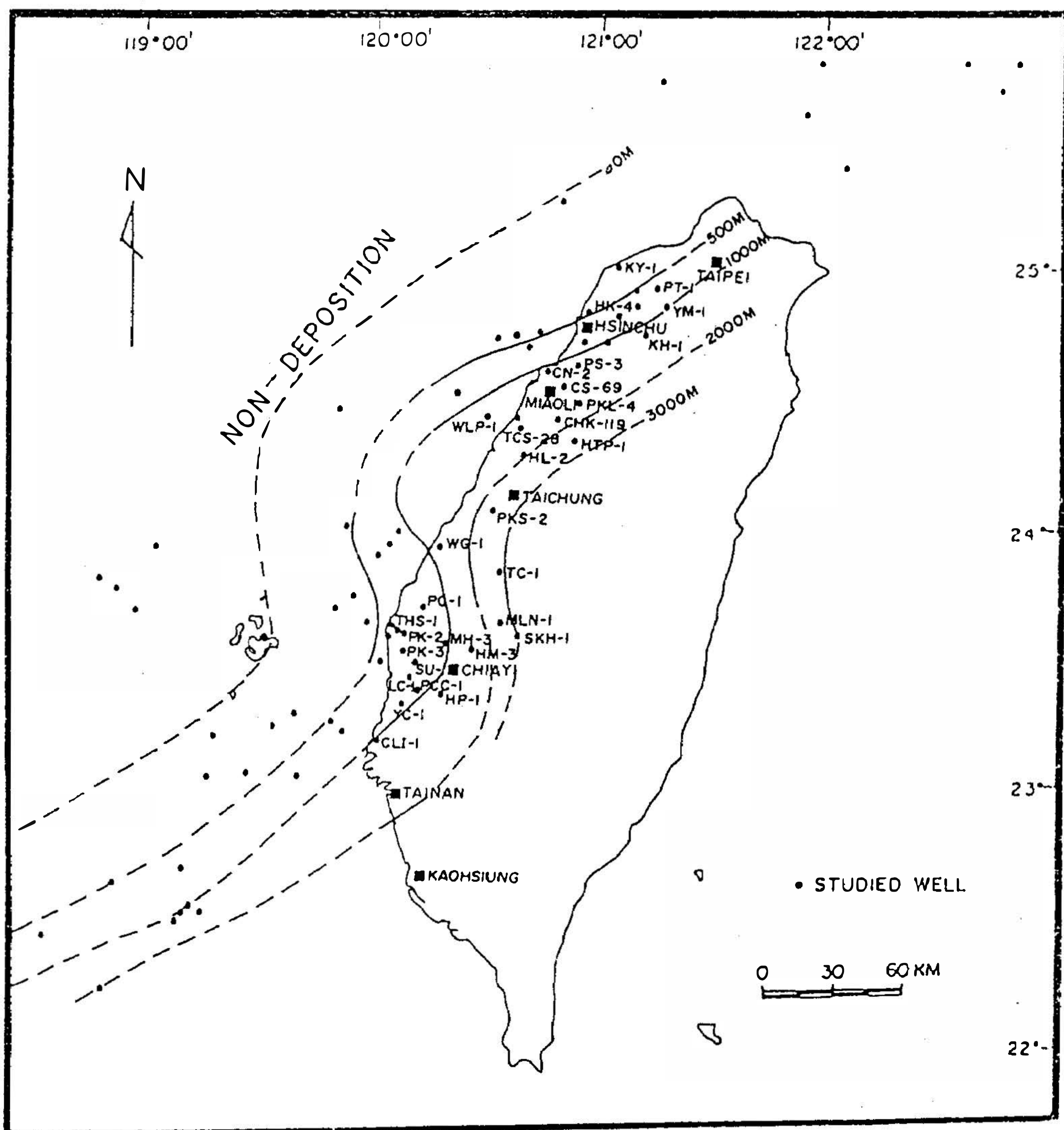


Fig. 19. Isopach map of the Toukoshan Formation, Western Taiwan Basin.

4. CONCLUSIONS

The subsurface geologic reports, paleontological data, and stratigraphic correlation studies of 42 onshore and offshore exploration wells completed by earlier researchers were incorporated in this study. Six regional stratigraphic profiles were thereby constructed. Profiles A and B trend north-south, whereas Profiles C, D, E and F are all east-west trending. The completion of these six regional stratigraphic profiles provides a better understanding of the distribution and thickness variation of every formation in Taiwan.

In addition to the geological data of the 42 wells studied in the construction of the six stratigraphic profiles, those of the other 18 onshore and 28 offshore wells were also studied in the construction of the isopach maps of each formation above the Wuchihshan Formation. This means the geological data of 88 wells were utilized in this study. With the aid of the isopach maps, it is possible to postulate the depositional center of the basin during each stage.

During the Oligocene, the depositional center was located to the east of the Hsinchu-Taoyuan-Taipei belt, and the thickness of the Oligocene formation increases from the west to the east. The sediment thickness increases from the south, i.e. the area to the north of the Peikang basement high, to the north and may reach to more than 1000 m in the depositinal center of the basin. The sediments were derived mainly from the northwest of Taiwan and partly from the Peikang basement high.

During the Miocene, the Peikang basement high acted as a sediment barrier and divided the Taiwan region into the Northern and Southern Basins. A tremendous amounts of sediment were deposited in each of these basins. For example, the total thickness of the Miocene formations may exceed 4000 m, while those in the Peikang basement high are less than 1000 m in thickness. The depositional center for the Miocene was situated to the east of the Miaoli-Hsinchu belt, and the source region of the Miocene sediments was situated northwest of the Island of Taiwan in the present Taiwan Strait. Those sediments were transported southward and southeastward down a paleoslope of gentle inclination in directions approximately normal to the isopachs of the Miocene clastic sequence (Chou,1980).

The configuration of the sedimentary basin and the source of the sediment of the Kueichulin and Chinshui Formations were not too different from those in the Miocene time in the Northern Basin. However, due to mountain building on Taiwan during the late Pliocene, the sediment originated in the east and a huge thickness of sedimentary rock was recorded in western Taiwan. The depositional center of the Cholan Formation was located to the east of the Taichung-Miaoli-Hsinchu belt.

The mountain building movement continued in the Toukoshan stage of the Pleistocene, sediments more than 3000m thick were deposited in western Taiwan. The sediment was mainly from the east, forcing the depositional center shifted to the Taichung-Nantou belt.

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3.2.10 Chinshui Formation

The thickness of the Chinshui Formation (Figure 17) in the KY-1, YSS, TCS to PKS-2 and TC-1 areas is between 100 to 200 m and increases toward the northeast where the maximum thickness may be in excess of 300 m. The depocenter is situated in the east of Hsinchu-Taoyuan. The sediments were from the west, northwest and southwest of Taiwan. The Chinshui Formation is generally absent in the offshore YML, YTH and YCI-3 areas and onshore PCC-1 areas.

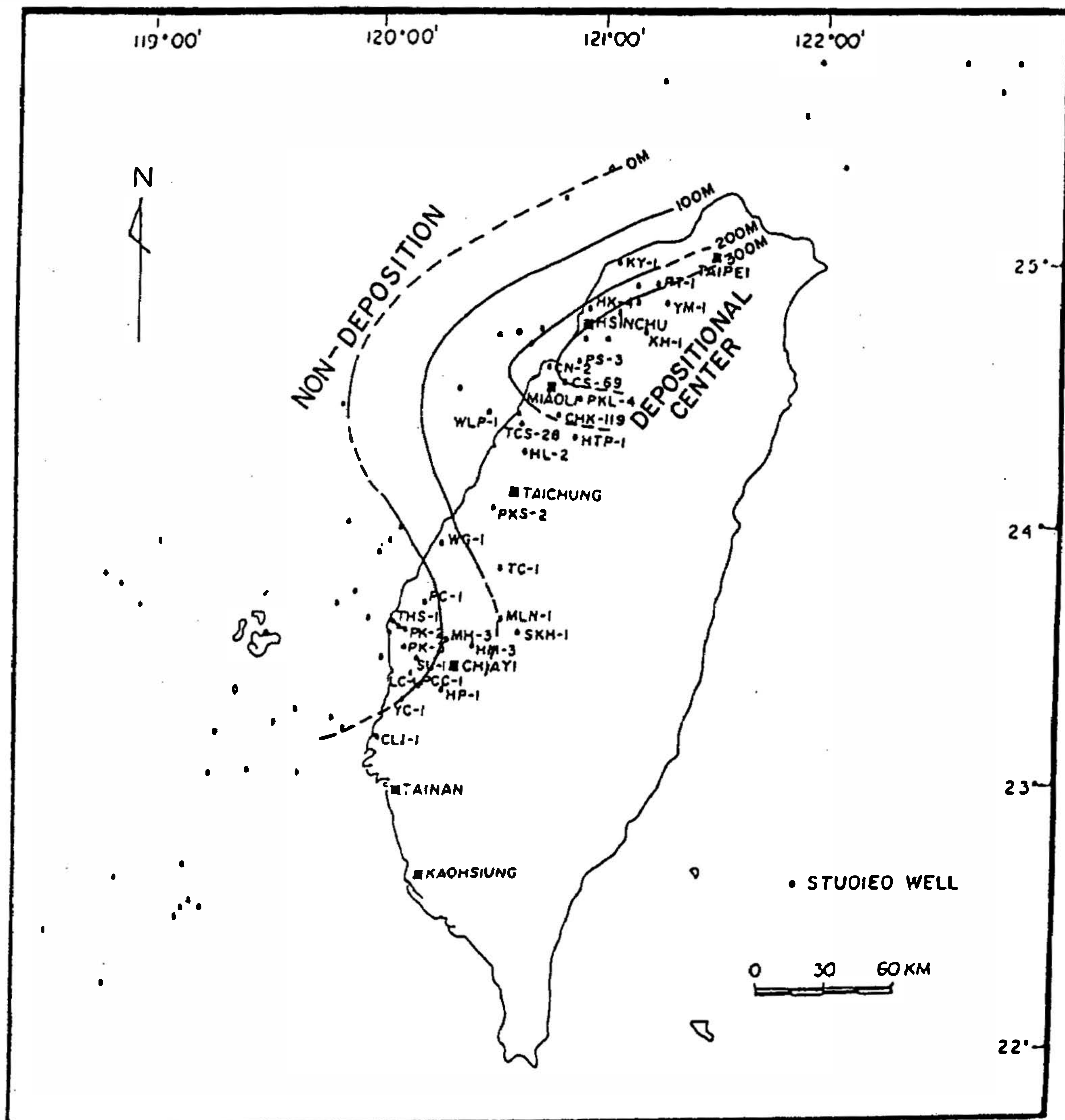


Fig. 17. Isopach map of the Chinshui Formation, Western Taiwan Basin.

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Index to Well Name

- KY (Kuanyin, 觀音)
 HK (Hukou, 湖口)
 CT (Chiting, 崎頂)
 CS (Chinshui, 錦水)
 PST (Paishatun, 白沙屯)
 TCS (Tiehchenshan, 鐵砧山)
 WG (Wangkung, 王功)
 PC (Paochung, 褒忠)
 TC (Tienchung, 田中)
 PK (Peikang, 北港)
 LC (Lutsao, 鹿草)
 PCC (Pachanghsi, 八掌溪)
 CLI (Chiali, 佳里)
 HP (Houpi, 後壁)
 PT (Pingting, 坪頂)
 YM (Yangmei, 楊梅)
 KT (Kengtzukou, 坑子口)
 CTH (Chingtsaohu, 青草湖)
 KH (Kuanhsi, 關西)
 PS (Paoshan, 寶山)
 CN (Chunan, 竹南)
 YHS (Yunghoshan, 永和山)
 PKL (Pakuali, 八卦力)
 CHK (Chuhuangkeng, 出磺坑)
 HL (Houli, 后里)
 PKS (Pakuashan, 八卦山)
 THS (Taihsi, 台西)
 SU (Suantou, 蒜頭)
 PH (Paiho, 白河)
 YC (Yichu, 義竹)
 FK (Fukuei, 富貴)
 TL (Tungliang, 通梁)
 TCN (Nearshore of Hsinchu, 新竹近岸)
 YTP (Offshore of Taipei, 外台北)
 YKL (Offshore of Keelung, 外基隆)
 YSS (Offshore of Hsinchu, 外新竹)
 YML (Offshore of Miaoli, 外苗栗)
 YTC (Offshore of Tienchung, 外田中)
 YTH (Offshore of Taihsi, 外台西)
 YPH (Offshore of Penghu, 外澎湖)
 YCI (Offshore of Chiayi, 外嘉義)
 YTJ (Offshore of Tainan, 外北台南)
 YTN (Offshore of Tainan, 外台南)
 YTG (Offshore of Kaoping, 外高屏)
 YPT (Offshore of Pingtung, 外屏東)