ORIGINAL ARTICLE

Potential ground water resources of Hat Yai Basin in Peninsular Thailand by gravity study

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Abstract

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Residual gravity anomaly with a minimum of about -140 mm s^{-2} with approximately NS trend and a limited axial length was observed over Hat Yai Basin in Peninsular Thailand. The modeled Hat Yai basin is about 1 km deep at its deepest, 60 km long and 20 km wide. The porosity of basin sediment and the amount of potential ground water reserves within the basin are estimated to be 39% and 121.7±0.8 km^3 respectively, assuming full saturation. Within the topmost 80 m of ground where the present extraction is concentrated, the estimated ground water reserve is 12.5±0.5 km^3.

Key words : gravity, ground water, Hat Yai Basin, peninsular Thailand

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บทคัดย่อ

วรวุฒิ โลหะวิจารณ์

ศักยภาพทรัพยากรน้ำใต้ดินของแอ่งหาดใหญ่ในคาบสมุทรไทย โดยการศึกษาด้านสนามโน้มถ่วง

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ค่าสนามโน้มถ่วงผิดปกติตกค้างของแอ่งหาดใหญ่ในคาบสมุทรไทย มีขนาดประมาณ -140 $\mu m\ s^{-2}$ มีความยาวจำกัดในแนวเหนือ-ใต้ จากการแปลความหมายค่าผิดปกติตกค้างดังกล่าว แอ่งหาดใหญ่จะมีความลึกมากที่สุด 1 กม. มีความยาว 60 กม. และมีความกว้างประมาณ 20 กม. ความพรุนของดินตะกอนและปริมาณของน้ำบาดาลสำรองภายในแอ่งหาดใหญ่ที่ประเมินได้เท่ากับ 39% และ 121.7±0.8 ลบ.กม. ตามลำดับ ทั้งนี้โดยการสมมติให้ดินตะกอนในแอ่งอิ่มตัวด้วยน้ำ สำหรับในดินตะกอนชั้นบนซึ่งหนาไม่เกิน 80 เมตร ปริมาณน้ำบาดาลสำรองจะเท่ากับ 12.5±0.5 ลบ.กม.

ห้องปฏิบัติการธรณีฟิสิกส์ ภาควิชาฟิสิกส์ คณะวิทยาศาสตร์ มหาวิทยาลัยสงขลานครินทร์ อำเภอหาดใหญ่ จังหวัดสงขลา 90112

Hat Yai Basin is a sedimentary basin in peninsular Thailand. It is located approximately between longitudes 100º 15′ E and 100º 30′ E and latitudes 6º 30′ N and 7º 15′ N (Figure 1).

The study area is topographically a flat area with an elevation of about 0 to 20 m above mean sea level. Its eastern and western rims are bounded by north-south trending mountain ranges. It was previously thought that Gulf of Thailand and the Thailand-Malaysia border respectively (Figure 2) bound the northern and southern boundaries of the basin.

Geologically, Hat Yai Basin is flanked to the east and west by granitic rocks intruding into Carboniferous and Triassic sedimentary and metamorphic rocks, which form the basement

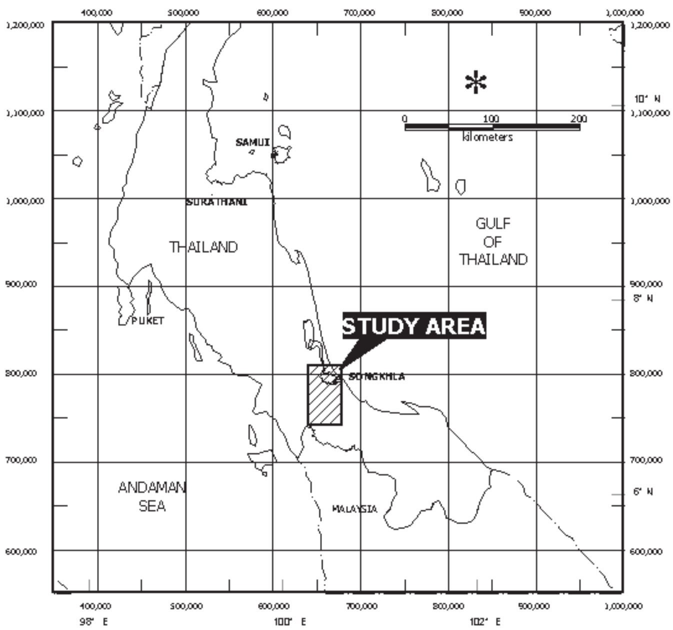


Figure 1. Location of study area

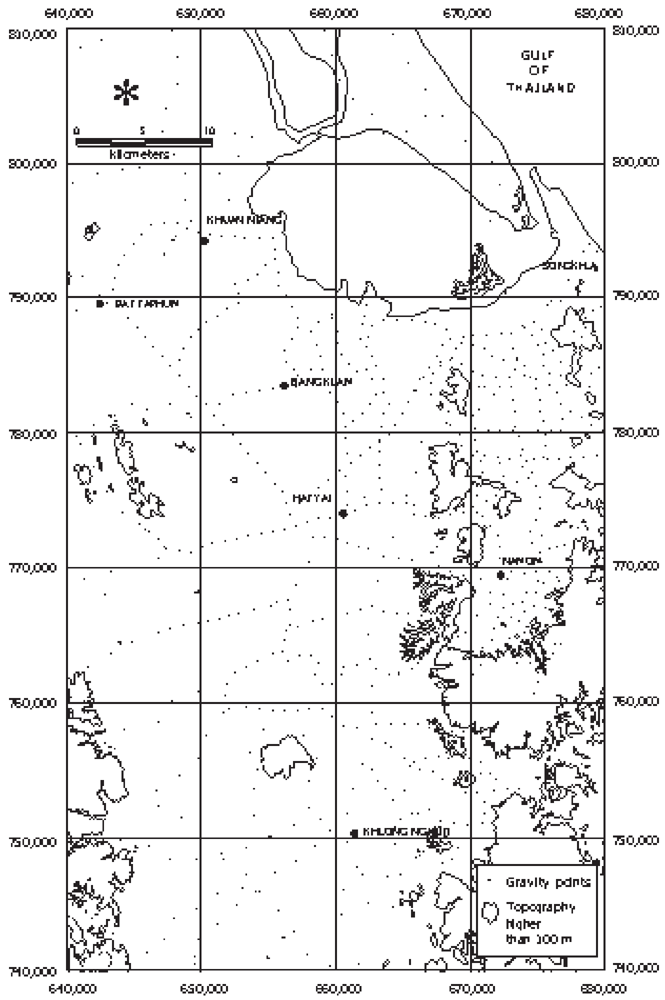
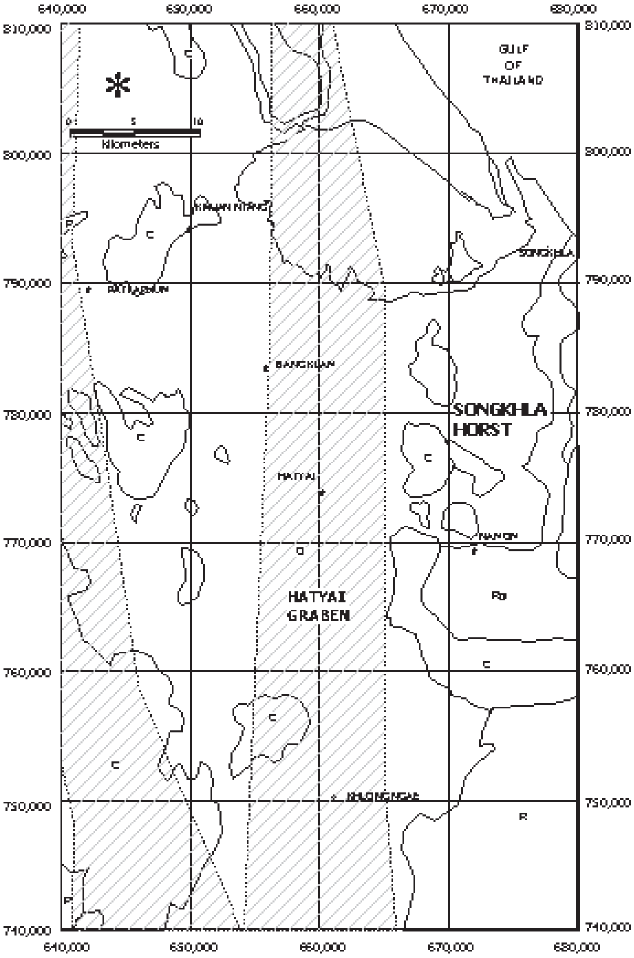


Figure 2. Topographic map and locations of gravity measuring points within the study area

rock of the basin (Figure 3). Carboniferous rock comprises sandstone, siltstone, shale, mudstone, chert, and argillite, whereas Triassic rock is composed of sandstone, siltstone, mudstone, conglomerate, massive limestone and chert. The granites are Late Triassic to Early Jurassic and Late Cretaceous to Early Quaternary in age. They are mainly coarse-grained porphyritic biotite granites with some fine-to medium-grained, muscovite-biotite granites and muscovite-granet granites. (Kobayashi *et al*., 1966; Igo, 1973; Grant-Mackie *et al*., 1978; Ishihara *et al*., 1980; Pungrassami, 1986; Charusiri *et al*., 1990; Chaisen *et al*., 2002). Quaternary alluvium in the basin contains three major aquifer units, namely, the HatYai aquifer, the Khu-Tao aquifer and the Khohong aquifer. They lie at depths of 20 to 40 m, 45 to 80 m and deeper than 100 m respectively (Ramnarong *et al*., 1984; BGS *et al*., 1997).

Structurally, Hat Yai Basin is thought to be a graben whereas the hill ranges and the small basins east of the graben are parts of a horst. This graben and horst structure is also thought to be a southern extension of a geological structure, formed by block faulting in Gulf of Thailand, where oil and natural gas reservoirs were trapped (Sawata *et al*., 1983). There are 2 sets of main lineaments, one in north-south direction and another in



Age	Sedimentary Rocks
Quaternary	Q Alluvium, eluvium, river gravel, terrace, local lateritic soils
Triassic	R Red bed of conglomerate, sandstone, mudstone and limestone
Permian	P Massive and bedded limestone, light to dark gray with chert nudules interbedded with sandstone and shale with fossils
Carboniferous	C Mudstone, sandstone, shale with fossils and cross-bedded, chert and quartzitic sandstone
Late Triassic to Early Jurassic	Rgr Biotite granite, biotite-muscovite granite, aplite pegmatite and quartz veins
	Graben proposed by Sawata, et al. (1983)

Figure 3. Geological map and graben/horst structures within the study area

northeastern direction, which control the horst and graben structure of the basin (Tonnayopas *et al*., 1997).

The total water consumption for domestic and industrial purposes in Hat Yai Basin was 53.36×10^6 m^3 per year in 1997 and it is expected to increase to 57.78×10^6 m^3 per year in 2005, and 62.77×10^6 m^3 per year in 2015. The annual supply from piped water to the water demand was 16.06×10^6 m^3 in 1997 and is predicted to be about

$32.12x10^6$ m^3 in 2005 (EMSONG, 1998). A supply of more than $25.66x10^6$ m^3 per year will certainly be derived from groundwater. Groundwater reserve in Hat Yai Basin could be estimated if the boundary of the basin and the porosity of sediment in the basin are known.

The objectives of the present study were therefore to delineate a boundary of Hat Yai Basin and to estimate groundwater potential in the basin by gravity study.

There are several successful examples of basin boundary mapping in Thailand with gravity measurement like Krabi Basin (Markirt *et al.*, 1984 and Rakyao, 1981), Chiang Mai Basin (Beshir, 1993) and Sob Prap-Serm Ngam Basin (Thumvitavas, 1995).

Materials and Methods

The selected study area is a flat area of approximately 3200 sq km bounded between UTM 640000E and 680000E in east-west direction and between UTM 740000N and 810000N in north-south direction.

Altogether 872 gravity points were measured in the study area. The spacing between gravity points laid along available roads and tracks was 2 km. However, in some parts of the study area, where detailed information of the basin was required, the spacing between gravity points was reduced to 1 km.

The gravity measurement was conducted in leapfrog loops with approximately 2 to 2.5 hours of time spent on each loop. The gravity reading was carried out with the LaCoste & Romberg gravimeter model G. The altitude of each gravity point was read from an altimeter, American Paulin System MDM-5, whereas the geographic positions of the points were read with a GPS, Trimble Pathfinder Basic Plus. In addition, air temperature and measuring time were also taken for altitude and drift corrections.

A benchmark in the Hat Yai campus of Prince of Songkla University was used as a reference point of absolute gravity value in this study. Its UTM coordinates are 660000E and 774637N, or longitude 100º 30′ E and latitude 7º 00′ N. The absolute value of gravity and altitude of this reference point are 9.7812198 m s^{-2} and 24.4 m respectively.

Standard corrections were applied to the measured gravity values for drift due to tides and creeping of gravimeter spring, elevation of the measuring point, material between measuring point level and sea level and local relief. A terrain density of 2,500 kg m^{-3} (Kaew-On, 1996; Lohawijarn, 1992 and Phethuayluk, 1996) was used in the Bouguer correction. The corrected data are Bouguer anomalies corrected for material above mean sea level.

The accuracy of gravity reading was ± 0.1 μm s^{-2} and that of the geographic position of measuring points in north-south direction was ± 5 m. The difference of the elevation determined by the altimeter compared with leveling technique was ± 7.7 m. This results in overall error in gravity anomaly of about ± 24 μm s^{-2}.

A contour map of Bouguer anomaly was constructed (Figure 4). Since a delineation of Hat Yai Basin is an object of this paper, the low gravity anomaly caused by Hat Yai Basin will be discussed in detail. The gravity anomalies of deep-source and surrounding geological bodies were then considered as regional field. Gravity values of some selected points on the gravity map around the low anomaly were picked up as representatives of this regional field and fitted to two-dimensional polynomial surfaces of degree 1, degree 2 and degree 3 to find the best regional field (Figure 5).

Residual gravity anomalies along a hydrogeological profile WW′ (UTM 643352E, 768860N and UTM 668833E, 777789N, Figure 6) were derived by subtracting from the Bouguer anomaly the regional field of polynomials of different degrees along that profile. Cross-sections of the sedimentary basin on that profile were then modeled with 2.5 dimensional body, a body of constant density with polygonal cross-section and a limited strike length. The density contrast used in the modeling was -500 kg m^{-3}, based on difference in densities of Quaternary sediment and Carboniferous rocks.

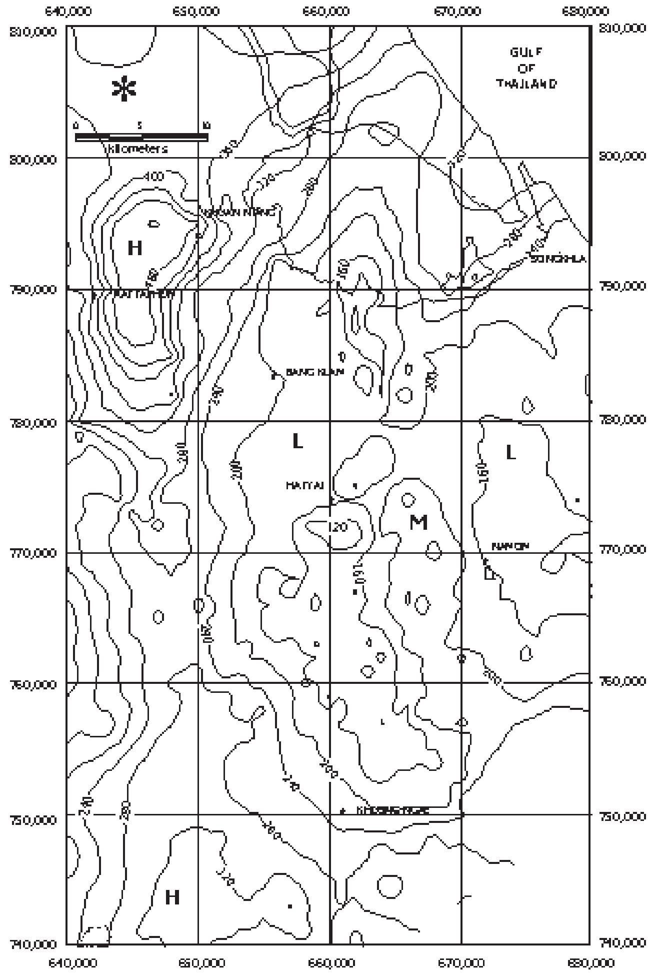


Figure 4. Bouguer anomaly contour in $\mu m\ s^{-2}$ of the study area.

The boundaries of the basin obtained from the modeling were then compared with the hydrogeological cross-section and depths of water wells (DMR, 2001) available along the same profile WW′. The modeled parameters which gave the best agreement for the boundary between the modeled basin and the hydrogeological and water wells information were used in modeling other parts of the basin. The parameters are the correct degree of polynomial function representing regional gravity field across the basin and the most plausible density contrast between basin sediment and basement rock.

Some residual gravity profiles were taken on each residual anomaly map and Hat Yai Basin was modeled from these by making use of density contrast chosen previously. The location of these profiles is already shown in Figure 6. The depths of the modeled basin were contoured to produce a depth-map. Depths of some water wells available in the study area were used in verification of the depth map of Hat Yai Basin in certain locations. It should be noted that the depths of water wells were depths from mean sea level to the maximum depth of screening in water wells.

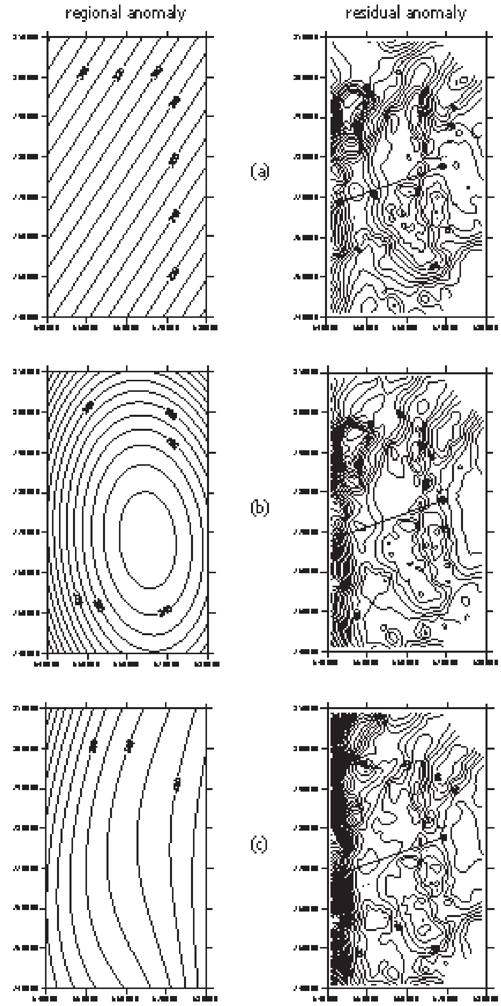


Figure 5. Regional anomalies and the corresponding residual anomalies in the study area. The contours are in $\mu m\ s^{-2}$ (a) regional anomaly estimated with polynomial surface of degree 1 and the corresponding residual anomaly (b) regional anomaly estimated with polynomial surface of degree 2 and the corresponding residual anomaly (c) regional anomaly estimated with polynomial surface of degree 3 and the corresponding residual anomaly.

Results and Discussion

1. Boundaries of Hat Yai Basin

Alternately high and low anomalies with approximately north-south trend are clearly observed in Figure 4 (distinct high anomaly, "H", between UTM 640000E and 650000E and low anomalies, "L", between UTM 650000E to 665000E and UTM 670000E to 680000E). These anomalies correspond to the horst/graben structure (Figure 3), which was proposed by Sawata *et al.* (1983). The low gravity anomaly between UTM 650000E to 665000E corresponds with previously known Hat Yai Graben. However, low gravity anomaly was also observed on the proposed Songkhla Horst, east of Hat Yai Graben, whereas high gravity anomaly was observed on another horst, west of Hat Yai Graben. In addition, it is

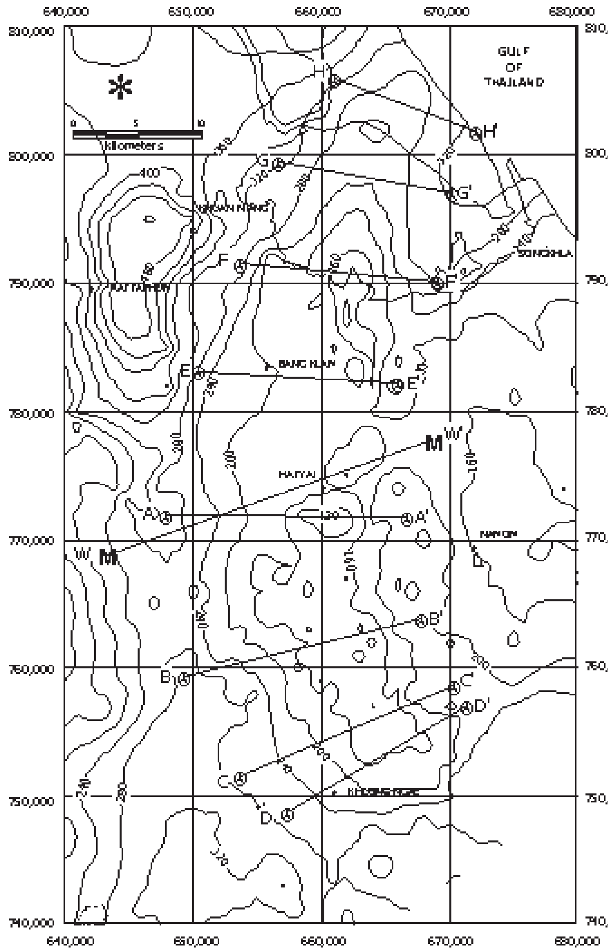


Figure 6. Bouguer anomaly contour in μm s^{-2} and locations of gravity modeling profiles within the study area.

likely that low gravity anomaly between UTM 650000E to 665000E does not continue northward into the Gulf of Thailand or southward to the Thailand - Malaysia border as supposed until now for Hat Yai Basin.

We are presently interested in determining the horizontal boundary and the vertical extension of the Hat Yai sedimentary basin, which causes the low gravity anomaly between UTM 650000E to 665000E. The western, northern and southern boundaries of the basin are clearly observed on the gravity map at about UTM 650000E, 810000N, and 752000N, respectively. The eastern boundary of the basin can be placed at the medium gravity value ridge, along about 665000E, between the low gravity anomaly on the Quaternary sediment and that on the eastern granite pluton.

The regional gravity anomalies and the corresponding residual anomalies are shown in Figure 5. The negative residual anomalies suggest a low-density sedimentary basin bounded in all directions. They also show that the southern boundary of the basin is at UTM 750000N, while the northern boundary is probably at UTM 810000N. Another observation is that the basin does not lie in a straight NS direction as previously supposed but bends eastward at its northern and southern ends. This is probably an effect of a northeastern lineament within the basin reported by Tonnayopas *et al.* (1997).

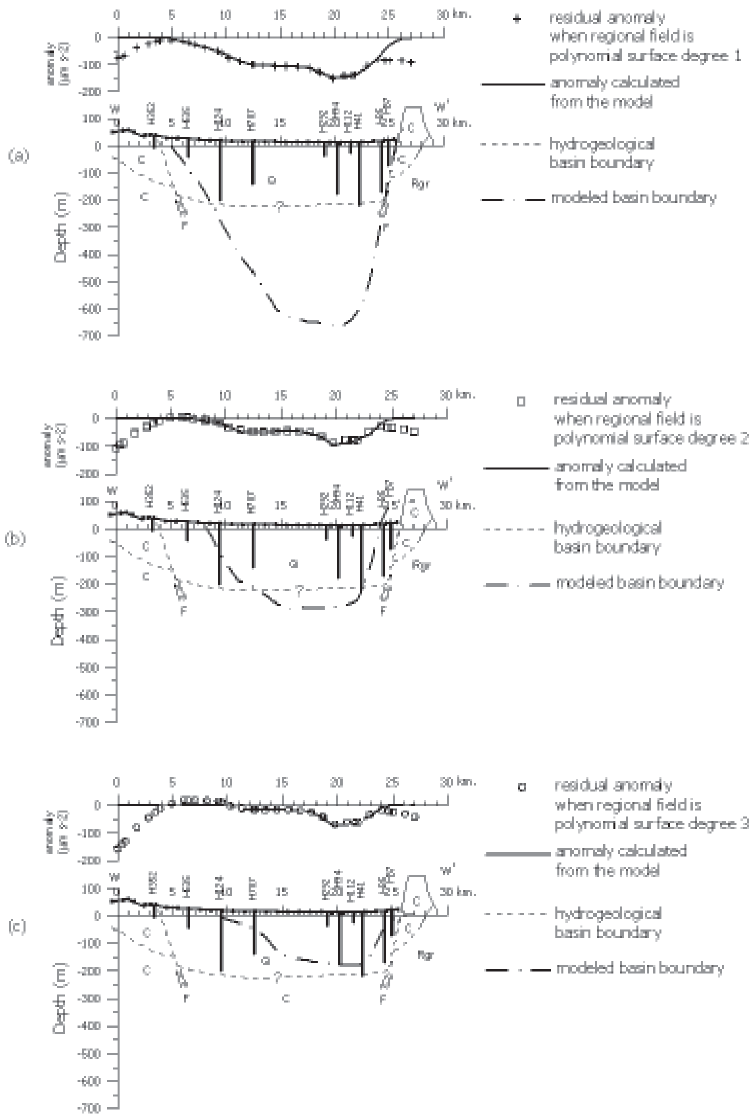


Figure 7. Residual anomalies, their corresponding modeled depth sections in comparison with hydro-geological cross-section along profile WW′. (a) when regional anomaly was estimated with polynomial surface degree 1, (b) when regional anomaly was estimated with polynomial degree 2, (c) when regional anomaly was estimated with polynomial degree 3.

The densities of Quaternary sediment and Carboniferous basement rock are 2000 kg m^{-3} and 2520±40 kg m^{-3} respectively (Kaew-On, 1996; Lohawijarn, 1992 and Phethuayluk, 1996). However, the density contrast should perhaps be rounded off to -500 kg m^{-3} to allow for some increase in density of Quaternary sediment with depth.

The modeled basin along profile WW′ (Figure 6) including the hydrogeological information and depths of water wells are shown in Figure 7.

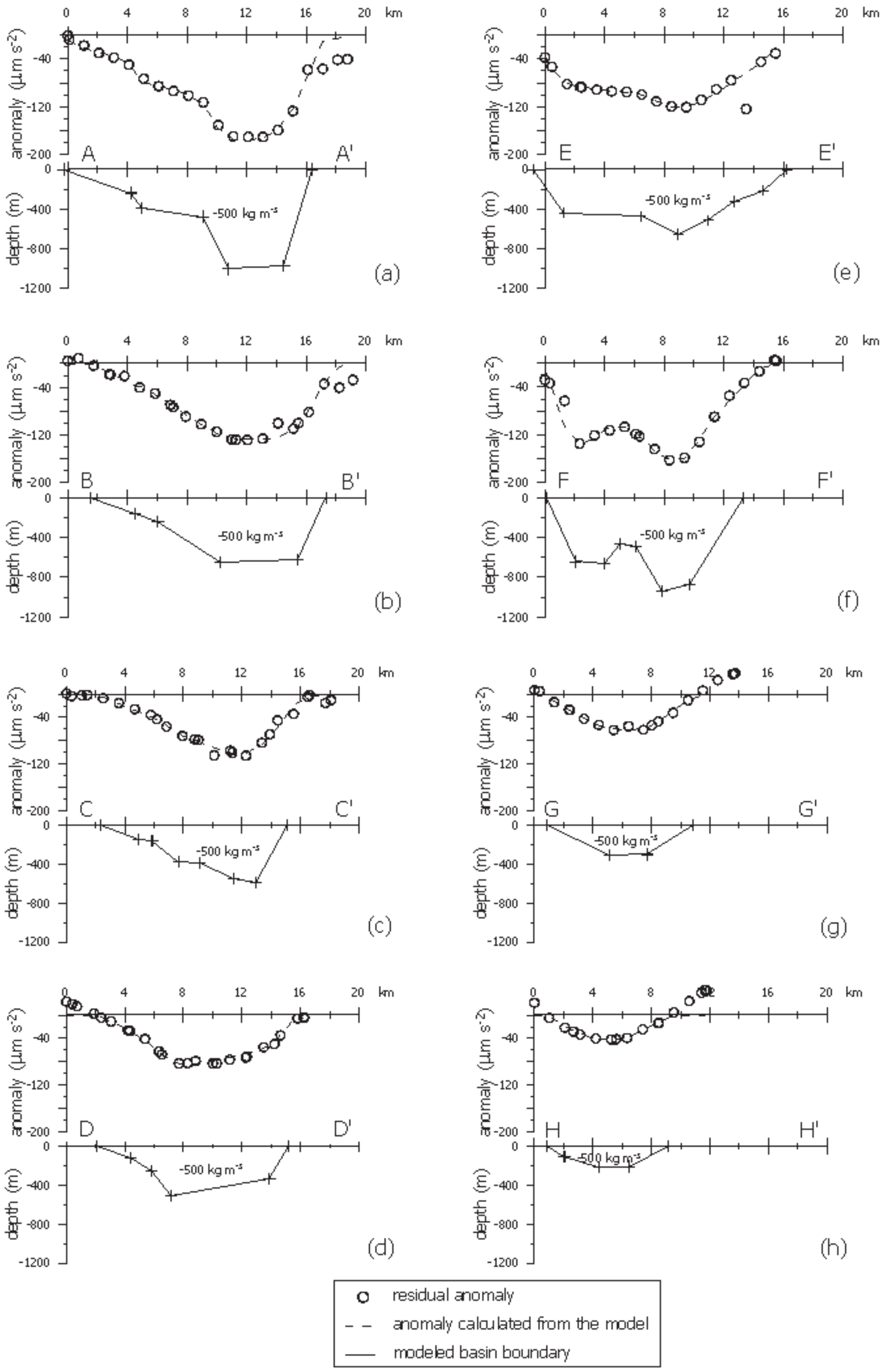


Figure 8. Residual gravity profiles and their corresponding basin model along 8 different profiles which run across the study area.

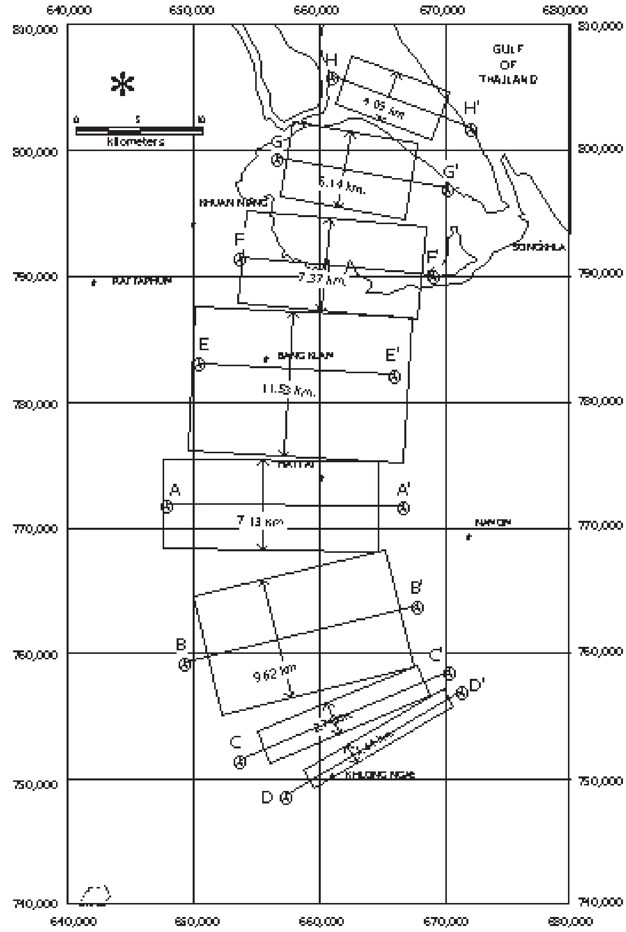


Figure 9. Plan view of model for HatYai Basin.

The horizontal boundary of the basin modeled on residual anomaly derived from regional anomaly of polynomial degree 1 agrees reasonably well with that of the hydrogeological boundary. The eastern boundaries of the modeled basin and the hydrogeological basin are exactly on the same place and with similar slope whereas their western boundaries are about 1 km apart. Disagreement was observed between water wells H41 and H35 where the boundary between the Quaternary sediment and Carboniferous rocks is horizontal whereas a steep slope appears in the modeled basin. Since there was only one deep well, H41, that approach the boundary, it is arguable whether it is really a horizontal boundary or it is just a large boulder of Carboniferous rock in Quaternary sediment. The maximum depth of the modeled basin along profile WW′ is about 650 m below mean sea level.

The boundary of modeled basin based on the regional anomaly of polynomial of degree 2 does not agree with the hydrogeological boundary. The modeled width is about 6 km less than the width of the basin shown on the hydrogeological map, eventhough the west and east slopes of the modeled basin are similar to those of the hydro-geological information. The maximum depth of the modeled basin along profile WW′ in this case is about 300 m below the mean sea level.

Similarly to the above, the boundary of the modeled basin based on the regional anomaly of polynomial of degree 3 does not agree with the

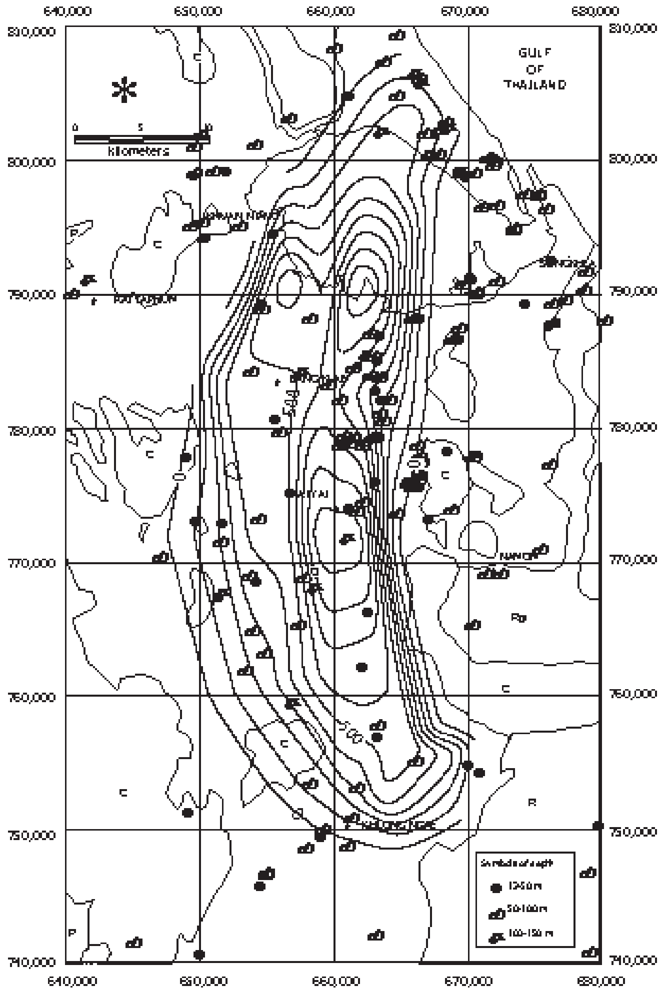


Figure 10. Depth contours in meter of HatYai Basin obtained from present study in comparison with depth of ground water wells.

hydrogeological boundary. The modeled width is about 6 km less than the hydrogeological width. In addition the slope on the eastern boundary of the modeled basin is gentler than the hydrogeological slope. The maximum depth of the basin is about 200 m below mean sea level in this case.

In summary the polynomial surface of degree 1 is considered to best represent the regional gravity anomaly.

A complete structural model of Hat Yai Basin was obtained by modeling the other 8 selected gravity profiles shown in Figure 6 using residual gravity anomalies based on a regional anomaly polynomial surface of degree 1. A density contrast of -500 kg m^{-3} was employed in the modeling. The anomalies and cross-sections of the bodies along these profiles are shown in Figure 8. These were calculated using the GMM program of Geovista AB company, Sweden. The program can handle upto 20 separate bodies of 2.5D geometry. The basin was modeled with 8 different bodies. The plan view of the model is shown in Figure 9 and the cross-section of each body, constant in the north-south direction, can be seen in Figure 8 on the respective profile. All bodies are present in calculating the anomaly on any of the profiles.

We observe that in the central part of the study area, which is covered by profiles AA′, BB′, EE′ and FF′, the depths to the basement of the basin vary from 650 m to 1000 m. The depth decreases to about 500 m in the southern part of the study area, which is covered by profiles CC′ and DD′. The depth to the basement decreases to about 200 m in the northern part of the study area, which is covered by profiles GG′ and HH′. These indicate that the basin has a limited axial length of about 60 km in an approximately north-south direction.

A depth map to Carboniferous basement rock underlying the basin is shown in Figure 10. The positions and depths of water wells are also shown in this map. There is good agreement between the depth in the depth map and the depth of the water wells within the boundary of the basin. However, disagreement was observed outside the boundary of the basin, e.g. at UTM 650000E and 800000 and south of UTM 750000E where, in these areas, the depths of some water wells reach 100 m. Since only depths of water wells and not any geological logs of the water wells were available, it is difficult to say whether the depth of water wells represents the thickness of Quaternary sediment in the basin. Bottom ends of some wells may stay within Quaternary basin while those of others may reach Carboniferous basement rock.

2. Estimates of anomalous mass and ground water potential in Hat Yai Basin

The anomalous mass of sediment in the basin can be estimated from the surface integration of residual anomaly by the following relationship: $\Delta M = 2.39 \times \sum \Delta\bar{g}\Delta s$, where M is the anomalous mass in tons if $\Delta\bar{g}$ is in μm s^{-2} and s in m^{2} (Parasnis, 1997). For this surface integration, the area of negative anomaly bounded by a contour line of 0 μm s^{-2} was divided into a number of squares of 4 sq km, and the average residual anomaly of each square was determined with an accuracy of ± 5 μm s^{-2}. The products of area and average anomaly of every square when summed up yield 6.80±0.03 x10^{10} μm s^{-2} m^{2}. The anomalous mass of Hat Yai basin is then equal to 16.25±0.07 x10^{10} tons or 16.25±0.07 x10^{13} kg. This estimate of anomalous mass is independent of any model or any geological assumption.

With the density of the Carboniferous host rock of 2520 kg m^{-3} and of the sediment of 2000 kg m^{-3}, the actual mass of the sediment will be (2000/520) × (anomalous mass) or 62.5±0.3 x10^{13} kg. The "gravitational" volume of basin sediment will then be 31.2±0.2 x10^{10} m^{3} or 312±2 km^{3}. The volume of the sediment can also be evaluated from the depth map (Figure 10). Similar to the surface integration of residual anomaly mentioned above, the horizontal area bounded by the basin was divided into squares of 4 km^{2} each and an averaged depth of each square was determined with an accuracy of ±50 m. The products of area and average depth of every square were summed up and yielded the "geometrical" volume of the basin sediment of 3.13±0.03 x10^{11} m^{3}, or 313±3 km^{3}. There is thus very good agreement between the "gravitational" and geometrical volumes of the basin.

By assuming the average matrix density of 2650 kg m^{-3} and fully saturated sediment, the porosity of the sediment and the overall ground water reserve in the Hat Yai basin will be approximately 39% and 121.7±0.8 km^{3} respectively. However, the current information of the water wells showed that water is extracted mainly from shallow aquifers of less than 80 m deep and much more from aquifers of less than 45 m deep. This is because deeper aquifers give less yield than the shallow ones (Sakulkeaw, 1996; EMSONG, 1998). The estimated volume of the topmost 80 m ground is 6.4±0.3 x10^{10} m^{3} or 64±3 km^{3}. With the same porosity of 39%, the estimated water reserve will be 25±1 km^{3}. The true ground water reserve could probably be less than half of the above figure, say 12.5±0.5 km^{3}, because impermeable beds of variable thickness are found interbedding with layers of aquifer. On the other hand, major normal faults in Quaternary deposits and older rocks of the basin (Tonnayopas *et al.*, 1997) may increase porosity of formations and aquifer yields. By considering the estimated annual recharge of about 33x10^{6} to 166x10^{6} m^{3} (EMSONG, 1998), the travel time of days to weeks and decades for water from ground surface to aquifers at 5 m and 50 m depth respectively (BGS, 1997), the estimated ground water reserve is sufficient to meet the expected water consumption of the HatYai basin beyond 2015.

Conclusion

With gravity measurement, Hat Yai Basin was found to be about 1 km deep at its deepest, 60 km long and 20 km wide. It does not continue southward to Malaysia or northward to the Gulf of Thailand as previously suggested by Sawata *et al*. (1983). The porosity of basin sediment and the amount of potential groundwater reserves within the basin are estimated to be 39% and 121.7±0.8 km^3 respectively, assuming full saturation.

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