New Regional Boundary of Maha Sarakham Formation in the Northeastern Thailand: Results from 2D Seismic Mapping

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ABSTRACT
Regional subsurface contours of near top Khok Kraut unconformity and Maha Sarakham formation determined by two-way travel time (twt) map with 2D seismic data have shown that the near surface boundary of Maha Sarakham formation is divergent from those shown in the current regional map constructed by Department of Mineral Resources (DMR). Map of the near top Maha Sarakham formation illustrates that the Khorat and Sakon Nakorn basins cover the areas of 45,944 km² or about 28% of the entire Northeastern region. The rock salt underneath the ground surface has an area of ~25,620 km² in the Khorat basin and it has an area of ~20,323 km² in the Sakon Nakorn basin. The basement below the Maha Sarakham formation is about 0.7 sec (~1.2-1.3 km) in the Khorat basin and it is about 0.5 sec (~0.8-0.9 km) in the Sakon Nakorn basin. The Khorat and Sakol Nakorn basin geometries in the Northeastern area indicate asymmetrical fold with NW-SE trending, thereby suggesting that the Northeast has been subjected to compression, with the major compressive stress regime in NE-SW direction. A few minor normal faults and reverse faults cut through the Phu Tok formation have also been identified. These findings argue that the geologic map of the Northeastern Thailand and stratigraphic units need revision to provide a correct and accurate geologic map. In addition, the findings argue that the Huai Hin Lat, Nam Phong, Maha Sarakham and Phu Tok formations need to be obliterated from the Khorat Group. Thus new groups should be named and assigned these formations.

Keywords: seismic interpretation, two-way travel time map, rock salt deposit, geological map of Northeastern Thailand, Maha Sakham formation.

1. INTRODUCTION
A recent regional geologic map of the Department of Mineral Resources (DMR) in a scale of 1:1,000,000 appears to inadequately outline the contact boundaries between Mesozoic and Cenozoic rocks in the Northeastern Thailand. The regional DMR geologic map displays overly simplified geology from Mesozoic Era to Cenozoic Era. Thus, the DMR geologic map has caused the area of the Northeastern Thailand to be out of interest for construction of detailed geologic map. The regional DMR map has been used for urban planning, mineral exploration, groundwater exploration and exploitation, and saline soil management. The map has particularly provided misleading information about the Maha Sarakham and the Phu Tok formations. An angular unconformity between the Khok Kuart and the Maha Sarakham formations has been found and well documented by Satayaruk since 1983 (Satayaruk, 1983). Additionally, contact boundary and age during deposition of Mesozoic sequence reported by several studies showed divergence from the DMR geologic map (e.g., Satayaruk, 1985; Suwanich, 1995; Piyasin, 1995; Racey et al., 1996; Satayaruk et al., 1998). However, these findings were not incorporated in the latest DMR regional geologic map that was constructed in 1999. The latest version in the Northeast therefore remains almost unchanged. This has led to a number of confusions when one tries to read the regional geologic map.

Thus the present paper sought concrete evidence to encourage a revision of a proper area of Maha Sarakham formation exposure in regional geologic map of the Northeastern Thailand. The evidence presented has been based on the interpretation of regional 2D seismic data (Figure 1) conducted as a part of our main research in Maha Sarakham rock salt exploration, exploitation and management in the Northeastern Thailand. In addition, a discussion related to a depositional environment and basin evolution has been included.

2. SEISMIC DATA
The 2D seismic data used for the study consists of 59 lines from 4 surveys including K79A, U81A, K82A, and 82-PTH. The surveys all were conducted as a part of regional study. The first three surveys were acquired for Exxon by Western Geo PTY during 1981-1983. The last survey was acquired for Phillips Petroleum by SSL Party 201 in 1982. Table 1 shows the acquisition parameters and data quality assessment of the surveys.
Figure 1: Location of the study area, Northeastern Thailand, highlighting provincial boundary and seismic line locations.

Table 1: Seismic data used in the present study.

<table>
<thead>
<tr>
<th>Company, Survey</th>
<th>Source</th>
<th>Station interval</th>
<th>Record length</th>
<th># Fold coverage</th>
<th>Data quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exxon, K79A</td>
<td>Dynamite</td>
<td>100 m</td>
<td>6 sec</td>
<td>24 Fold Stack</td>
<td>Good</td>
</tr>
<tr>
<td>Exxon, U81A</td>
<td>Dynamite</td>
<td>100 m</td>
<td>5 sec</td>
<td>24 Fold Stack</td>
<td>Good</td>
</tr>
<tr>
<td>Exxon, K82A</td>
<td>Vibroseis</td>
<td>100 m</td>
<td>5 sec</td>
<td>24 Fold Stack</td>
<td>Good</td>
</tr>
<tr>
<td>Phillips Petroleum, 82-PTH</td>
<td>Vibroseis</td>
<td>150 m</td>
<td>5 sec</td>
<td>24 Fold Stack</td>
<td>Good</td>
</tr>
</tbody>
</table>

The Exxon lines from the three surveys, K79A, U81A and K82A, appeared to have produced good reflection responses from the Basement, Haui Hin Lat, Nam Phong, Khok Kraurt and top of rock salt bodies from Maha Sarakham formation. All surveys appeared to have produced the best and useful reflection responses. Mapping scale for this study was set at 1:1,000,000. With this map scale, the minimum dimension of depicted geologic features is about 1-2 km. The data quantity and quality are considered to be reliable and acceptable for regional mapping (1:1,000,000 map scale).
3. GEOLOGIC FRAMEWORK

Northeastern Thailand is located in a geographical province of Khorat Plateau with the underneath igneous, metamorphic and sedimentary rocks. The sedimentary rocks of the Khorat Plateau were deposited during the Paleozoic, Mesozoic and Cenozoic eras. Sedimentation of the Mesozoic era began in Triassic period at and a series of half-graben rift basins were developed sporadically. The deposition in these rift basins were mainly lacustrine and fluvial clastic sediments. This Triassic sequence of lacustrine and fluvial deposits was mapped as Huai Hin Lat formation. A depositional period of the Huai Hin Lat formation ended around late Triassic due to the first episode of the Indosinian Orogeny (Figure 2). After uplift and erosion events, the region was subsided and consequently superimposed by thick fluvial red beds sequence. This red beds sequence was mapped as Num Phong formation. The deposition of the Num Phong formation was terminated as a result of a second episode of the Indosinian Orogeny. After a termination of uplift and erosion events, subsidence took place and red beds sequence mapped as Phu Kra dung, Pra Wihan, Sao Khua, Phu Phan, and Khok Kraut formations were deposited. The Khok Kraut formation is the top most of the red beds sequence. The termination of red beds sequence was due to Mid-Cretaceous regional folding and uplift. A large scale basin was created as a result of the regional folding.

The basin was later filled with evaporite deposited of Maha Sarakham formation. The latest Mesozoic sequence sitting above Maha Sarakham formation was the Phu Tok formation. No unconformity was found between Maha Sarakham and Phu Tok formations. A contact boundary between Maha Sarakham and Phu Tok formations is depositional contact and is assigned at the top most evaporate sequence (Sattayarak et al., 1998). The Cenozoic sediments in the Khorat Plateau consist of fluvial, alluvial and eolian deposits.

Figure 2 illustrates the simplified Khorat Plateau lithology, rock units, and tectonic events of Mesozoic to Cenozoic eras. Generalized stratigraphy between Huai Hin Lat to Phu Tok formation is shown in Figure 2. The Mesozoic sedimentary rocks between Huai Hin Lat and Khok Kraut formations typically consist of siltstone, sandstone shale and claystone. The Pre-Mesozoic rocks consist of various types of sedimentary, metamorphic and igneous rocks. Figure 2 suggests strong and continuous reflectors from the near top five regional unconformities including Pre-Mesozoic, Huai Hin Lat, Nam Pong, Khok-Kraut and Phu Tok. Furthermore, reflector at the interface between rock salt and claystone displays strong events as a result of high contrast in acoustic impedance between rock salt and claystone. Figures 3-5 are the interpreted regional cross sections representative of the Northeastern region.

<table>
<thead>
<tr>
<th>Description</th>
<th>Lithology</th>
<th>Formation</th>
<th>Tectonic Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-consolidated to unconsolidated sediments of sands, silt, and clay</td>
<td>Phu Tok</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandstone and siltstone</td>
<td>Mahasarakham</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interbedded of claystones, rock salt, and anhydrite/gypsum</td>
<td>Khok Kraut</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interbedded of siltstones, sandstones, and conglomerates</td>
<td>Phu Phan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interbedded of sandstones, siltstones, shales, mudstones, and conglomerates</td>
<td>Sao Khua</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interbedded of sandstones, siltstones, shales, and shales</td>
<td>Phu Wihan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interbedded of sandstones, siltstones, shales, and conglomerates</td>
<td>Phu Kra dung</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interbedded of siltstones, sandstones, and conglomerates (siltstone ~70%)</td>
<td>Nam Phong</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interbedded of shales, siltstones, sandstones, and conglomerates</td>
<td>Huai Hin Lat</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2: Simplified stratigraphic units for the Northern region, highlighting unconformities and tectonic events.
Figure 3: A representative regional cross section, Line 1, across Khorat basin with interpretation and geologic sketch from the above seismic section. Line location is shown in Figure 1.

Figure 4: A representative regional cross section, Line 2, across Khorat basin with interpretation and geologic sketch from the above seismic section. Line location is shown in Figure 1.
Figure 5: A representative regional cross section, Line 3, across Sakon Nakorn basin with interpretation and geologic sketch from the above seismic section. Line location is shown in Figure 1.
4. METHOD OF STUDY

The present subsurface geological study consisted of seismic horizons picking of five unconformities and the near top Maha Sarakham Formation, twt map construction, and interpretation. The five unconformities consisted of the near top Pre-Mesozoic or Basement, Huai Hin Lat, Nam Pong, Khok Kraut and Phu Tok. However, only the near top Khok Kraut unconformity and Maha Sarakham formation were chosen for constructing the 1:1,000,000 twt maps (Figures 6 and 7; see more detail in Youngmee et al, 2004). Irregular bodies of salt domes were not depicted because a coarsely spaced seismic data were used. Contours of the near top Khok Kraut unconformity and Maha Sarakham formation maps were constructed by using Surfer software and contour lines were later edited manually.

The reflector of the near top Khok Kraut unconformity could be easily detected from the surrounding reflectors because the near top Khok Kraut unconformity reflector revealed high continuity throughout the entire section (Figures 3-5). In general, the reflector from the near top Khok Kraut unconformity displayed parallel reflected layers conforming to the near top Nam Phong unconformity (Figures 3-5). The reflector of the near top Maha Sarakham formation displayed strong amplitudes evidenced by high contrast in acoustic impedance between the rock salt and the claystone or the siltstone.

5. RESULT AND INTERPRETATION

Figure 6 is a twt map of the near top Khok Kraut unconformity or near base Maha Sarakham formation. Figure 7 is a twt map of the near top Maha Sarakham formation. Subsurface contours, shown in figure 7, exhibit a regional distribution of the Maha Sarakham formation. A series of salt domes revealed in figures 3-5 was not outlined in figure 7 which was not applicable to salt domes imaging.

Figure 8 illustrates a proponent new boundary of Maha Sarakham formation on the DMR regional geologic map. Figure 8 shows that the area of Khorat basin with the Maha Sarakham formation is ~25,620 km² and Sakon Nakorn basin is ~20,323 km². The basement below the Khorat basin is about 0.7 sec (~1.2-1.3 km), and the basement below the Sakon Nakorn basin is about 0.5 sec (~0.8-0.9 km) (Figure 6). The basin geometry in the Northeastern area indicates asymmetrical fold with NW trending. The folding suggests the Northeastern area to be subjected to compressive environment, with a major compressive stress regime in NE-SW direction after the Phu Tok had been deposited. A few minor normal faults and reverse faults cut through the Phu Tok Formation could be identified (e.g., Figure 5). The results of twt structure maps of the near top Khok Kraut unconformity and the near top Maha Sarakham formation indicate that the thickness of the Maha Sarakham formation is 0.7-0.8 kilometers and are located in the Khorat basin (Figures 6 and 7).

The subsurface geology with rock salt in Maha Sarakham formation found in 16 provinces is evidenced from combination of the results in the Figure 1 with Figures 6-8. The percent proportions of the area with rock salt in individual provinces vary considerably. It is 86% in Nongkai, 85% in Maha Sarakham, 79% Nakorn Phanom, 66 in Roi Ed, 58% in Sakon Nakorn, 53% in Yasothorn, 38% in Udon Thani, 28% in Sakon Rachasima, 27% in Khon Kaen, 19% in Amnat Charoen, 9% in Chatuyaphum and Kalasin, 7% in Buriram, 6% in Surin and Ubon Ratchathani, and 4% in Srirakat. A subsurface rock salt deposit was not found in the following provinces; Nong Bua Lumpoo, Mukdaharn, and Loei.

The results from Figures 3-7 together with a reviewed literature suggests that the evolution of the Maha Sarakham formation is as follows. During Cretaceous period, the Northeast area was subjected to compressive stress regime created by a collision of Western Burma and Shan Thai plates. An inland lake (basin) was created. Subsequently, there was seawater invasion into the lake. Sedimentation in the lake was comprised of claystone and evaporite minerals (rock salt and potash). There were at least three cycles of invasion and storage of seawater in the lake. The evaporite deposits were ended because the lake had been filled with wind blown silt and sand particles. At the beginning of Paleocene to early Eocene (60-65 million years), the Khorat and Sakon Nakorn basins and Phu Phan fold belt were created by folding mechanism in consequence of the collision of the Indian and Eurasian plates. The rock salt in the Phu Phan areas were transported into the Khorat and Sakon Nakorn basins, because of plasticity properties of the rock salt.

Mesozoic to Cenozoic structural evolution and deposition of the Khorat Plateau can be subdivided into 10 main stages including (1) folding, uplift and erosion of the Pre-Mesozoic rocks, (2) rifting and creation of localized half-graben basins, lacustrine and fluvial sediments filled in rift basins, (3) structural inversion, uplift and erosion, (4) gravity collapse and regional subsidence, fluvial sediments filled in subsidence area, (5) uplift and erosion, (6) regional subsidence, fluvial sediments filled in subsidence area, (7) folding, uplifting and erosion, (8) basin subsidence, evaporate and later alluvial and aeolian filled in basin, (9) folding, uplifting and erosion, (10) localized alluvial, fluvial, and/or aeolian deposits.

6. CONCLUSION

New evidence of subsurface geology and the evolution of the Maha Sarakham formation have emerged from analyses of geological and geophysical data in the areas of Khorat and Sakon Nakorn basins, Northeastern Thailand. The twt subsurface contours map of the Khok Kraut unconformity, the Maha Sarakham formation and the current regional DMR geologic map reveal a divergent boundary of the near surface Maha Sarakham formation. The twt map of the near top Khok Kraut unconformity displays that the Maha Sarakham formation covers an area of 45,944 km² (about 28% of the entire Northeast region). In contrast with the twt map, the DMR map shows that the Maha Sarakham formation covers an area of 50,000 km² (about 30% of the entire northeast region). The maximum area of the rock salt underneath the ground surface exhibited by the twt map is ~25,620 km² in the Khorat basin and it is ~20,323 km² in the Sakon Nakorn basin. However, the DMR geologic map exhibits the maximum rock-salt area of 33,000 km² in the Khorat basin and of ~17,000 km² in the Sakon Nakorn basin. The major divergent boundary appears at the southern Khorat basin.
Figure 6: (Top) The DMR regional geologic map and twt contours of the near top Khok Kraut unconformity. Zero time twt contour meant the near surface exposure of the Khok Kraut unconformity. (Bottom) Three-dimensional subsurface image of the Khok Kraut unconformity.
Figure 7: (Top) DMR regional geologic map and twt contours of near top Maha Sarakham formation. Zero time twt contour meant the near surface exposure of the Maha Sarakham formation. (Bottom) Three-dimensional subsurface image of the near top Maha Sarakham formation.
Figure 8: The new boundary of Maha Sarakham formation evident from the results of 2D seismic interpretation.

7. ACKNOWLEDGEMENTS
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8. REFERENCES


