# 6. Results of the Study and Recommendations

## 6.1 Distribution of Rock Salt and Soil Salinity in the Study Area

### 6.1.1 Overview

The surface geology of the study area is mostly characterized by Quaternary sediments. These Quaternary sediments overly locally the Tertiary Phu Tok Formation, composed of fine- to medium-grained sandstone and siltstone. Underlying the Phu Tok Formation is the Cretaceous Maha Sarakham Formation composed of claystone, siltstone, and three rock salt beds: the Lower, the Middle and the Upper Salt Member. Most of the current margins of the basin are formed by dissolution, as are the upper and lower contacts of the salt units (Warren, 1999). This formation overlies the Khok Kruat Formation which is composed of sandstone and siltstone.

The Middle and the Upper Salt Members are generally flat lying and correlatable from well to well. In contrast, seismic, geomorphologic analysis, and borehole logs data show that the Lower Salt of the Maha Sarakham has flown so that the thickness is much more variable from well to well. The study of Warren (1999) suggested that the texture in the Lower Salt member ranges from well preserved depositional textures in the upper part immediately below the potash entraining intervals to flowage features lower in the section. Petrographic evidence for salt flowage includes overburden-controlled elongate flattening of crystals and pervasive recrystallisation that has destroyed original bedding features. In wells that reach deeper into the Lower Salt Member there is often a transition down core from pristine depositional textures into flowage textures, implying that flow into the pillow was fed mostly from the deeper parts of the Lower Salt Member. That is also consistent with the motion of the upper portions of the salt unit still being deposited while the lower parts of the same unit were flowing into pillows.

### 6.1.2 Results from Present Work

#### 6.1.2.1 Results from Borehole Logs Study

Borehole log data and subsurface topographic maps of the study area indicate that the thickness and the depth to the uppermost rock salt layer, which plays an important role for the salinity in the Khorat Plateau, vary from place to place. The geologic cross-section in northwest-southeast and southwest-northeast direction shown in Figure 6.1 and Figure 6.2 support this statement.

A simplified block diagram showing the general subsurface condition of the study area from borehole data covered with a three dimensional surface image is shown in Figure 6.3. Figure 6.4 shows a block diagram, look direction northeast, with the three rock salt members of the Maha Sarakham Formation in the vicinity of study area. Figure 6.5 shows the three dimensional surface of the study area derived from the False Color Composite of Landsat 7 acquired on December 7, 1999, bands 4, 3, 2 as red, green, blue showing locations of boreholes (green dots) used in this study (above). Figure 6.5 also shows the digital elevation model of the surface of the study area (middle), and it also shows the topographic elevation model of the surface of the

uppermost rock salt in the study area (below). According to the subsurface conditions as shown in Figure 6.3 to Figure 6.5, the depth to the surface of the uppermost rock salt layer increases eastward to the depocenter of the Khorat Plateau. Layers of rock salt undergo ductile deformation more readily than do the more common sedimentary rock types such as sandstone and limestone. Salt flows at subsurface conditions under the force of gravity and some tectonic environment. The density of salt contrasts with the greater density and strength of the enclosing sediments. A great variety of subsurface structures can be ranging from shallow to deep. The internal structure of these salt features provides abundant evidence of plastic flow with folds, foliation and other structures.

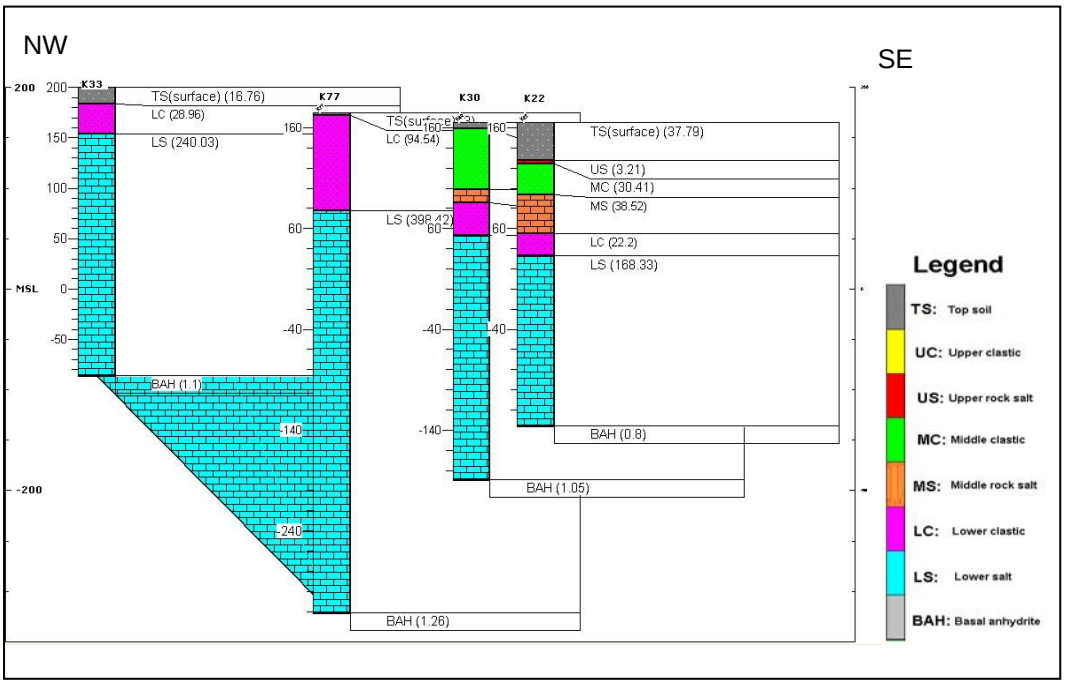


Figure 6.1 Geologic cross-section in northwest – southeast direction of the study area indicates that thickness and depth to the rock salt increase toward the depocenter of the Basin.

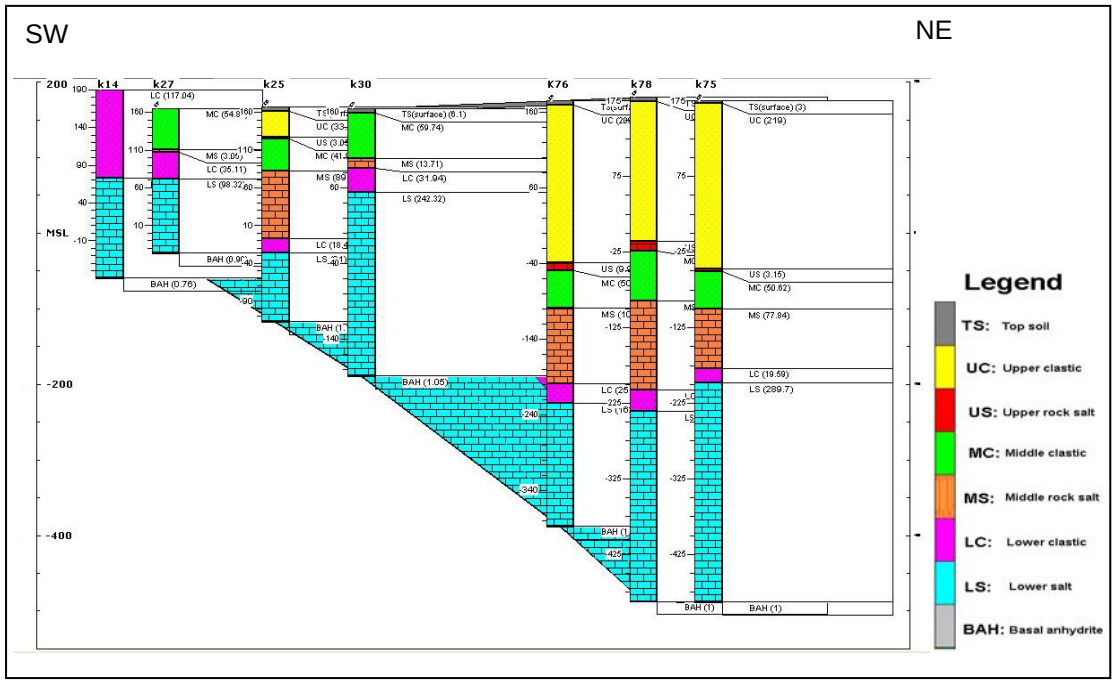


Figure 6.2 Geologic cross-section in southwest – northeast direction of the study area indicates that thickness and depth to the rock salt increase toward the depocenter of the Basin.

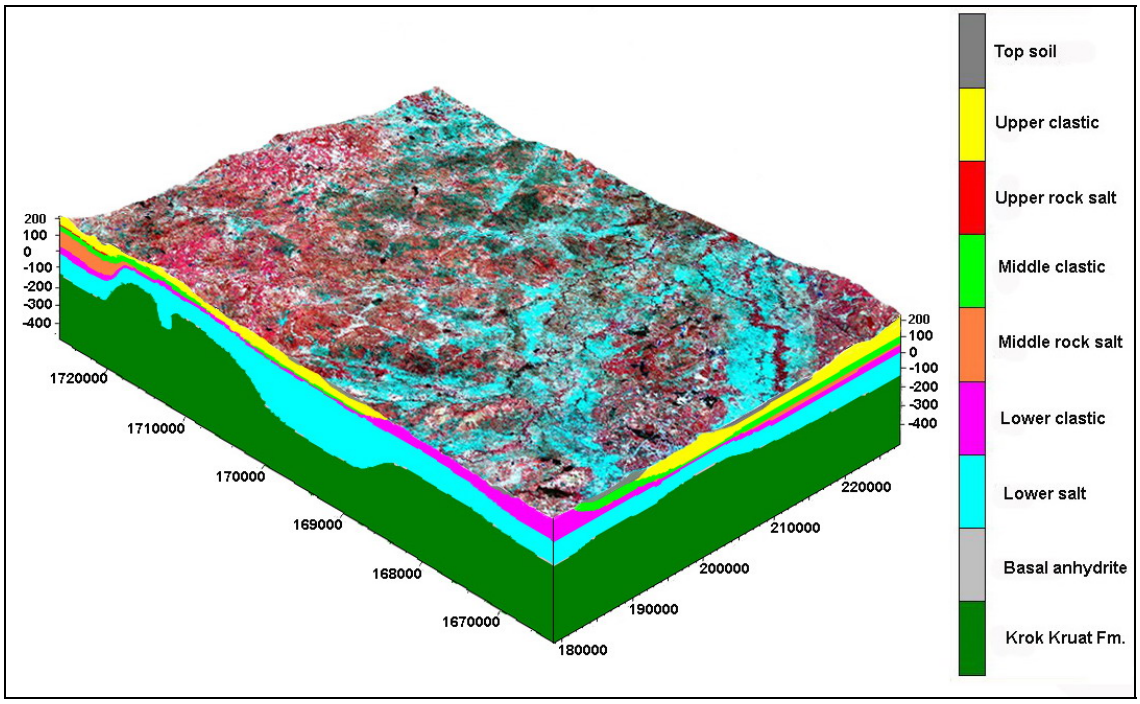


Figure 6.3 Simplified block diagram showing the general subsurface conditions of the study area according to borehole data, covered with a three-dimensional surface image.

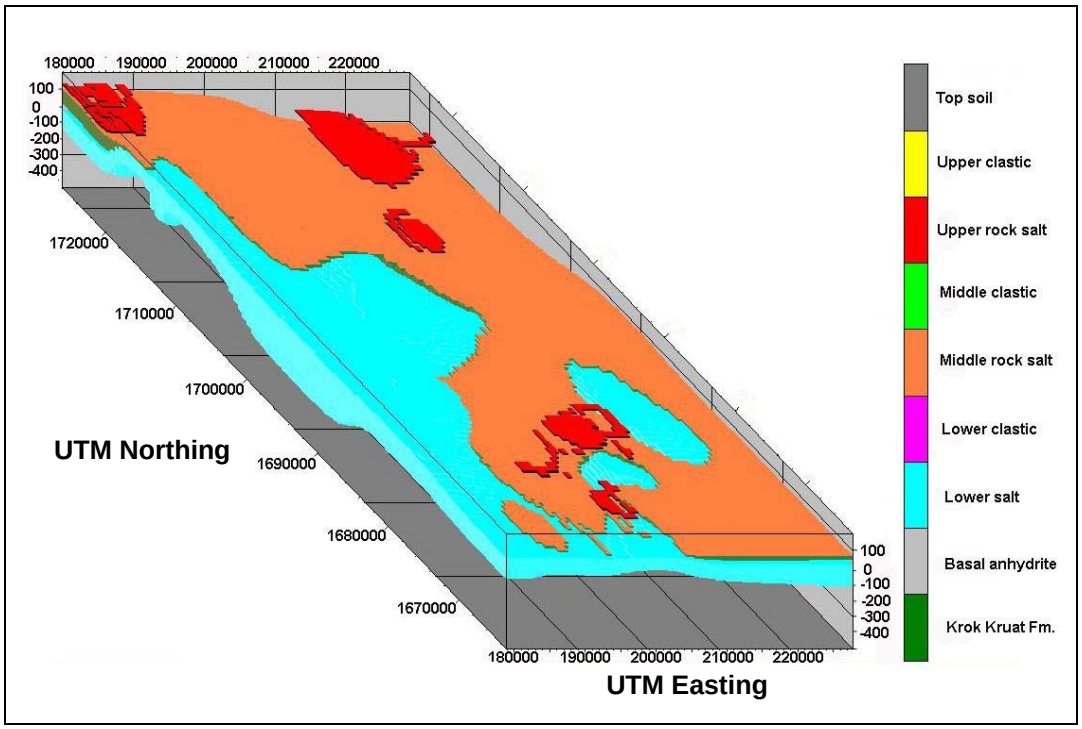


Figure 6.4 Block diagram, look direction northeast, showing the three rock salt members of the Maha Sarakham Formation in the vicinity of study area.

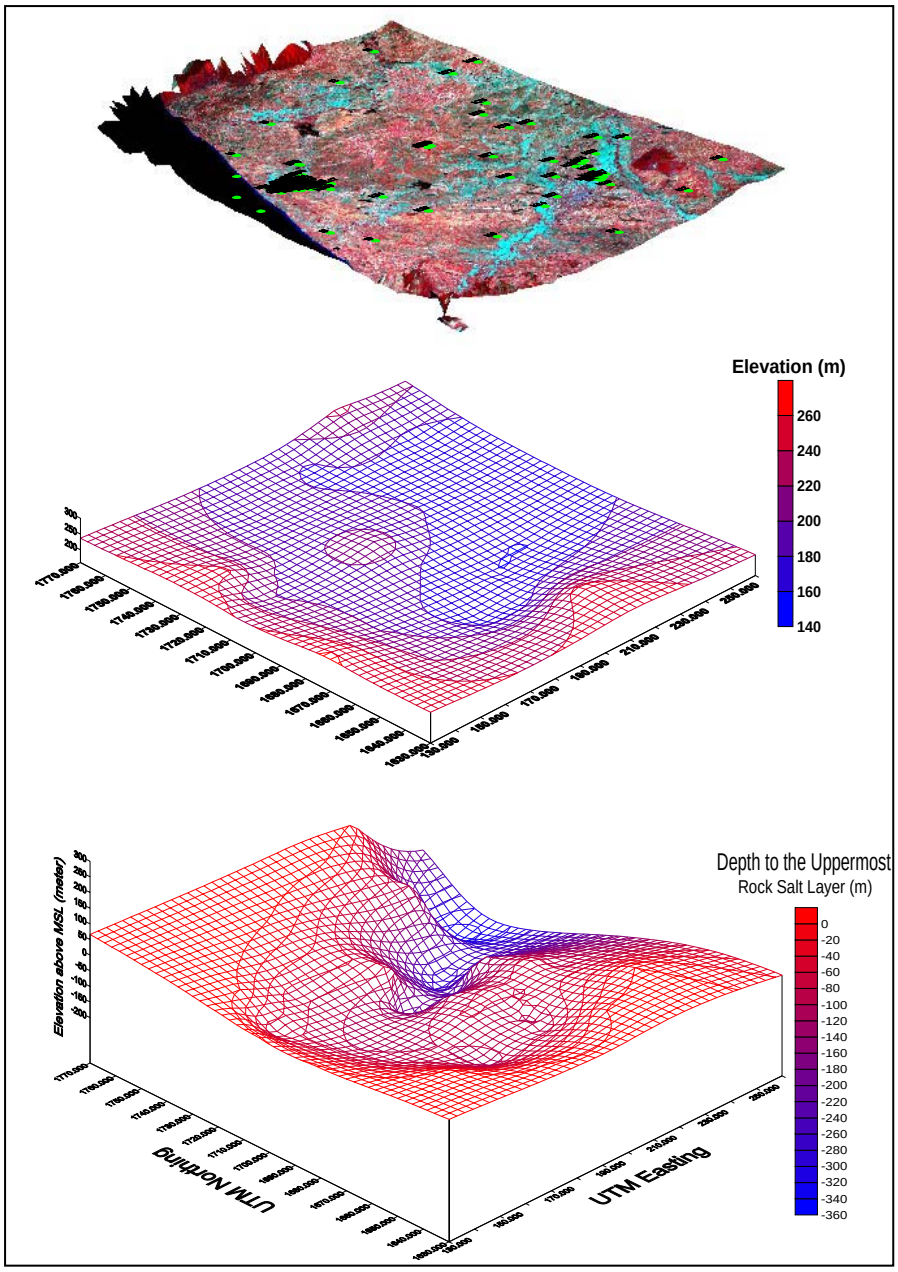


Figure 6.5 Three-dimensional surface of the study area derived from the False Color Composite of Landsat 7 acquired on December 27, 1999, bands 4, 3, 2 as red, green, blue showing location of borehole (green dots) used in this study (above). The digital model elevation of the study area (middle) shows high elevation at the southern, western and northern rim of the study area and slopes eastward. The topographic elevation model of the surface of the uppermost rock salt in the study area (below) indicates that the surface of the uppermost rock salt layer decreases eastward to the depocenter of the Khorat Plateau.

### 6.1.2.2 Results from Geophysical Investigations

To explain the underground conditions and to locate the depth to rock salt in the Maha Sarakham Formation, which occurs throughout the Khorat Plateau, apart from the drilling of boreholes, it can be detected in the underground by geophysical methods.

The fairly thin sedimentary cover, 50 to 300 m, of the rock salt formation, encourages the use of geophysical investigation methods. Three different geophysical methods were employed in this study, electric resistivity, seismic and microgravity, to determine the thickness and the top of the rock salt. Three areas located in study area were selected as training and test sites:

1) Site 1: Ban Sida Village, Khong District, Nakhon Ratchasima Province,
2) Site 2: Dan Khun Thot District, Nakhon Ratchasima Province and
3) Site 3: Ban Basiew Village, Jaturat District, Chaiyaphum Province, respectively.

The locations of the three geophysics investigation sites are shown on the False Color Composite image of Landsat 7 data acquired on December 27, 1999, bands 4, 3, 2 as red, green, blue in Figure 6.6. The results of these geophysical investigations in this study can be summarized as follows:

**Site 1: Khong District, Nakhon Ratchasima Province.**

**- Results from Seismic Reflection Investigations**

- As the result of seismic data processing, depth conversion and velocity analysis, the velocity within rock salt unit is 4 000 - 4 500 m/s, and depth to the top of rock salt approximates 180-300 m. The shape of the rock salt unit is both flat and folded. The seismic reflection two-way time profile of the Site 1 along a SSE-NNW line approximately 700 m long is shown in Figure 6.7. The top of the uppermost rock salt layer is marked in red. The areas of shallow salt structures are also located in the anticlinal folding structure at Ban Nong Pharn Pran, which coincides with the results of resistivity measurements. The axes of the salt anticline are NE-SW, parallel to the prominent lineament direction. The relationship of the interpreted seismic section along the survey line to the result from resistivity and microgravity is shown in Figure 6.8(a).

**- Results from Resistivity Investigations**

- At depths between 1.5 – 30 m, the apparent resistivity values represent a low to high resistivity zone, ranging between 1.5 – 170 Ωm. Therefore, according to Shaman (1986) and Milsom (1998), the apparent resistivity values in this range can be interpreted as saline soil, clay, silt, sand and sandstone, respectively, in the increasing value order. From 30 - 120 m, the apparent resistivity values vary from 0.6 to 15 Ωm (low - medium resistivity zone). This zone is interpreted as mud, clay and claystone or brine-saturated.

- According to potash exploration boreholes logs, the rock salt units are found below a clay layer. The apparent resistivity values below this clay/claystone layer are ranging between 5.3 - 25.3 Ωm. Solgosoom (1999) wrote that the

low resistivity zone (clay layer) is considered to be a low conductor as compared to salt (high conductor). He concluded that the layer below the clay/claystone is rock salt (high resistivity). The salt layer and overburden sediments along the survey line are shown in Figure 6.8(b).

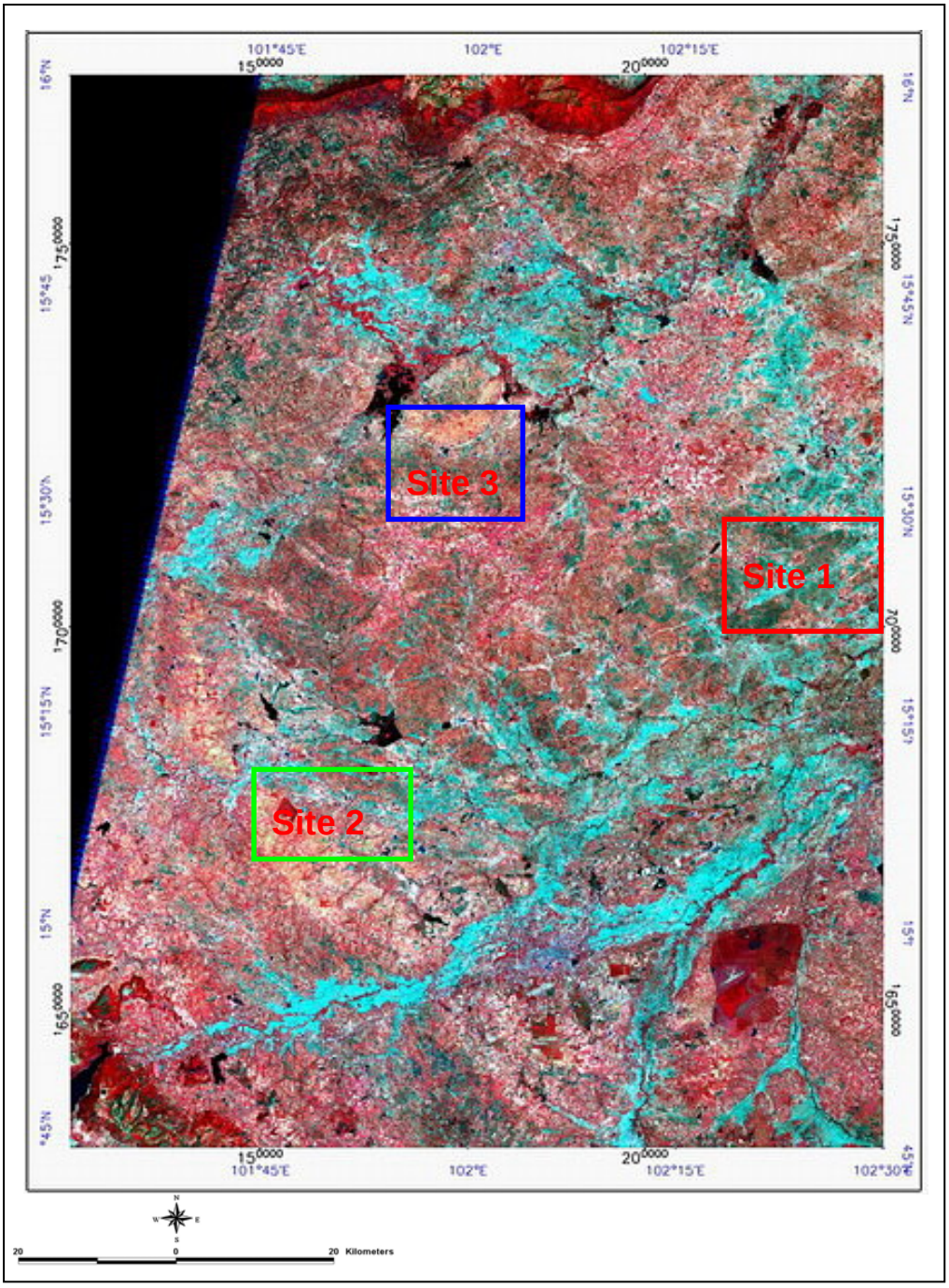


Figure 6.6 False Color Composite image of Landsat 7 data acquired on December 27, 1999, bands 4, 3, 2 as red, green, blue showing the location of the three geophysics investigation sites: Site 1 (Khong District, within red rectangular), Site 2 (Dan Khun Thot District, within green rectangular) and Site 3 (Jaturat District, within blue rectangular).

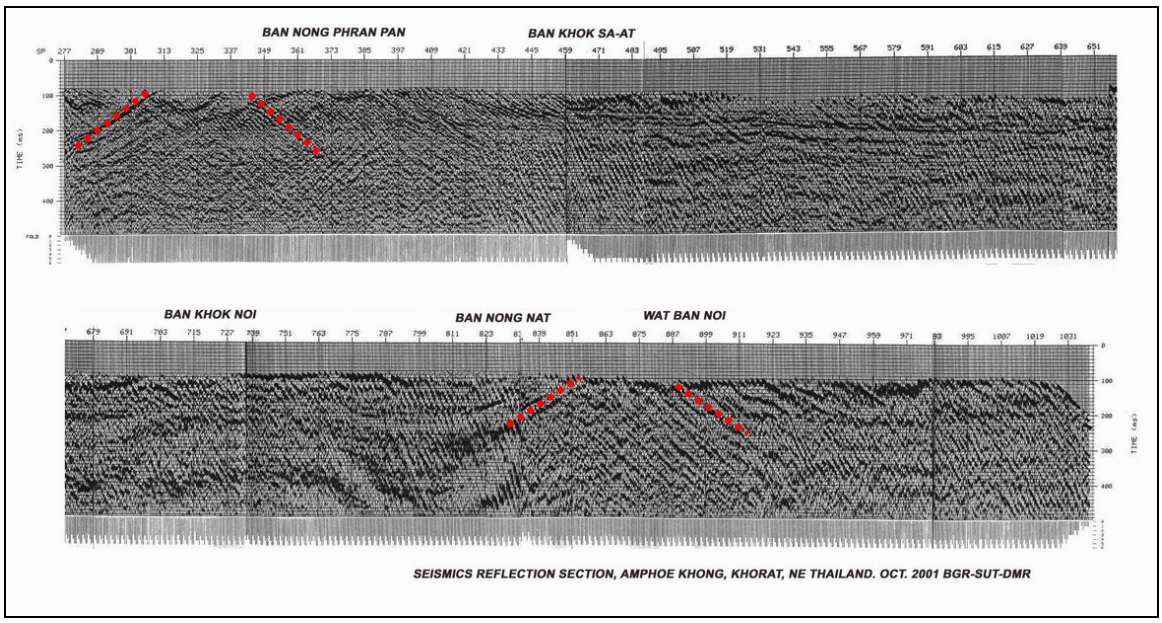


Figure 6.7 Seismic reflection two-way-time profile at Khong District site along SSE – NNW approximately 700 m long. The red dot-line represents the top of the uppermost rock salt layer.

- According to the results of the Vertical Electrical Sounding (VES) investigation and their locations, the rock salt can be found at shallow depths in the low-lying areas. Fresh water with an apparent resistivity above 30 Ωm appears at shallow depths (0-30 m), particularly on higher elevated terrain. Therefore, the results and their interpretation indicate that the top of salt is not an even but an undulating surface and can be found between 200 – 400 m depth. The elevation of the top of salt is higher underneath lineaments observed on satellite images. At the surface, the areas having salt at shallow depth show swamps, depressions and high soil salinity.

**- Results from Microgravity**

- The two-dimensional gravity anomaly distribution corresponding to the underground structures along the survey lines is shown in Figure 6.8(c). There are considerably low gravity anomalies (over -360 mGal) in two areas. These low gravity anomalies could be regarded as low density anomalies. Ban Nong Phran Pan and Ban Nong Nat can be interpreted as shallow depth salt unit when correlated with regional stratigraphy.

- The result of this study indicates that the Bouguer anomalies suddenly change at Ban Nong Pharn Pan (-365 mGal) and Ban Nong Nat (-363 mGal) and these locations are where low elevation and natural reservoirs are present. Thus, the salt structure underneath Ban Nong Pharn Pan and Ban Nong Nat should be shallower than in the other areas. Therefore, the narrow long low lands between high-elevated lands are corresponding with negative Bouguer gravity

anomaly. On interpreting gravity data, the shallow salt dome concept of Seni & Jackson (1983) is employed as a working hypothesis. The negative Bouguer gravity anomaly indicates a diapiric salt structure underneath the surface according to an initial model by Warren (1989).

The results from resistivity, seismic reflection and microgravity surveys indicate that the surface of the rock salt is higher wherever major lineaments are visible in the satellite image. These areas are characterized on the surface by saline soil, swamps and ponds, e.g. Ban Nong Phran Pan and Ban Nong Nat Villages.

In contrast, elevated areas appear to have thicker sediment cover and the rock salt lies deeper than in low-lying areas, e.g. Ban Nong Bua Village. The relationship between lineament features seen on satellite image and results from three different geophysical investigations are shown in Figure 6.8. This site is a good example of surface features corresponding to the rock salt structures beneath.

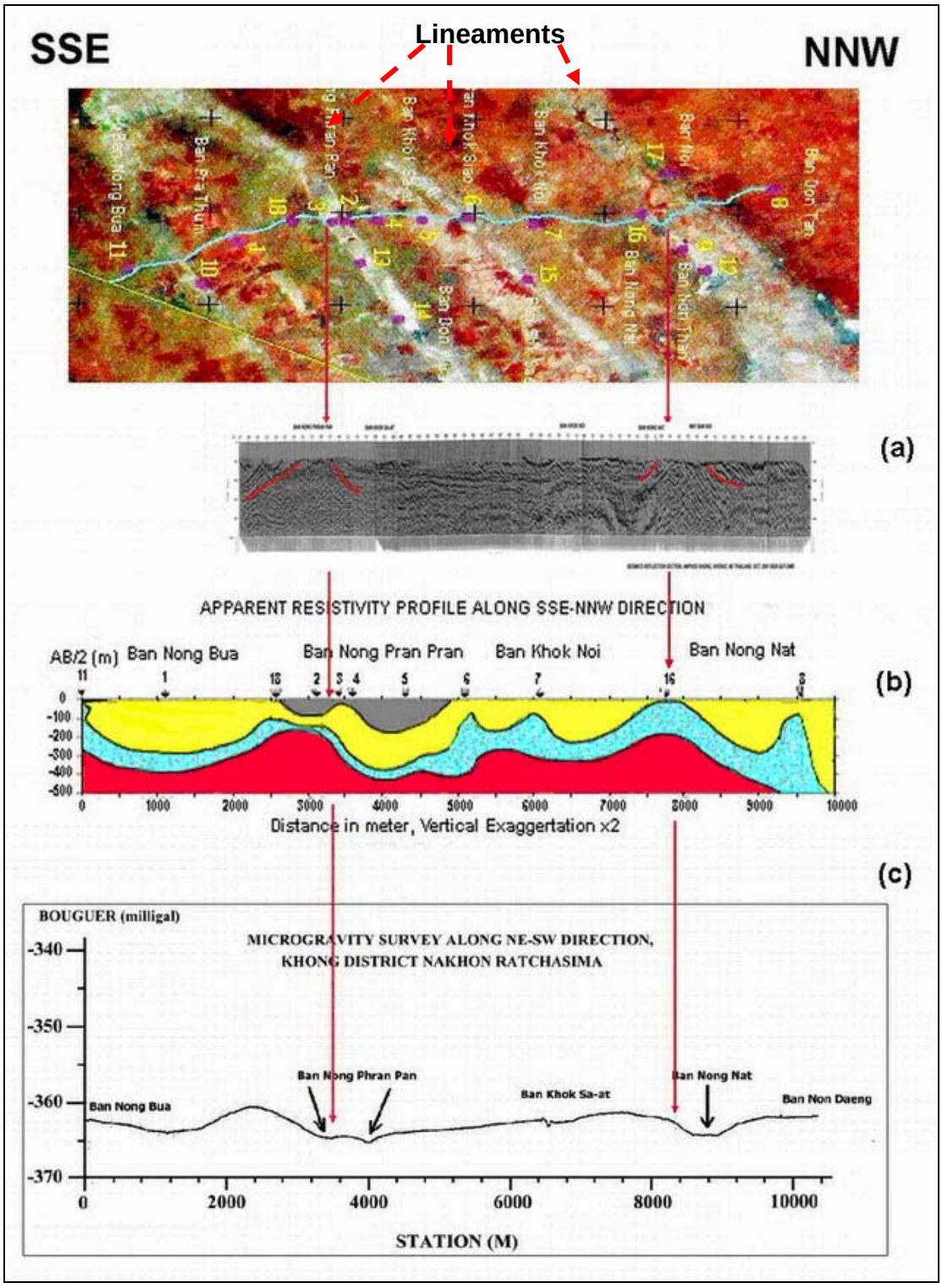


Figure 6.8 Relationship between lineament features seen on satellite image and results from seismic survey, resistivity survey and gravity survey at Site 1, Khong District site, Nakhon Ratchasima Province, showing the results from seismic reflection (a), showing the top of the rock salt in red line, and resistivity investigation (b) and microgravity (c).

**Site 2: Dan Khun Thot District, Nakhon Ratchasima Province**

**- Results from Seismic Reflection Investigations**

- Along the profile Ban Bu the rock salt is located at 80 – 100 milliseconds (two way time, twt) or at a depth between 60 – 100 m after conversion to depth (Franke *et al*., 2002) (Figure 6.9(a)). The rock salt shows a relatively smooth surface and there are some indications for the formation of sinkholes along the line.
- On Line 4, the top of rock salt seems to vary in depth as the northern part of the line shows the top of rock salt at the depth of 200 millisecond (two way time) and slightly dipping toward the south and the top of rock salt present at the depth around 100 – 130 millisecond (twt). This might be due to the formation of a salt dome caused by the thick sedimentary overburden, recent tectonic movement or the generation of faults.

**- Results from Resistivity Investigations**

- Most of the VES points indicate the top of the rock salt present at an average depth of 130 m below surface. Resistivity values of the cover sediments are generally very low (<10 Ωm) with the exception of thin, nearest to surface layers. Layers with values of less than 1 Ωm are frequent immediately above the dry salt. The brackish groundwater contained by an up to 100 m thick layer was recognized in sounding 6 and 10 with resistivity values of 7.6 and 6.1 Ωm respectively (Eberle, 2002). The clear relationship between the results from seismic reflection profile and resistivity investigations is show in Figure 6.9(b).

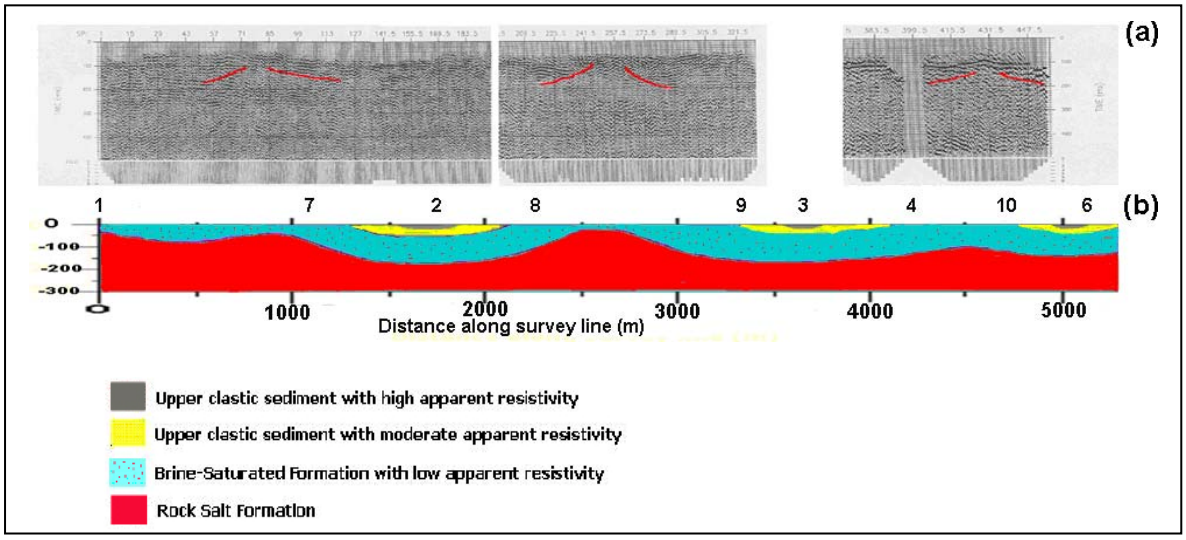


Figure 6.9 Relationship between the results from seismic reflection of Line 4 on two-way-time (millisecond) profile and resistivity investigations (Vertical Electrical Sounding, VES) of Site 2 (Dan Khun Thot District). Results from seismic reflection investigation (a) show dome-like features of rock salt e.g. at VES point 7, 8 and 10 which correspond to the results from resistivity investigation (b) that show the dome-like features at the same positions.

**Site 3: Jaturat District, Chaiyaphum Province.**

**- Results from Seismic Reflection Investigations**

- According to this study, along the profile BS50 the rock salt is located at 220 – 250 millisecond (two way time, twt) or at depth range between 120 – 140 m from surface, after being converted to depth section. The time and depth profile of this line is shown in Figure 6.10 and Figure 6.11.

- On profile BS501 rock salt is located at 300 – 320 milliseconds or at about 100 – 120 m deep from the surface, and disappears when the line crosses the salt-trace lineament up to the elevated area of the circular feature. It is believed that the rock salt is thinning and ending at this salt-trace lineament, which is believed to be the boundary between the Maha Sarakham Formation and the older and more competent Khok Kruat Formation. This result is supported by the uppermost rock salt layer map, synthesized from borehole data in this region (the details are discussed and shown later), and the time and depth profiles of this line are shown in Figure 6.12 and Figure 6.13.

- The Line BS502, together with Line BS503 show that salt may be located at 220 – 240 milliseconds or about 100 - 120 m deep from the surface. The time and depth profile of this combined line is shown in Figure 6.14 and Figure 6.15.

- The shortest line, BS25, was designed after getting some interpretation results from previous lines. It was designed to detect the shallow rock salt layer located beneath the salt-trace of the curvilinear feature at Ban Basiew Village. A very short (2.5 m) shot interval was employed for detecting the very shallow and thin rock salt layer. This thin and very shallow rock salt is believed to be the main source of salinity both of soil and groundwater in this area and also other areas having the same conditions, such as the area located nearby the boundary between Maha Sarakham and its elder Formations at the rim of the Khorat Basin. The result showed that the top of this thin rock salt located at 160 – 180 milliseconds or only about 60 m deep from the surface and its bottom was detected at 200 – 220 milliseconds or about 70 m deep from the surface. Therefore, this rock salt layer is approximately 10 m thick.

- The presence of this shallow and thin rock salt layer is evidenced and supported by the borehole data of well K-56 and K-79 located behind the Jaturat District town hall about 15 km west of this line, which indicates that there is a thin rock salt layer, 4.57 and 3.97 m thick, respectively, and located at very shallow depth of 71.63 and 37.18 m, respectively. The time and depth profile of this line is shown in Figure 6.16 and Figure 6.17.

- According to the shallower rock salt at 60 to 70 m of the Line BS25 compared to the depth to rock salt of other lines, which are present at range between 100 – 140 m depth, this rock salt is interpreted as a different rock salt layer apart from those of other lines. It is believed to be the Upper Rock Salt Member of

the Maha Sarakham Formation, while the rock salt layer that had been detected by other lines is believed to be the Middle Rock Salt Member according to the study of Suwanich (1986) and after correlating to the log description of the borehole data well K-56 and K-79 where the Middle Rock Salt Member is detected at about 70 – 100 m deep. Moreover, the rock salt layer interpreted from time and depth profiles from this investigation shows a relatively smooth surface and some small broad anticlines, e.g. on the time and depth profile of Line BS50.

Consequently, the results from resistivity, seismic reflection and microgravity investigation indicate that the surface of the rock salt is higher wherever major lineaments are visible in the satellite image. These areas are characterized on the surface by saline soil, swamps and ponds, e.g. Ban Nong Phran Pan and Ban Nong Nat Villages, Khong District, Nakhon Ratchasima Province. In contrast, elevated areas appear to have thicker sediment cover and the rock salt lies deeper than in low-lying areas, e.g. Ban Nong Bua Village, Khong District, Nakhon Ratchasima Province.

Rock salt, which lies under rock boundaries, is located at a shallow depth ranging between 80 – 100 m. Surface topography of this area is normally low-lying covered with salt crust in dry season, turning into swamps or marshy areas in rainy season e.g. in the vicinity of Site 2, Dan Khun Thot District.

However, depth to the uppermost rock salt layer is mostly ranging from the shallowest, 60 – 70 m at Site 3, Jaturat District, up to 400 m at Site 1, Khong District. The subsurface topography of the uppermost rock salt layer is varying from slightly smooth as shown in seismic survey line Ban Bu at Site 2, Dan Khun Thot District, to dome-like structure as shown in seismic survey line at Site 1, Khong District.

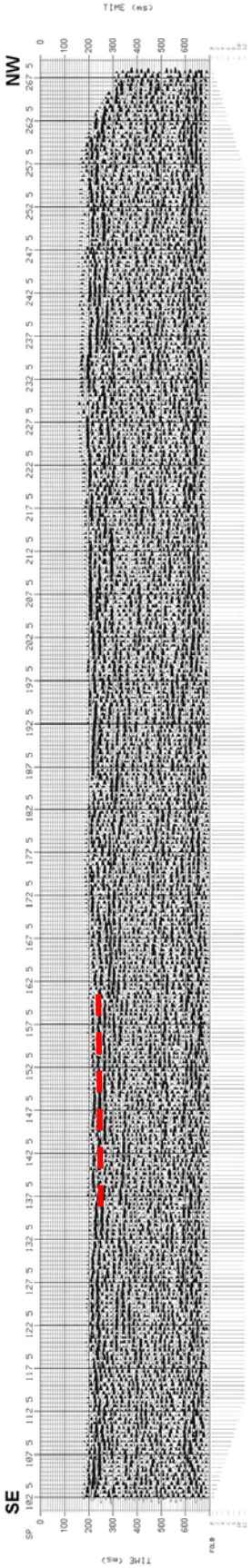


Figure 6.10 Time profile of the seismic survey Line BS50. The uppermost rock salt layer is indicated by red dash line.

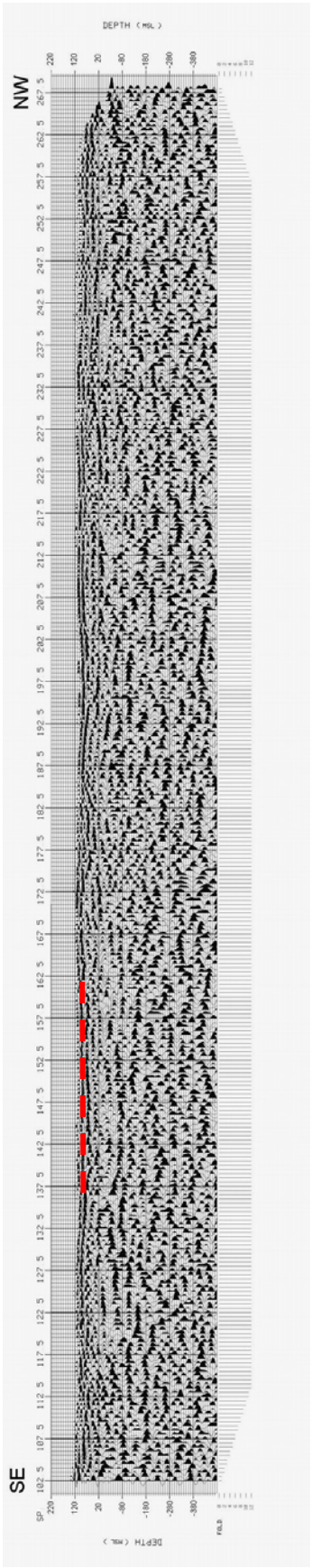


Figure 6.11 Depth profile of the seismic survey Line BS50. The uppermost rock salt layer is indicated by red dash line.

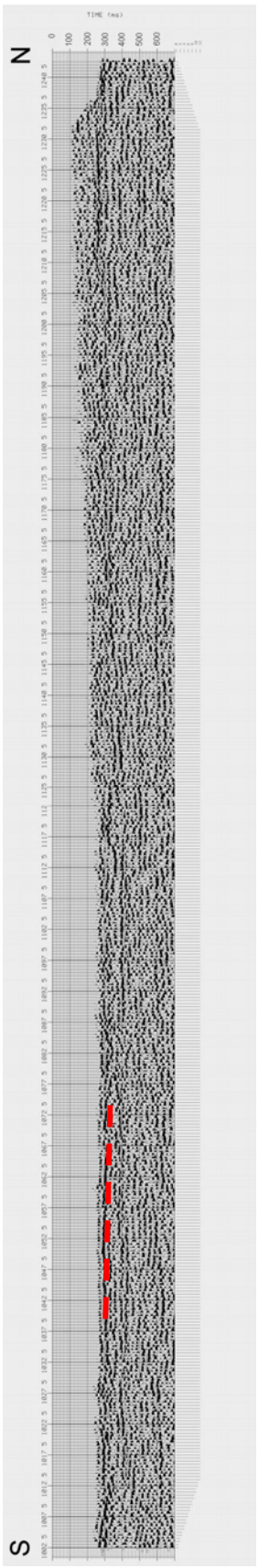


Figure 6.12 Time profile of the seismic survey Line BS501. The uppermost rock salt layer is indicated by red dash line.

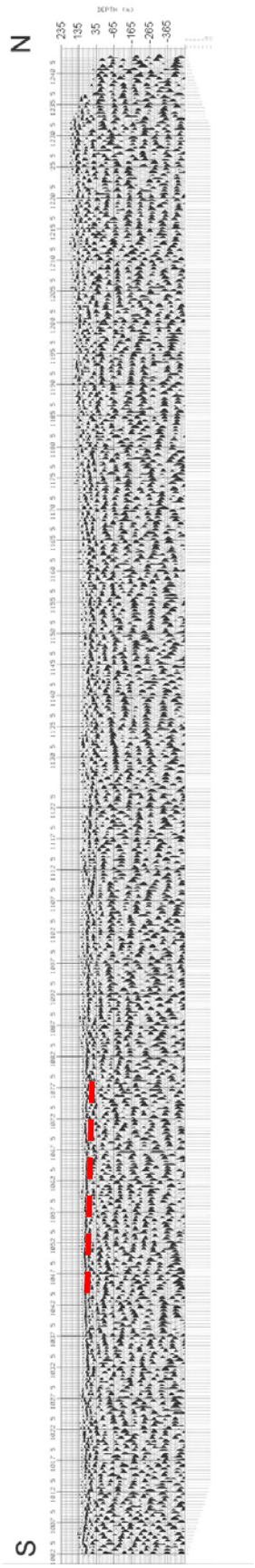


Figure 6.13 Depth profile of the seismic survey Line BS501. The uppermost rock salt layer is indicated by red dash line.

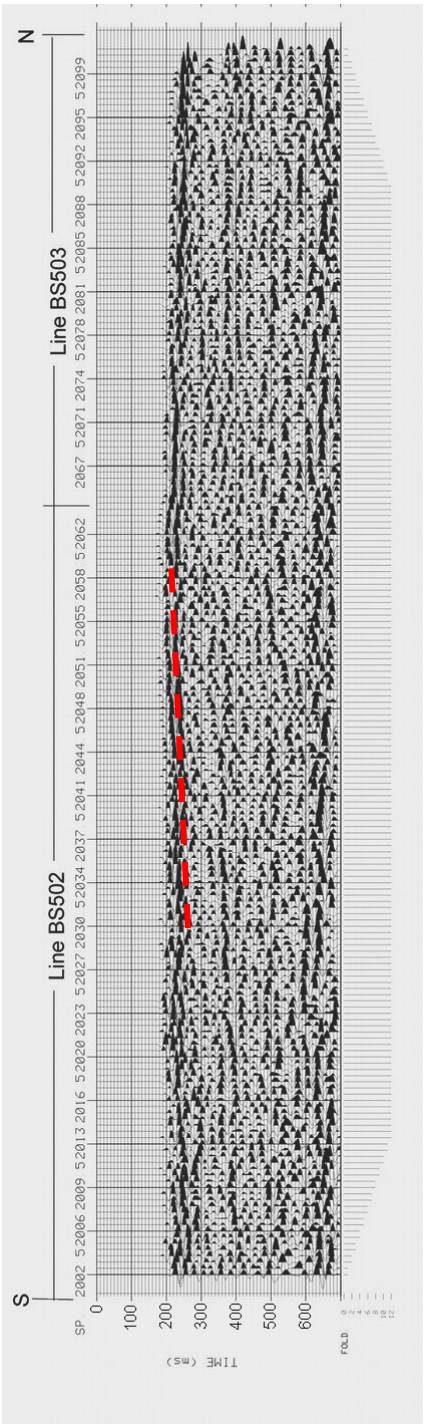


Figure 6.14 Time profile of the seismic survey Line BS502 and Line BS503. The uppermost rock salt layer is indicated by red dash line.

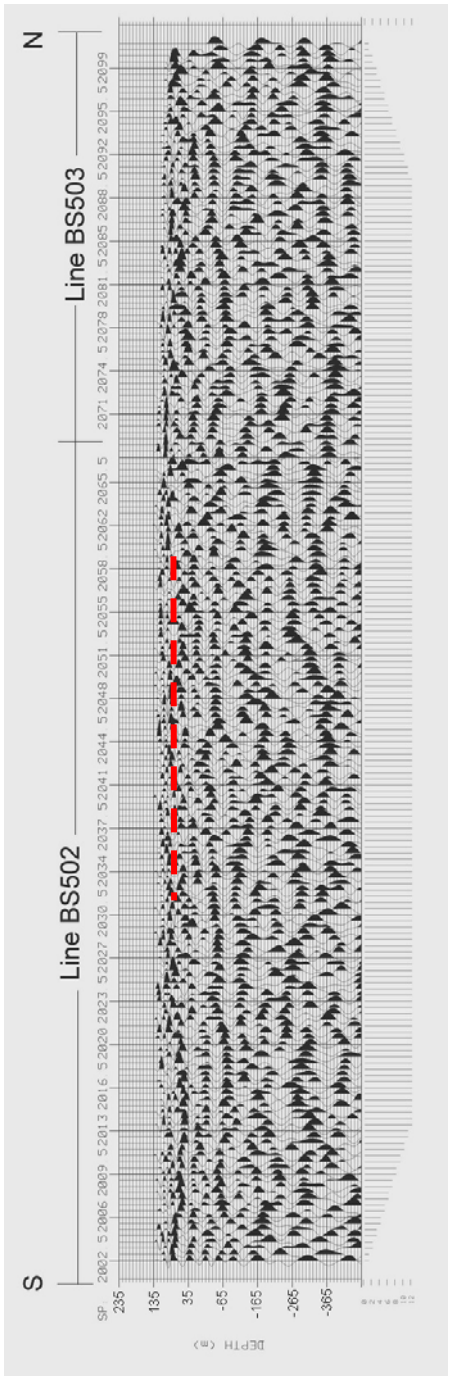


Figure 6.15 Depth profile of the seismic survey Line BS502 and Line BS503. The uppermost rock salt layer is indicated by red dash line.

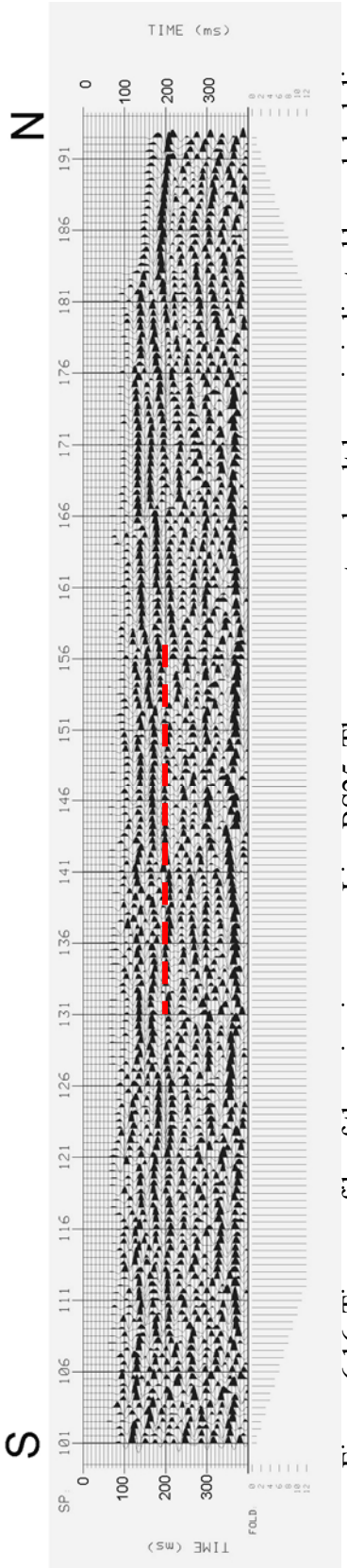


Figure 6.16 Time profile of the seismic survey Line BS25. The uppermost rock salt layer is indicated by red dash line.

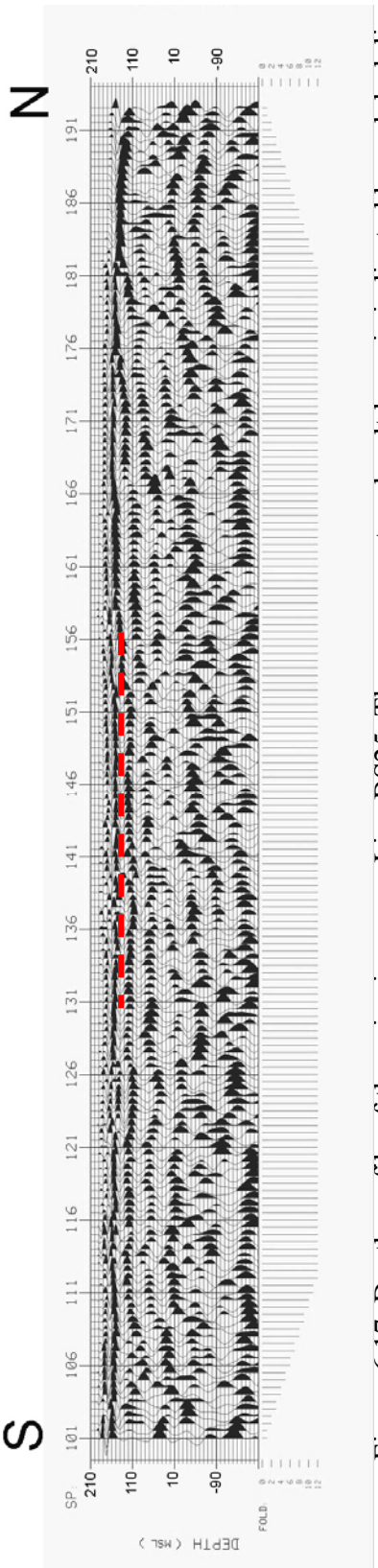


Figure 6.17 Depth profile of the seismic survey Line BS25. The uppermost rock salt layer is indicated by red dash line.