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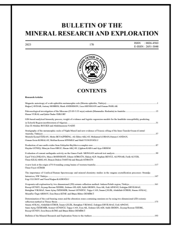

Evaporate salt exploration by two dimensional (2D) seismic reflection method: Ankara-Polatlı region, Türkiye

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Research Article

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ABSTRACT

The presence of the evaporate salt zone in Ankara-Polatlı region has been determined by the drillings. It is thought to be the largest reserve in Türkiye. The seismic reflection method was used to determine the top-bottom levels of the region; its depth; its thickness and extent boundaries; the horst-graben structures; base depth and tectonic movements affecting the study area. Data were collected on three seismic lines. The near-surface tomographic velocity sections were compatible with the top-of-the-zone depth observed in the drillings. As a result of the study, the depth and thickness of the top-bottom of the zone were determined along the lines. Within the scope of the study, a combined interpretation was made on the lines by using gravity and seismic data. The extent of the ore zone was determined only in the E-W direction section, but not in the north-south direction lines since they are outside the license area and the seismic lines. The closest point of the evaporate zone to the surface is approximately 150 m, the deepest point is approximately 310 m, the average thickness is approximately 100 m and the maximum thickness is 185 m.

1. Introduction

Evaporate minerals (salts) used in many industrial areas are easily soluble formations. Due to this feature, they do not outcrop under the influence of atmospheric conditions and must be covered with cover layers (clays) in order not to be affected by atmospheric conditions (Kırtıl et al., 2020).

The study area is located in the district of Polatlı, approximately 80 km southwest of Ankara (Figure 1). Evaporates in the study area were determined to deposit in the playa lake complex developed effectively in paleoclimatic conditions, periodic terrestrial volcanism with tectonism, and depositional systems with different lithologies (Güngör, 2005). Sodium sulfate (42.64% grade), polyhalite (23.74%

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Figure 1- Study area (yellow box) and license area (black line).

grade), and Halite (36.30% grade) mineralization were detected intensively in the drillings carried out in the region between 2017-2019 (Kırtıl et al., 2020).

Although many geological studies are carried out in the license area, geophysical studies; are only limited to regional gravity data and ground electrical study. Geological data indicate that the Evaporite zone was deposited in a lacustrine environment and the tectonic regime of the region was characterized by a series of horst and graben formations; geophysical studies support this information. However, no high-resolution geophysical survey has been carried out in the region.

Determining the depth, thickness, and extent limits of the ore-bearing zone are extremely important for mining operations. Therefore, detailed imaging of the underground is required. The seismic reflection method has been frequently used in investigating evaporitic salt zones (Gendzwill, 1978; Tay et al., 2002; Leveille et al., 2011; Butler et al., 2014; Jones and Davison, 2014; Yamamoto et al., 2017; Protasov et al., 2017).

The aim of this study with the seismic reflection method is to determine the closest point to the earth's surface, top-bottom levels, depth, thickness, and spreading limits of the evaporate salt zone, as well as the depth of the basement topography of the study area, the horst-graben structures formed throughout the basin and the tectonic movements affecting the study area. In this context, seismic reflection studies were carried out on 3 critical lines determined in the license area, in the light of the prior information available.

2. Geology of the Study Area

The study area is located within the Tethys belt, in the west of Central Anatolia, in the Central Anatolian Plain Regime under the effect of N-S direction stress tectonics according to Şengör (1979). Tertiary and Quaternary volcanism have been very effective in the study area. Most of the volcanic units in the area are related to young plate tectonics that developed from the Eurasian-Arabic plates (Gözler et al., 1996). Arıkan (1975) stated that the Haymana-Polatlı basin extends to the southeast and connects with Salt Lake. In the NW-SE direction in the Polatlı-Haymana Basin, sediments extending from Triassic to Quaternary were observed (Ünalan et al., 1976; Turgay and Kurtuluş, 1985). The study area is covered by Miocene, Pliocene aged volcano-sedimentary, evaporitic, carbonate, clastic units, and young sediments (Gözler et al., 1996). In general, most of the Miocene sediments are covered with Pliocene lacustrine deposits and outcrops in a limited area (west of the study area). It was stated that evaporitic and palustrine deposition on a vertical and lateral scale in a partially closed system in the lake sedimentary deposition had occurred several times, and the thickening in the basin margin sequences was under the control of block faults controlling the geodynamic structure of the basin (Varol et al., 2005). The geological map and the stratigraphic units of the study area are illustrated in Figure 2 and Figure 3, respectively.

3. Preliminary Studies

Many geological studies have been carried out on the Evaporate salt zone in the study area (Aydoğdu, 2004; Varol et al., 2005; Güngör, 2005; Zeybek, 2007; Kırtıl, 2008). Kırtıl (2008) revealed the deposition phases of the evaporate sequences (Figure 4). The Bouguer gravity data calculated from the variation of the gravitational field studies, measured within

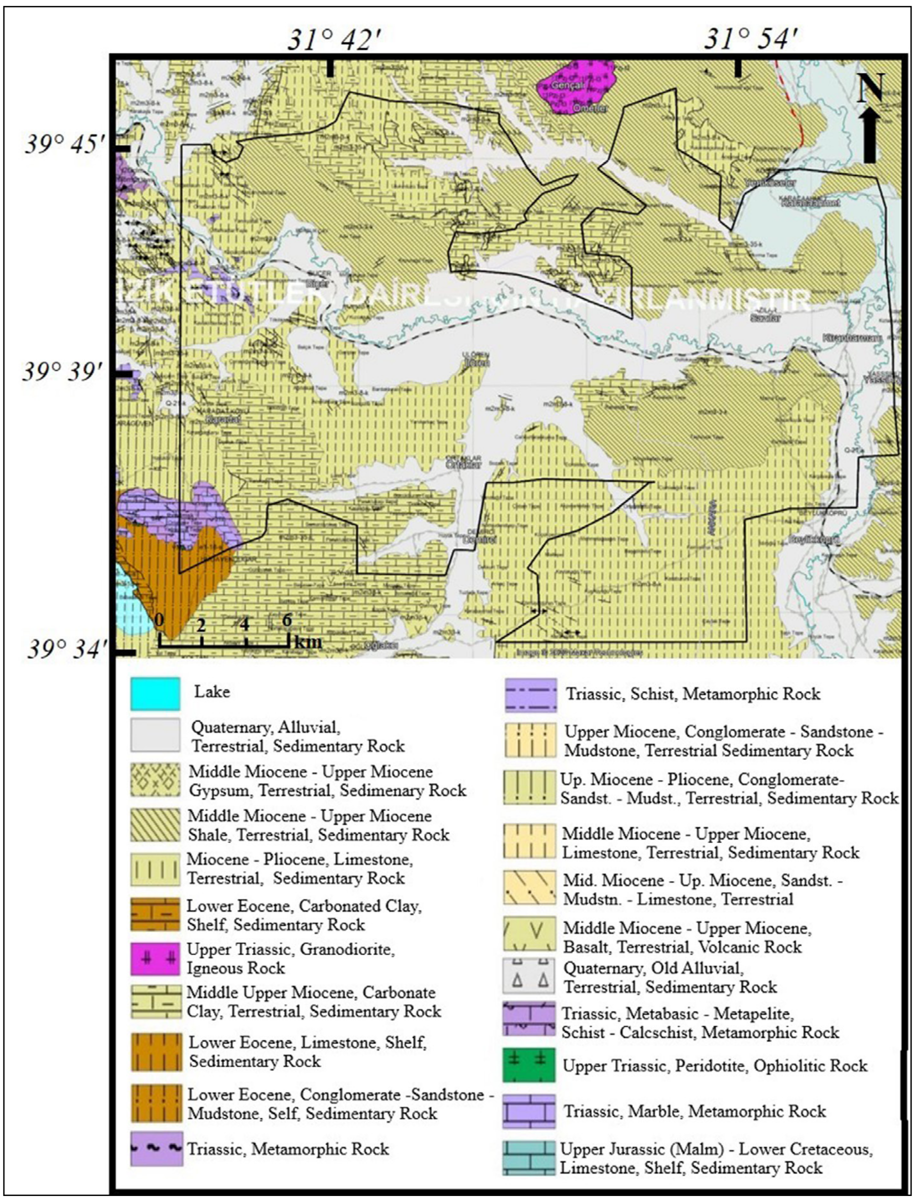

Figure 2- Geological map of the study area (modified from MTA, 2012; Kırtıl et al., 2020).

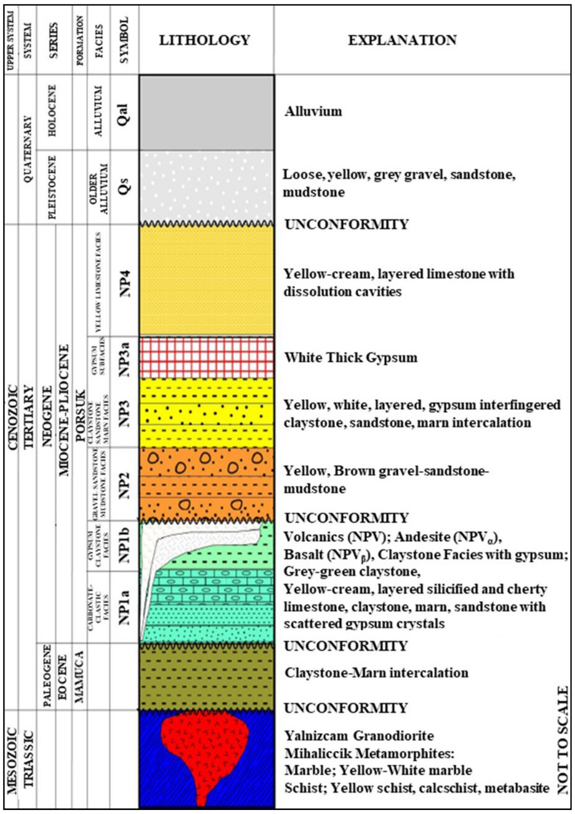

Figure 3- Stratigraphic section of the study area (modified from Gözler et al., 1996; Kırtıl et al., 2020).

the scope of many projects, primarily the Türkiye Geophysical Regional Gravity Maps Project between 1973-2021 by the General Directorate of Mineral Research and Exploration (MTA), can be seen in Figure 5. Türkiye Bouguer gravity dataset have tidal, declination, latitude, free air, topography and Bouguer corrections. The presentation of the gravity data was prepared as 2D profile graphs, interpolated with a sampling interval of 100 m in order to adapt to the geometry of the seismic data and to enable easier visual inspection. In addition, the total horizontal derivative filter, which is widely used in the evaluation of potential field data, was applied to all gravity profile data for the purpose of visualizing near-surface subsurface structures/bodies and discontinuities. Ataman et al. (2019) stated that the basin, in general, is the main graben and that there are many horst and graben structures within the main basin.

4. Data and Methods

Considering the information given above, three seismic lines were designed in the license area. One of the lines is approximately E-W, and the other two are approximately N-S directional lines (Figure 6). The

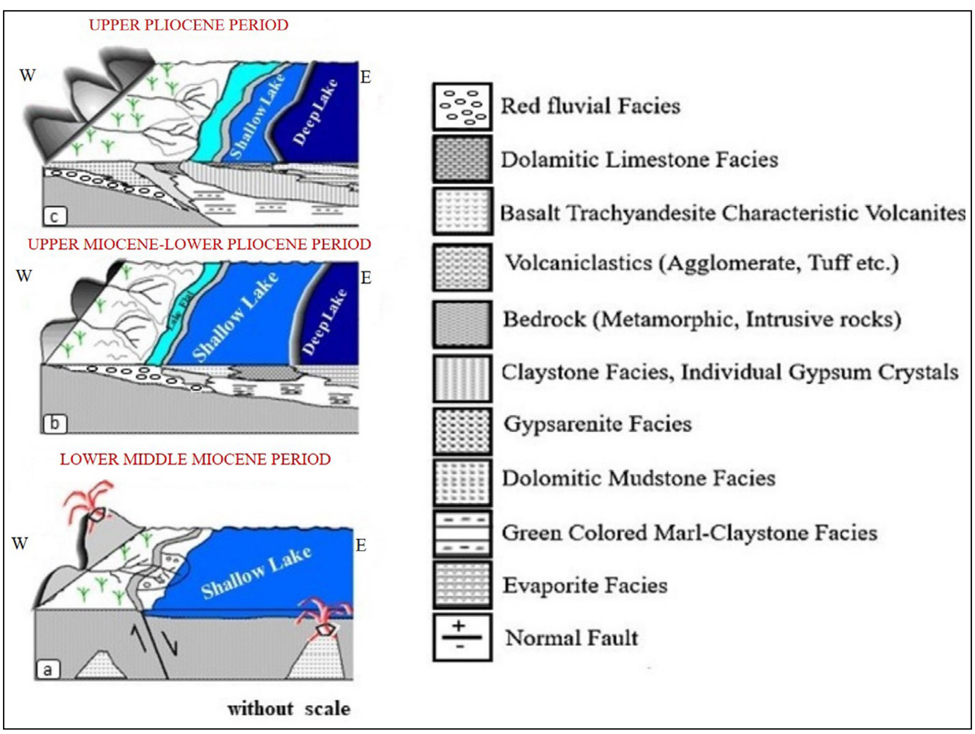

Figure 4- Sedimentation phases of evaporate sequences (Kırtıl, 2008); a) Lower-Middle Miocene, b) Upper Miocene – Lower Pliocene, and c) Upper Pliocene.

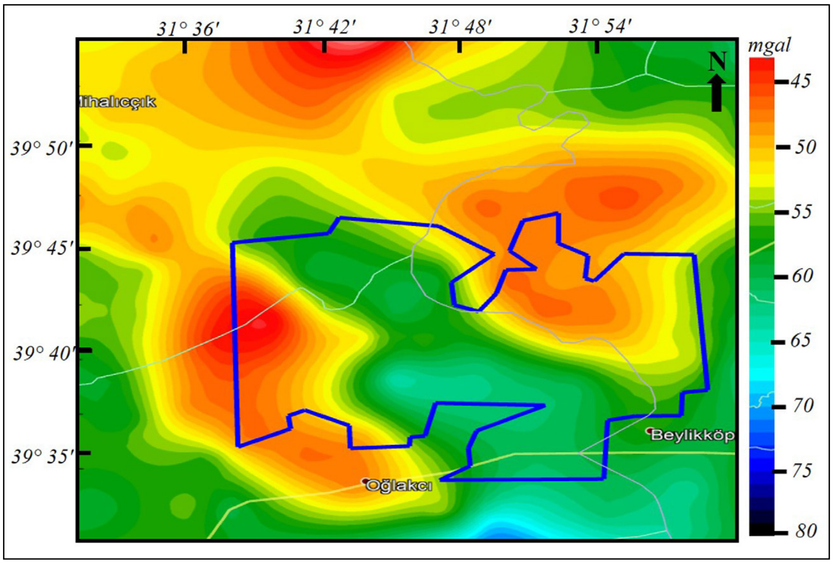

Figure 5- Regional gravity anomaly map of the license area.

purpose of the study, imaging the evaporate salt zone estimated at 20-500 m depth (the primary purpose), and the schist bedrock estimated to be at about 1500 m depth. The seismic studies carried out in this context were tested and carried out with the determined parameters (Özerk et al., 2021).

During the data acquisition, Sercel 428 XL acquisition equipment and two vibro (12000 pounds each) as active seismic energy sources (Mini Vib II) were deployed. Field recording parameters were decided based on the depth target, the purpose of the study, the expected horizontal-vertical resolution, and obtaining high data quality (Table 1). Within the scope of the project, the most ideal seismic sections were attempted to be obtained by processing the data collected in the field (Table 2). ToModel software for

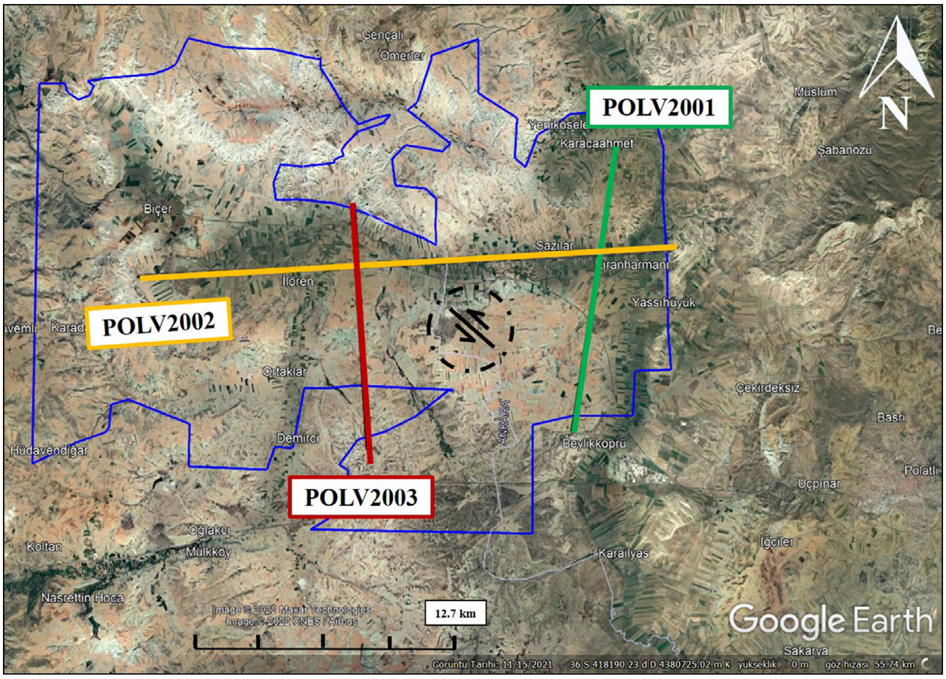

Figure 6- Licensed area, seismic lines, and left-lateral strike-slip fault (black dashed line area, Kandemir and Kanar, 2018).

static correction of seismic data; Disco Focus 5.4 and SeisSpace ProMAX software for data analysis and processing; and Petrel software for data interpretation were used.

Table 1- Acquisition parameters used in seismic reflection study.

Near Offset (m)	5
Far Offset (m)	2495
Live Channel Number	350
Start Frequency (Hz)	12
Stop Frequency (Hz)	126
Number of Vibro	2
Number of Sweep	6
Sweep Time (sn)	14
Sweep Type	Logarithmic -3dB
Taper (ms)	400
Shot Interval (m)	10
Group Interval (m)	10
Receiver Interval (m)	0.9
Spread Type	100-250 (Asymmetric)
Record Length (ms)	4095
Sampling Interval (ms)	1

Table 2- Data processing flowchart.

Data Input
Geometry Definition
Trace Edit/Kill
Static Correction (Datum: 1000 m, Velocity: 1500 m/sn)
True Amplitude Recovery
Ground Roll Attenuation (FK Domain, Coherent Filter)
Predictive Deconvolution (Prediction lag: 36 ms, Operator length: 400 ms)
Bandpass Filter (Cutting Frequencies: 15-50 Hz)
CDP Sort
Velocity Analysis -1 (250 m, 50 CDP)
NMO
Brut Stack-1
Residual Static Correction -1
Velocity Analysis -2 (125 m, 25 CDP)
Brut Stack-2
Residual Static Correction -2
Final Stack (Datum : 1000 m)
FX Migration (15-50 Hz)

5. Research Findings

On the POLV2001 line, 14550 m seismic reflection data were acquired in approximately N-S direction. Near-surface tomographic velocity sections were also created using refractive tomography from the data. Evaporate zone top level - seen in the drillings that were previously made in the region and with a maximum 100 m distance to the seismic line (19/28, 18/103, 18/70, 18/44, 18/47-6, 18/4, 18/19, 18/11, and 18/12) - were marked on the tomographic sections (Figure 7). The levels where the seismic velocity increases in the near-surface tomographic velocity section are consistent with the evaporate salt zone top level. Five different horizons were followed in the seismic time section (Figure 8a). By utilizing nearby drilling data, the uppermost horizon (green) between 450-500 ms was interpreted as claystone-gypsum claystone, the second horizon (turquoise) between 500-600 ms as the top of evaporate salt zone, the third one (blue) between 650-700 ms as claystone-glauberite-gypsum, fourth horizon (dark green) between 900-1000 ms as claystone-siltstone, and the last one (brown) between 1050-1250 ms as basalt. The first three horizons were inspected by the boreholes close to the area. All faults are marked as yellow. Additionally, in the seismic section, the area near the CDP numbered 22200 was interpreted as horst, and the fault near the surface around CDP numbered 20675 was interpreted as a thrust fault. Since the region is in the extensional regime, it may be interesting to see the thrust fault. This thrust fault is most likely associated with the strike-slip fault in the region (Figure 6). According to the regional Bouguer gravity data, a soft rise is observed in the Bouguer gravity amplitudes (Figure 8b) from south to north depending on the topography for the POLV2001 line that cuts through the basin in S-N direction from the eastern border. Especially deep faults drawn on the interpreted seismic section are clearly observed in the gravity total horizontal derivative graph (Figure 8c).

On the POLV2002 line, approximately 26510 m of seismic reflection data in the E-W direction was acquired. A refractive tomographic section of the data was created (Figure 9). In the tomography section, a deformation thought to be due to fracture is observed between approximately 18000-22000 m. By utilizing nearby drilling data (20/02, 20/20, 19/18,

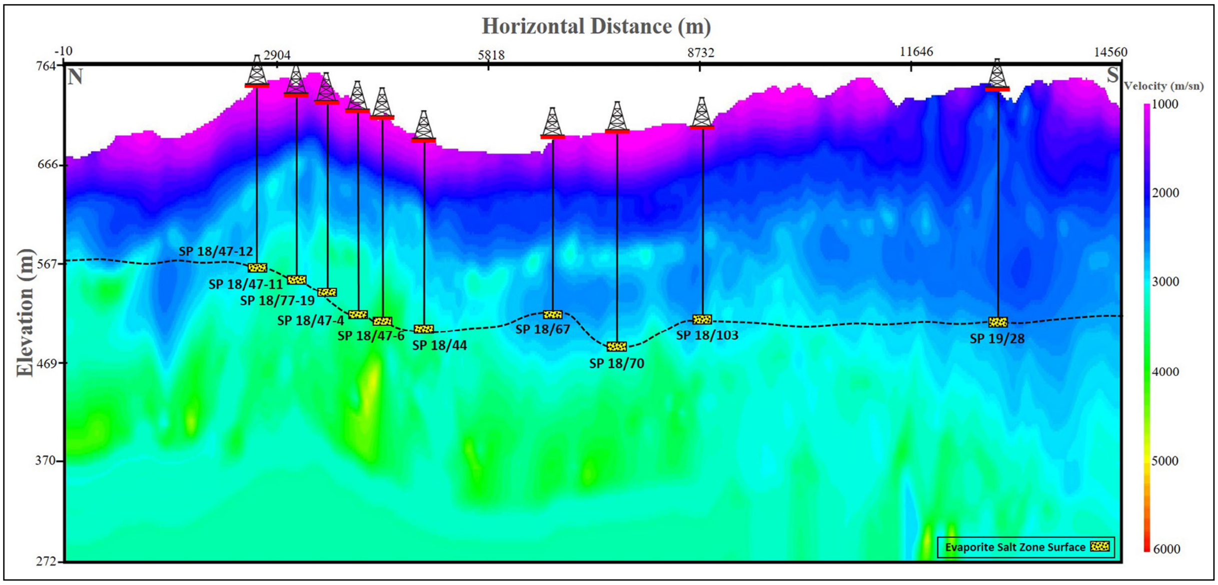

Figure 7- Near surface tomographic velocity section of POLV2001 line and the elevation to the top of evaporate salt zone obtained from the boreholes close to the line.

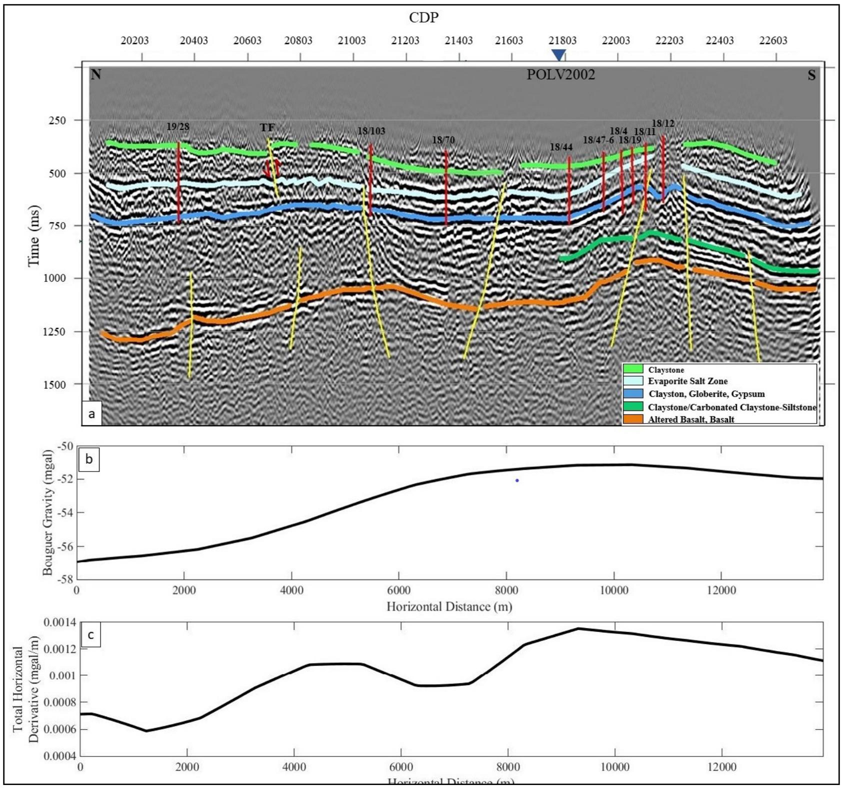

Figure 8- a) Interpreted seismic time section of the POLV2001 line, boreholes (red) and numbers of boreholes, faults (yellow), and interpreted horizons in the area, b) Bouguer gravity graph and c) total horizontal derivative graph.

19/125, 19/118, 18/143, 18/90, 18/89, 18/86, 19/138, 19/151, 19/123, 19/153, 19/141, 18/47-3, 18/44), six horizons could be followed in the seismic time section (Figure 10a). Seismic reflection horizons which are the uppermost horizon (green) as claystone-gypsum claystone, the second horizon (turquoise) as the evaporate salt zone, and the third horizon (blue) as claystone were interpreted. The fourth horizon (dark

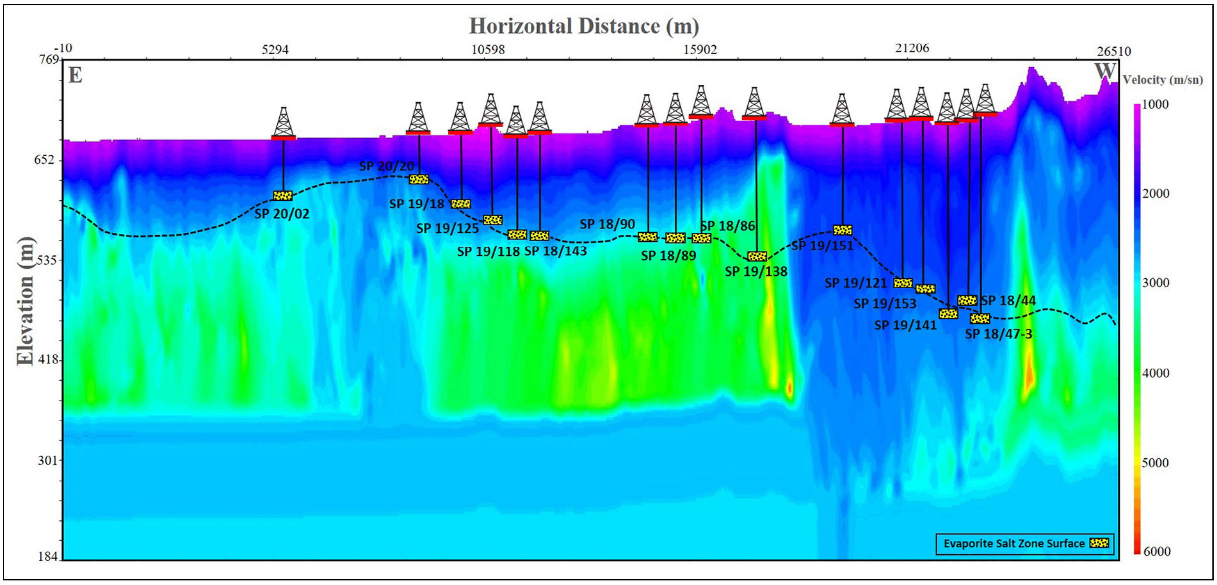

Figure 9- Near surface tomographic velocity section of POLV2002 line and the elevation to the top of evaporate salt zone obtained from the boreholes close to the line.

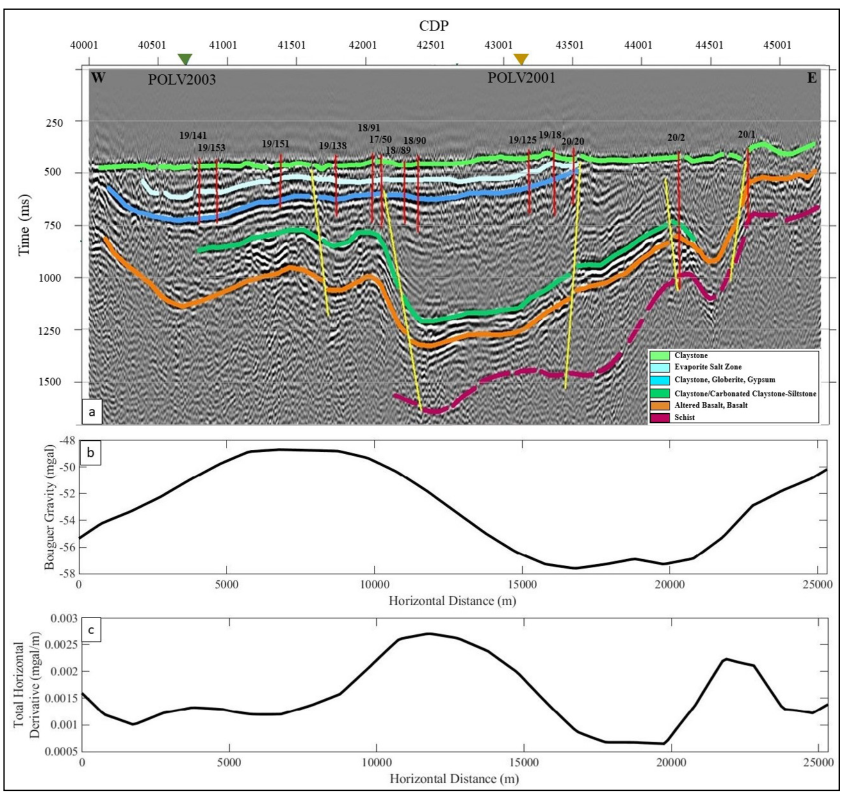

Figure 10- a) Interpreted seismic time section of the POLV2002 line, boreholes (red) and numbers of boreholes, faults (yellow), interpreted horizons in the area, b) Bouguer gravity graph and c) total horizontal derivative graph.

green) was interpreted as claystone-siltstone, the fifth one (brown) as basalt, and the last one (purple) as metamorphic basement schist. It is seen that the extensional boundaries of the evaporate salt zone continue for approximately 18000 m (CDP numbered 43600) from the beginning of the line (CDP numbered 40000). Evaporate salt was not seen in the boreholes numbered 20/1 and 20/2. Faults defining the basin structure are shown in the seismic section. Moreover, horst structures were observed around CDP numbers 42100 and 44200. In the Bouguer gravity profile graph presented in Figure 10b for the POLV2002 line that intersects the basin in the E-W direction, it has been interpreted that the basin boundaries may be between 10-23 km of the line horizontally from east to west. The faults observed in the interpreted seismic section (Figure 10a) can also be observed in the Bouguer gravity profile graph (Figure 10b). However, this situation can be controlled much more clearly in the total horizontal derivative profile curve given in Figure 10c.

On the POLV2003 line, 12020 m of seismic reflection data were collected in the approximately N-S direction. In the tomographic velocity section (Figure 11), although the resolution is poor in the southern part of the line, it is seen that the top of evaporate salt zone matches the high-velocity zone in the northern part of the line. By utilizing nearby drilling data (17/129, 20/18, 19/36, 20/48, 19/69, 20/49, 19/82, 19/41, 19/35), six levels are interpreted in the seismic time section (Figure 12a). Although the first three levels are interrupted in some parts, they can be followed throughout the line. The uppermost seismic reflection horizon (green) was interpreted as claystone-gypsum claystone, the second horizon (turquoise) as the evaporate salt zone, the third horizon (blue) as claystone, the fourth horizon (dark green) as claystone-siltstone, the fifth one (brown) as basalt and the last one (purple) as metamorphic basement schist. Approximately 61100 CDP area of the line has been interpreted as horst. In the Bouguer gravity profile graph presented in Figure 12b for the POLV2003 line, which intersects the basin almost from the middle of it approximately in the N-S direction, it is observed that the amplitude values from north to south decrease towards the middle of the basin and then increase towards the southern border of the basin. As expected, the total horizontal derivative method (Figure 12c) showed signs of sudden changes in gravity values and it was seen that these symptoms were caused by faults as in the other two profiles.

The level interpreted as metamorphic basement schist was not observed in the POLV2001 line. The basalt level monitored continuously in all seismic sections could be partially observed in the POLV2001 line. The schist level, traced in POLV2002 and POLV2003 seismic sections, has been correlated utilizing the lithology information of boreholes 20/1

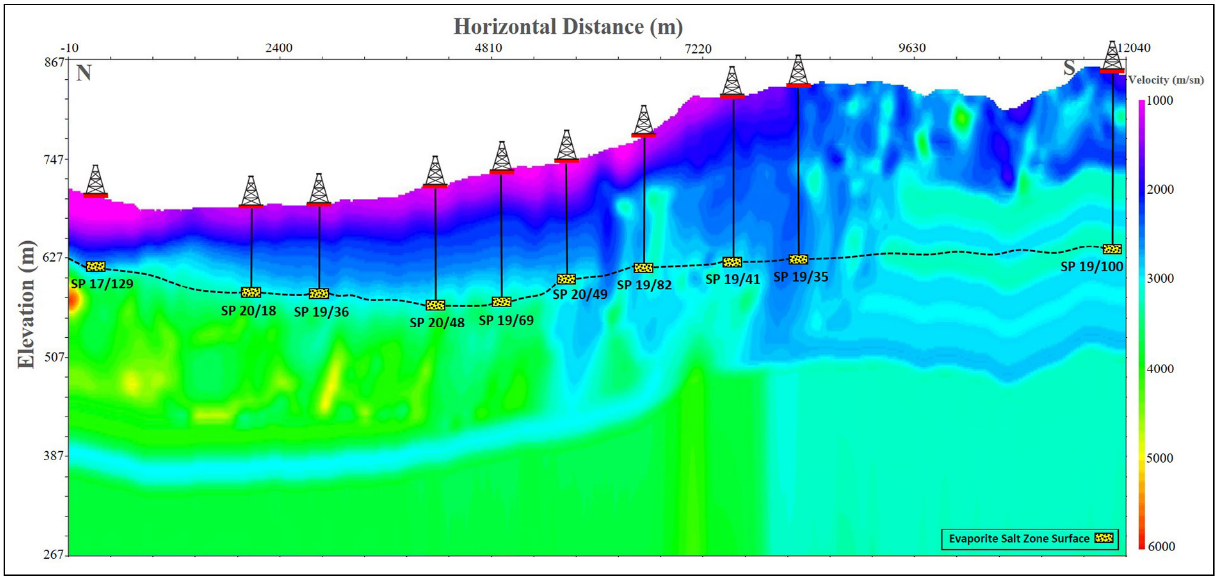

Figure 11- Near surface tomographic velocity section of POLV2003 line and the elevation to the top of evaporate salt zone obtained from the boreholes close to the line.

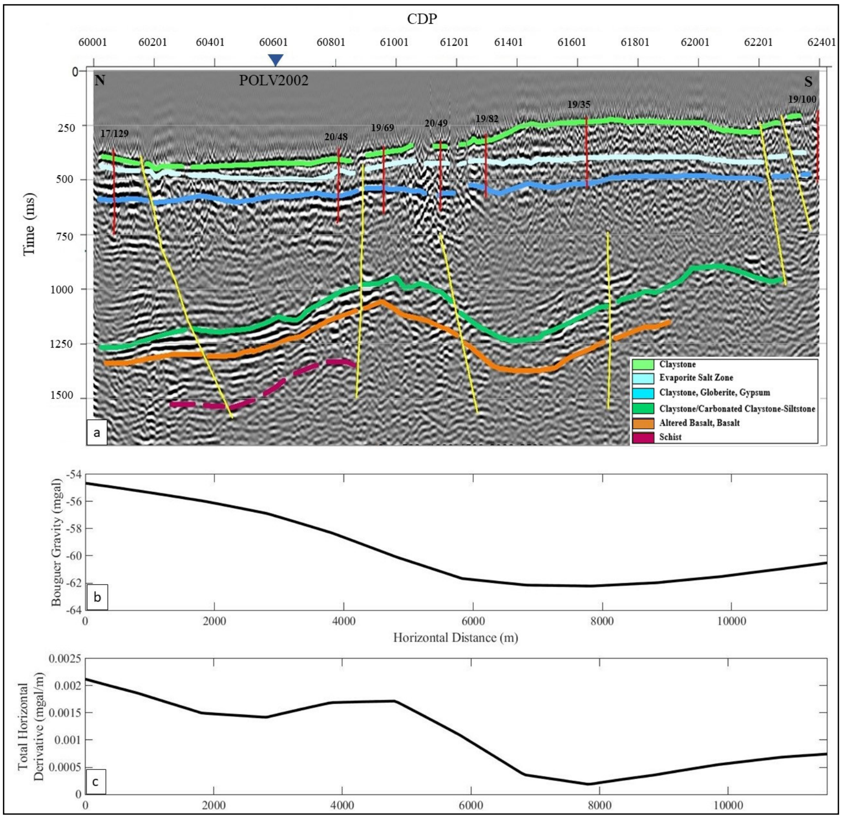

Figure 12- a) Interpreted seismic time section of the POLV2003 line, boreholes (red) and numbers of boreholes, faults (yellow), and interpreted horizons in the area, b) Bouguer gravity graph and c) total horizontal derivative graph.

and 20/2 (Figure 10). Figure 13 shows the 3D views of the tomographic velocity sections and the seismic time sections.

6. Discussion

The evaporate salt zone, located in the tectonically not very complex region, was deposited in a lacustrine environment. It is known that the seismic reflection method produces good results in such sedimentary basins. Such basins, where the geological layers can be observed clearly, can be illuminated by seismic reflection studies and fewer drilling data.

Evaporate salt zone, which is extensive in the study area, was attempted to illuminate with three seismic lines. Evaporate salt zone was visualized along the seismic lines, but the extent limit of the salt zone could not be determined in the N-S directional lines as the ore zone across the license area.

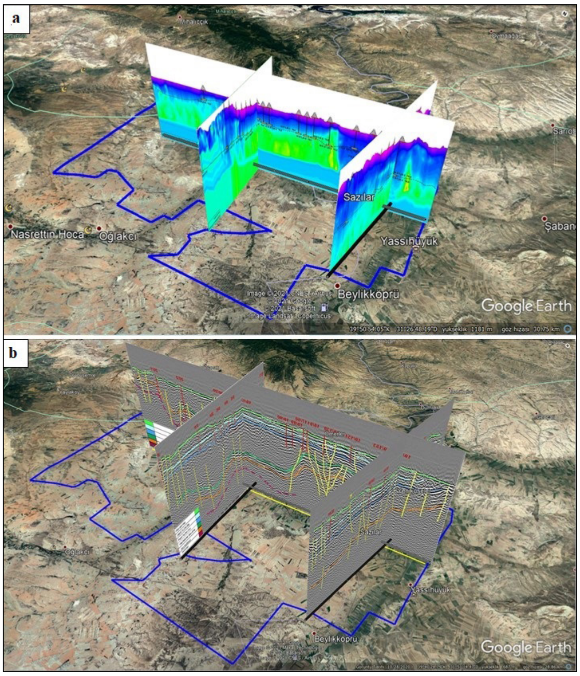

Figure 13- a) The 3D view of the near-surface tomographic velocity sections and b) the 3D view of the interpreted seismic time sections.

In the near-surface velocity models obtained by refraction tomography, it is seen that the approximate velocity of the evaporate salt zone is 3500 m/s and it is compatible with the depth of the evaporate zone determined in the boreholes close to the study area. However, discontinuities are observed in the tomographic velocity sections in some parts because of disruption at the arrivals of refracted data resulting in inconsistencies during the tomographic inversion.

The low-density anomaly seen in the gravity map of the region (Figure 5) supports the presence of salt in the basin. It is seen that especially the 2D total horizontal derivative data derived from the Bouguer gravity map show quite compatible changes with the faults observed in the seismic section. Thus, both methods inspected and supported each other.

Seismic lines remain within the main graben and there are many fracture lines. In addition, there are horst-graben structures in the basin (Ataman et al., 2019). Around CDP number 22200 of the POLV2001 line, around CDP number 42100 and 44200 of the POLV2002 line, and around CDP point 61100 of the POLV2003 line were evaluated as horst structures in the basin.

On the POLV2001 line, there is a thrust around the CDP number 20675 (Figure 10). Considering that the study area was formed by an extension in the horst-graben system, the presence of a thrust fault in the region is extremely interesting. Moreover, there is a left-lateral strike-slip fault in the geological map of the region (Figure 2). It is thought that the mentioned fault may have a reverse component at the point where it intersects the POLV2001 line. Since there are not many earthquakes in the region, no focal mechanism solution has been reached. So previous geological and geophysical studies have predicted that there are horst-graben systems in the basin. However, the horst-graben system was imaged as high resolution with seismic reflection study.

7. Results

In this widely spread sedimentary basin in which many drilling study have been carried out, seismic reflection studies were conducted only along three lines and a total of 53080 m of geophysical seismic reflection data were collected. Near-surface tomographic velocity models were produced and found to be consistent with the top depth of the evaporate salt zone. The schist level, which is the metamorphic basement rock (locally in POLV2002 and POLV2003 lines); and the depth of the Evaporate salt zone in the three seismic lines were determined. The evaporate salt zone thickness and depth were presented with the help of these seismic lines and the drilling data previously obtained in the field. However, the extent limit of the salt zone could only be determined on the POLV2002 line in the E-W direction. On the lines in the N-S direction (POLV2001 and POLV2003), the evaporate salt zone exceeds the license area.

By utilizing previously obtained drilling data in the field, on the POLV2001 seismic line, there are 5 interpreted horizons: claystone-gypsum claystone, evaporate salt zone, claystone-glauberite-gypsum, claystone-siltstone (partly), and basalt. The seismic line remained within the Evaporate salt zone and its boundaries could not be determined. And one of the faults on the line was interpreted as a thrust fault. On the POLV2002 seismic line, there are 6 interpreted horizons: claystone-gypsum claystone, evaporate salt zone, claystone-glauberite-gypsum, claystone-siltstone, basalt, metamorphic basement schist (partly). On this line, the western and eastern boundaries of the evaporate salt zone could be determined. On the POLV2003 seismic line, there are 6 interpreted horizons: claystone-gypsum claystone, evaporate salt zone, claystone-glauberite-gypsum, claystone-siltstone, basalt (partly), metamorphic basement schist (in a very short space). The seismic line remained within the evaporate salt zone like the POLV2001 seismic line and its boundaries could not be determined.

According to the interpreted seismic lines, the ore thickens towards the north and the thickest point (approximately 185 m) is the beginning of the POLV2001 line. Based on seismic lines, the average thickness of the ore is around 100 m. The points where the ore is closest (approximately 150 m) to the surface are on the POLV2002 line. The furthest point of the ore from the surface is about 310 m.

In addition, the basement topography and faults seen in the seismic section were inspected with the 2D Bouguer gravity and total horizontal derivative graphs derived from Bouguer gravity maps. In particular, the changes in the total horizontal derivative graphs fit very well with the faults and basement topography interpreted in the seismic sections.

The fault, marked at the CDP point approximately 20675 of the POLV2001 section and cuts the first two levels, was evaluated as a thrust fault. In such large basins, it would be beneficial to design narrow more seismic profiles so that the interpretation of geological structures and the fault correlation with each other could be more accurate. Planning of more efficient and beneficial drilling with detailed seismic reflection studies is an important step for underground illumination.

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