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3-D Gravity modeling of basins with vertical prisms: Application to Salt Lake region (Turkey)

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Abstract: *A novel 3D modeling method for interpreting gravity maps over sedimentary basins was successfully applied on synthetic data as well as real data from Salt Lake, Turkey. This method utilizes 3D prisms rather than 2D ones and an optimization technique for the estimation of the block thickness. The Salt Lake sedimentary basin is represented with a series of juxtaposed prisms that exhibit parabolic density contrast and different depth to the bottom of the prism. By fitting a parabolic density contrast function on well log data from the same region, we determined the parameters of this function, in order to interpret the gravity data from Salt Lake. The 3D gravity modeling provided depths to the bottom of the basin by minimizing the difference between calculated and observed gravity data. A depth map of the Salt Lake Basin indicates that the thickness of this sedimentary basin reaches a maximum depth of approximately 7 km.*

Key words: *3-D basin, parabolic density contrast, gravity interpretation, Salt Lake.*

INTRODUCTION

Subsurface structures are usually complex and gravity data can not be interpreted using simple models. Sedimentary basins are represented by series of 3D juxtaposed vertical prisms whose upper surface is on the earth surface, bottom surface is at the bottom of the basin and density increases gradually with depth. Interpretation of the gravity data, is verified by constructing a theoretical, gravity map of the basin and comparing it with the field map. Here, the density in the sedimentary basins increases with depth, while its density contrast decreases gradually with depth.

Bott (1960), in one of the first studies about this subject, has represented the sedimentary basins as a series of 2D blocks. According to Cordell (1973) the depth-density relation in the sedimentary basins is exponential. Rao (1990) proposed a quadratic density function. Chai and Hinze (1988) have developed an iterative algorithm in the frequency domain to interpret the gravity anomalies of the sedimentary basins using an exponential density function. Visweswara Rao et al. (1993, 1994) have shown the relevance of the parabolic function for the prediction of the density contrast in sedimentary basins. Chakravarthi et al. (2002) and Chakravarthi and Sundarajan (2004) represented the sedimentary basins with three dimensional square and rectangular prisms. Chakravarthi and Sundarajan (2005) represented the 2.5-D sedimentary basins with 2D prisms exhibit different lengths. They proposed an optimization technique for the interpretation of gravity data along profiles.

In this study, we apply a modeling method which employs 3D prisms whose density contrast is described by a parabolic function. This method is tested on synthetic data for a model consisting of two basins. A three dimensional prismatic model is also used for the interpretation of the Bouguer anomaly map of the Salt Lake in Turkey.

PARABOLIC DENSITY CONTRAST

The density contrast in thick sedimentary basins decreases with depth. A parabolic density contrast function is more preferable for the interpretation of the gravity anomalies caused by sedimentary basins. This density depth relation verified by well data was proposed by Visweswara Rao et. al. (1993) and was modified by Visweswara Rao et al. (1994).

$$\Delta\rho(z) = \frac{\Delta\rho_0^3}{(\Delta\rho_0 - \alpha z)^2} \quad (1)$$

Here, $\Delta\rho(z)$ is the density contrast value for a certain z depth, $\Delta\rho_0$ is the density contrast on the surface and α is a constant obtained by fitting equation (1) to the well data or to seismic velocities.

GRAVITY ANOMALY OF THE VERTICAL PRISMS

Basins are represented by a series of juxtaposed vertical prisms extending from the earth's surface, to the base of the basin (Fig. 1). The gravity value on the P(x,0,0) point caused by a prism whose center is B(0,0,0) and density contrast decreases with depth (Fig. 2) was calculated by Chakravarthi et al. (2002).

In order to get the analytical expression of the gravity anomaly at P(x,0,0) it is necessary to integrate through out the volume of the prism:

$$g_{prism}(x,0,0) = G\int_{z_1}^{z_2}\int_{-T}^{T}\int_{-Y}^{Y}\frac{z_\ell \Delta\rho(z_\ell)dx_\ell dy_\ell dz_\ell}{\left[(x-x_\ell)^2+y_\ell^2+z_\ell^2\right]^{3/2}} \quad (2)$$

Here, G is the gravity constant, T is the half width of the prism, Y is the half strike length of the prism, z_1 is the depth to the top of the prism and z_2 is the depth to the bottom of the prism (Fig. 2).

By replacing $\Delta\rho(z)$ from equation (1) we get:

$$g_{prism}(x,0,0) = 2G\Delta\rho_0^3 Y\int_{z_1}^{z_2}\int_{x-T}^{x+T}\frac{1}{(\Delta\rho_0-\alpha z_\ell)^2}\cdot\frac{z_\ell dx_\ell dz_\ell}{\left[x_\ell^2+Y^2+z_\ell^2\right]^{1/2}(x_\ell^2+z_\ell^2)} \quad (3)$$

Integrating with respect to x between x-T and x+T, we get

$$g_{prism}(x,0,0) = 2G\Delta\rho_0^3\int_{z_1}^{z_2}\frac{1}{(\Delta\rho_0-\alpha z_\ell)^2} \times\left[\tan^{-1}\frac{Y(x+T)}{z_\ell\sqrt{(x+T)^2+Y^2+z_\ell^2}} - \tan^{-1}\frac{Y(x-T)}{z_\ell\sqrt{(x-T)^2+Y^2+z_\ell^2}}\right]dz_l \quad (4)$$

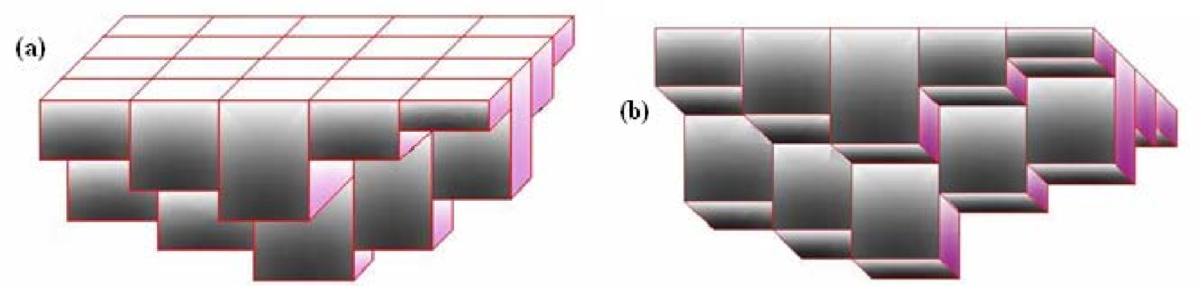

FIG. 1. The appearance of the basin consisting of vertical prisms from top (a) and bottom (b).

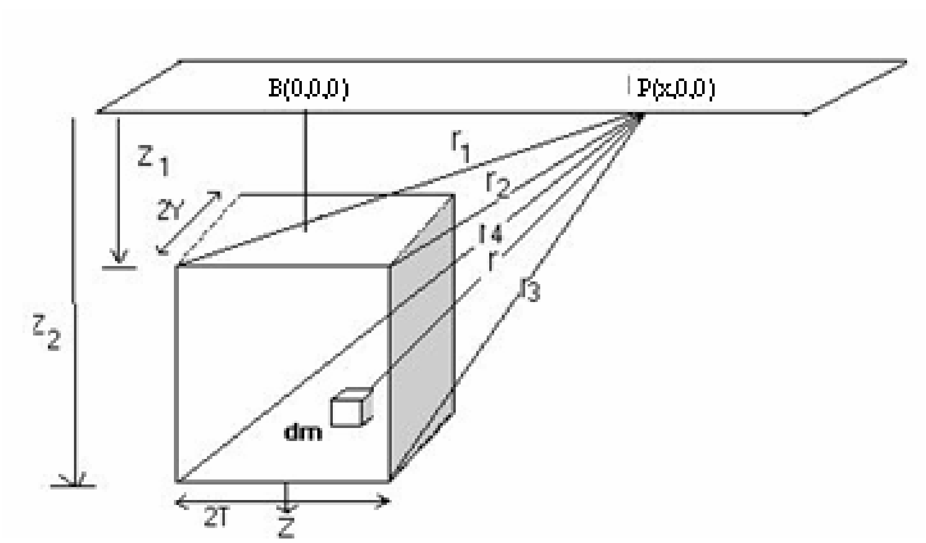

FIG. 2. Three dimensional prism model.

Since the top of the prism is on the surface, in this study z_1 is set to 0 and integration limits in equation (4) are 0 and z_2. This integral is calculated by applying Simpson's rule (Chakravarthi and Sundararajan, 2005).

Basins represented in this method by vertical prisms require starting depth z to the bottom of each prism. The following equation estimates this starting depth (Chakravarthi, 1995):

$$z = \frac{g_B \Delta\rho_0}{2\pi G \Delta\rho_0^2 + \alpha g_B} \tag{5}$$

where g_B is the Bouguer anomaly value. This depth estimate considers that each observation corresponds to an infinite horizontal slab whose density is depth dependent. Namely, the slab's density contrast is given by equation (1).

3D MODELING USING VERTICAL PRISMS

The modeling employs the following steps:

a) First, α and $\Delta\rho_0$ in equation (1) are determined from the seismic velocities or well logs.

b) Gravity map is discretized using N x M cells, whose size is $\Delta X=2T$, $\Delta Y=2Y$. A 2T x 2Y prism is placed under each sampling point.

c) Starting depth is assigned for each prism using equation (5) and the gravity value on top of it.

d) The calculated gravity on each point is equal to the sum of the gravity effect of each prism response, obtained from equation (4).

e) Then, *z* is calculated iteratively by:

$$z_{j,i}^{n+1} = z_{j,i}^{n} + \frac{\left[g_{obs}(j,i) - g_{calc}(j,i)\right]}{\left[2\pi G \Delta\rho(z)\right]} \tag{6}$$

for j=1 – N, i=1 – M, where g_{obs}(j,i) and g_{calc}(j,i) are the observed and calculated anomaly values, respectively. This process is sustained until the difference between observed and calculated values is very small.

NUMERICAL APPLICATION

The effectiveness of the modeling method is verified using synthetic data derived from a model consisting of two basins exhibiting different depth and size. Their base topography is shown in Figure 3.

Here; $\Delta\rho_0$=-0.5 g/cm^3, α=0.08, ΔX=1 km and ΔY=1 km. A gravity map consisting of 104 (8x13) stations was generated (Fig. 4a). Depth to the bottom of the basins is estimated by applying the proposed method. The calculated (Fig. 4b) and the original (Fig. 3a) base topography maps are similar.

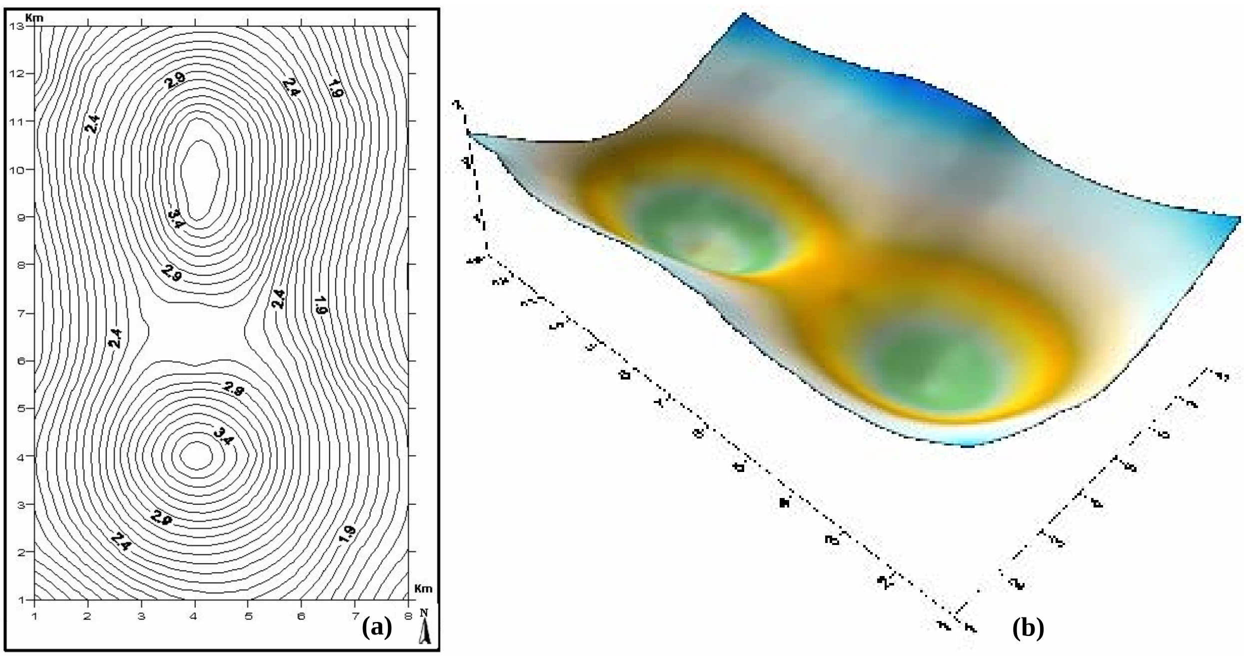

FIG. 3. Depth map of the theoretical model (a) (contour interval is 1 km) and its corresponding 3D representation (b).

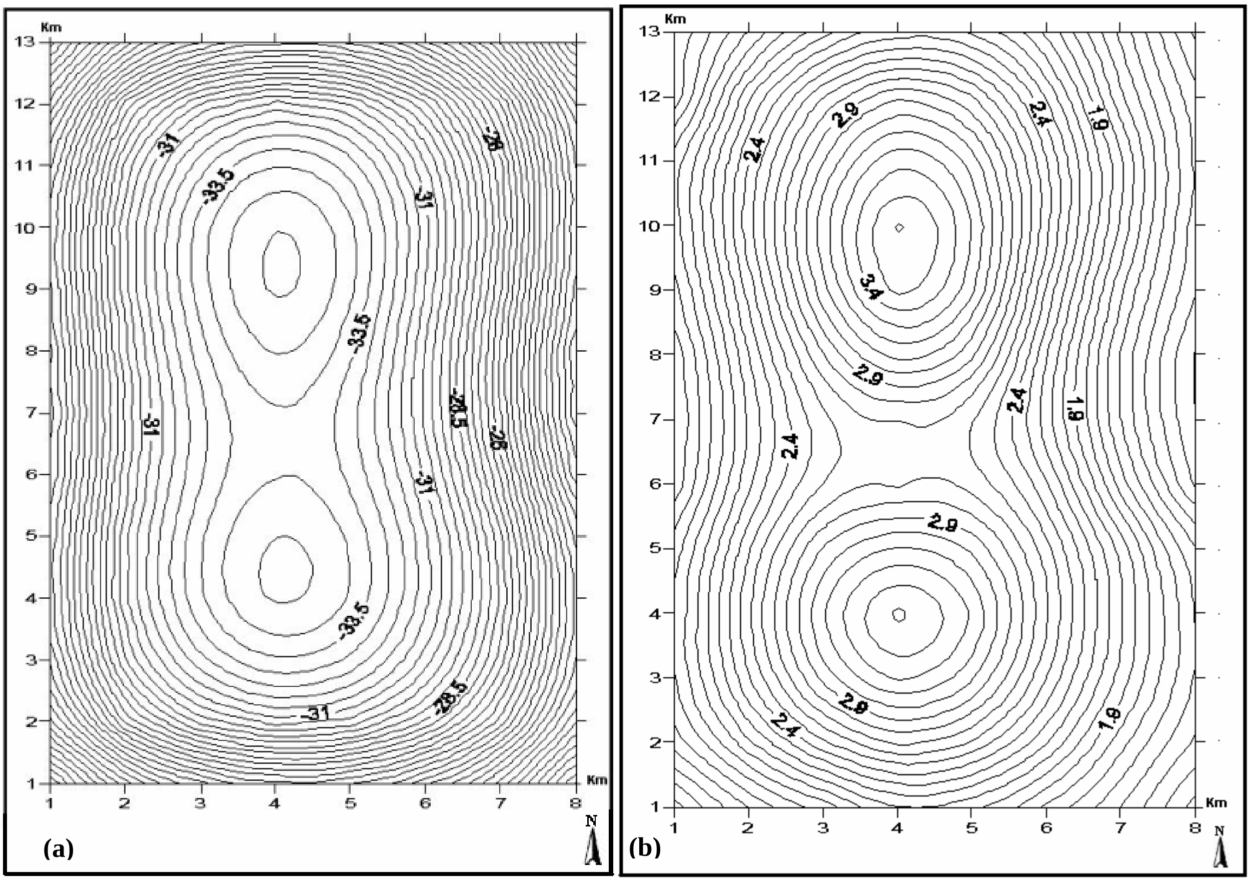

FIG. 4. Calculated gravity map of the model (a) (contour interval is 0.5 mgal) and the corresponding depth map, calculated with the proposed method (b) (contour interval is 0.1 km).

FIELD APPLICATION

This 3D modeling method is applied on the Salt Lake region (Turkey) residual gravity map (Fig. 5a). For this, firstly we estimated the parameters of the parabolic density contrast function by using well log data provided by TPAO (Fig. 5b). Namely, we determined the following parameters: $\Delta\rho_0$=-0.6 g/cm^3, α=0.13. Then, we derived the base depth topography (Fig. 6) and the AB cross-section (Fig. 7). According to these figures the maximum thickness of the Salt Lake is approximately 7 km.

CONCLUSIONS

A 3D modeling method for interpreting gravity maps over sedimentary basins which utilizes 3D prisms rather than 2D ones was successfully applied on synthetic data as well as real data from Salt Lake, Turkey. This novel method takes into consideration all available gravity data and employs an iterative technique for the estimation of the depth to the bottom of basin.

The sedimentary basin in this study is represented with a series of juxtaposed 3D prisms that exhibit parabolic density contrast. In order to interpret the gravity map from Salt Lake, we first estimated starting values for the depth to the bottom of each prism. By fitting a parabolic density contrast function on well log data from the same region, we determined the parameters of this function. 3D gravity modeling using this function, provided depths to the bottom of the basin by minimizing the difference between calculated and observed gravity data.

However, for the best result of this method, the regional on the anomaly map should be thrown away and the zero line on the gravity map should be selected correctly.

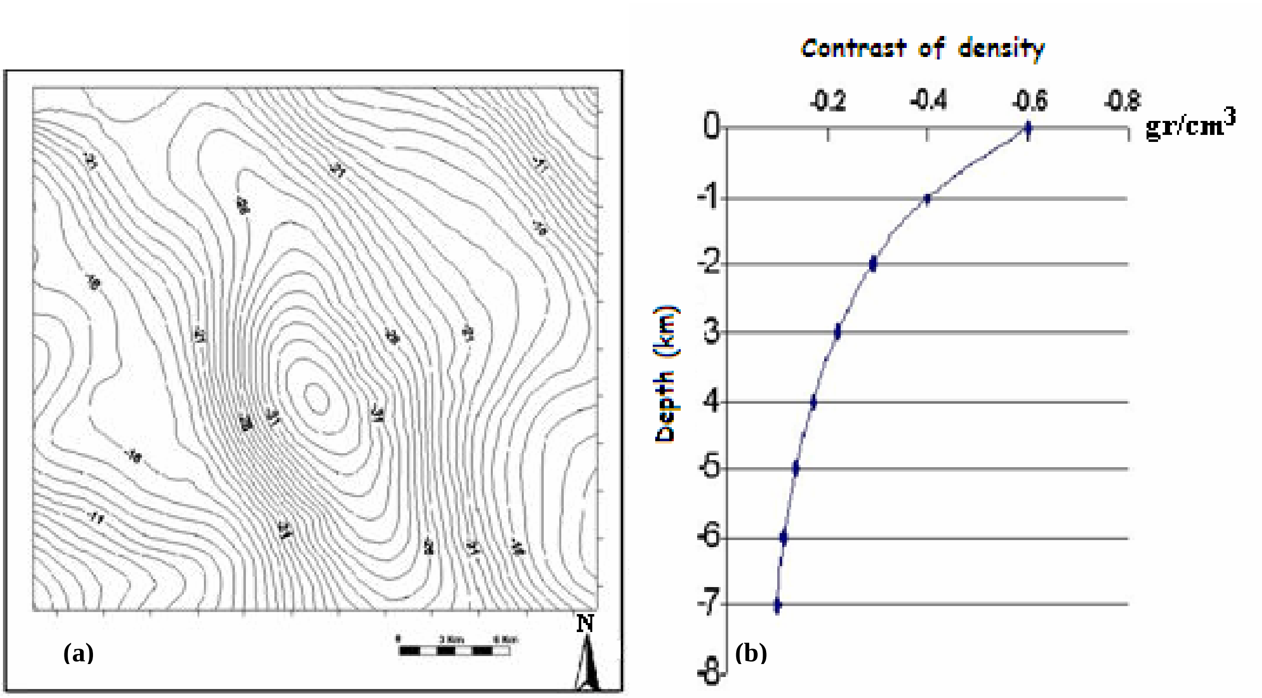

FIG. 5. Filtered gravity map of the Salt Lake basin (a) (contour interval is 1 mgal) (Özdemir 1983-1984) and the corresponding parabolic density contrast (b).

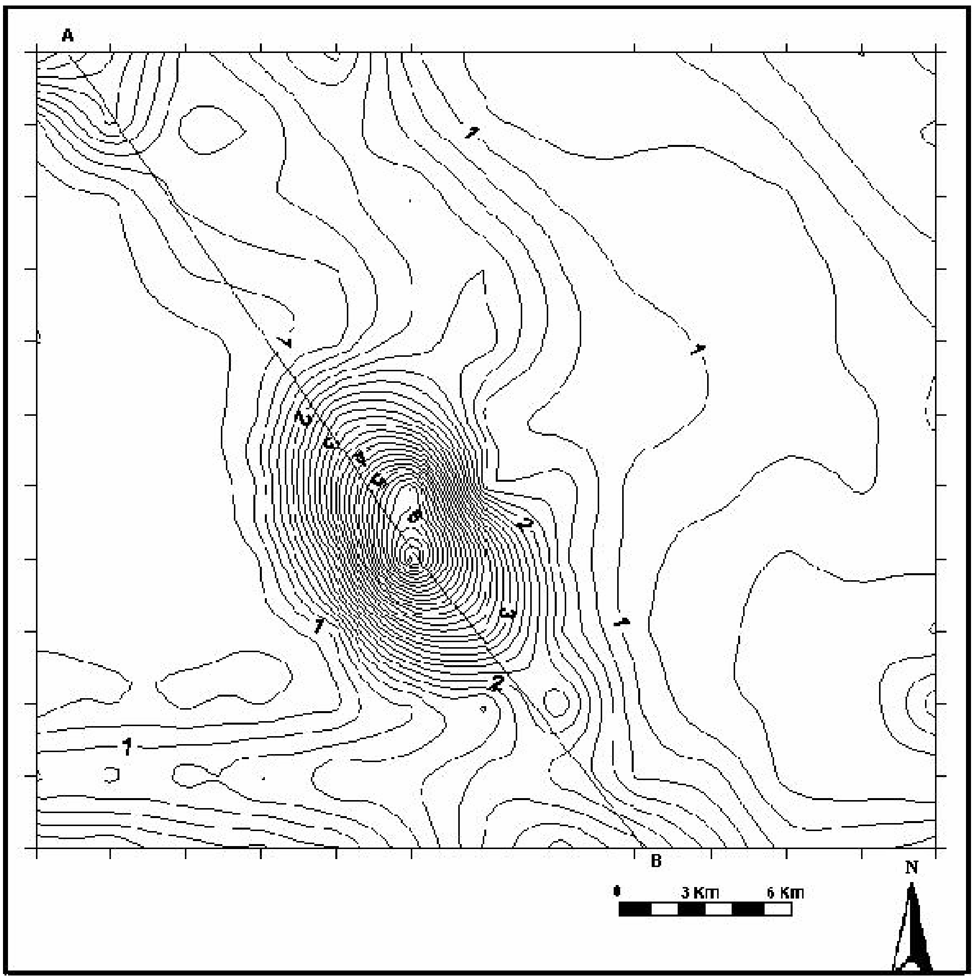

FIG. 6. Depth map of Salt Lake basin (contour interval is 0.2 km).

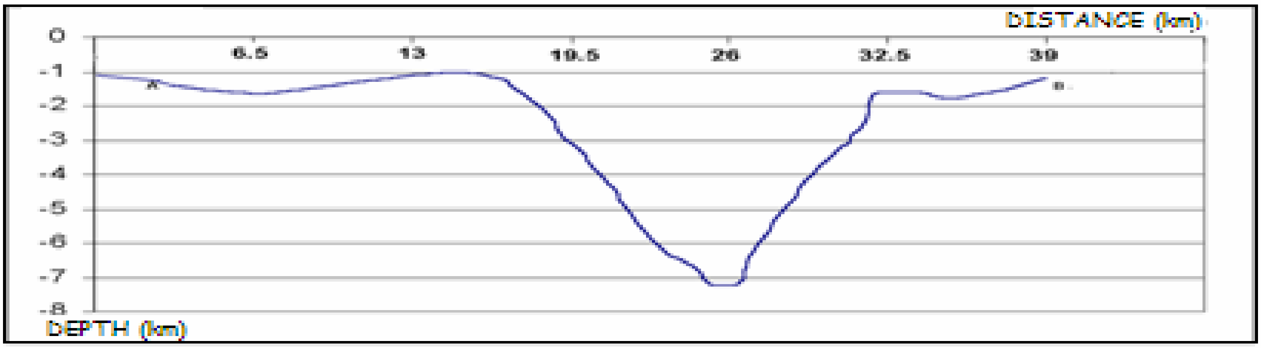

FIG. 7. Cross-section AB taken from the base depth map of Salt Lake Basin.

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