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Edge Detection in Microgravity Data: An Example of Bornova Plain and Its Surroundings, Western Anatolia, Turkey

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Abstract: Tilt angle (TA), total horizontal derivative (THDR) and tilt angle of the horizontal gradient (TAHG) methods were used to determine the structural edges in the Bornova Plain. First of all, a model representing the study area was formed in this study consisting of two steps, synthetic and field study, by using prisms in different depths and sizes. Structural edges were tried to be determined by applying these three methods to the gravity anomaly of this model. The mentioned edge detection methods were applied to the residual gravity anomaly, which was calculated by using microgravity data collected in the Bornova Plain, (Izmir, Turkey) in the next step. Although all of the three methods produce good results both in synthetic and field studies in general, the TAHG method produces more usable results since it makes the structural edges more dominant.

Mikrogravite Verilerinin Sınır Analizi: Bornova Ovası ve Çevresi (Batı Anadolu, Türkiye) Örneği

Anahtar Kelimeler

Sınır Analizi,
Tilt Açısı,
Toplam Yatay Türev,
Bornova Ovası,
İzmir

Özet: Bornova Ovası ve çevresindeki yapısal sınırların belirlenmesi için tilt açısı (TA), toplam yatay türev (THDR) ve toplam yatay türevin tilt açısı (TAHG) kullanılmıştır. Kuramsal ve arazi olmak üzere iki aşamadan oluşan bu çalışmada öncelikle çalışma alanını temsil eden farklı derinlik ve büyüklükteki prizmalar kullanılarak kuramsal model oluşturulmuştur. Üç farklı sınır analizi yöntemi gravite anomalisine uygulanarak yapısal sınırlar belirlenmeye çalışılmıştır. Bir sonraki adımda ise, Bornova Ovası ve çevresinde toplanan mikrogravite verileri ile hesaplanan residüel gravite anomalisine bu yöntemler uygulanmıştır. Her üç yöntem de genel olarak hem kuramsal hem de arazi çalışmalarında iyi sonuçlar vermesine rağmen, TAHG yöntemi yapısal sınırları daha baskın hale getirdiğinden dolayı daha kullanışlı sonuçlar üretmiştir.

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1. Introduction

The detection of the source body's edges is important in gravimetry and magnetometry brunch. There are many commonly used methods for determining the edges of the structures. Some of the commonly used methods are as follows; Analytic signal, total horizontal derivative (THDR), 3D Euler deconvolution, theta angle, tilt angle (TA), hyperbolic of tilt angle (HTA), normalized total horizontal gradient (TDX) and normalized horizontal derivative (NTHD).

Application examples of these methods are as follows; Oruç (2011) applied an edge detection technique to gravity data in the Kozaklı-Central Anatolian region, Turkey, the technique is based on the TA map obtained from the first vertical gradient of a gravity anomaly (1). Oruç et al. (2013) used tilt derivative (TDR) of Bouguer anomaly map of Erzurum Basin (Turkey) (2). Alvandi and Asil (2014) employed an HTA for detecting gravity source edges in the Qom salt dome in the central Iran (3). Altınoğlu et al. (2015) used a horizontal gradient, analytic signal, and TA methods to detect the edges of Denizli Basin and surroundings on Bouguer gravity map (4). Ghosh (2016) carried out 3D Euler deconvolution, horizontal gradient analysis, TA and horizontal tilt angle (TDX) analysis using gravity data in North-West Himalaya (5). Doğru et al., (2017) applied tilt angle method to Western Anatolia gravity data in order to estimate the edges of geological structures (6).

TA, THDR and TAHG method which was suggested by Ferreira et al. (2011) has been successful in revealing the edges of lapped structures. These methods were used to determine the structural edges in the Bornova Plain (Table 1).

Table 1. Used edge detection techniques.

Method	*Abbreviation*	*Formula*	*References*
Total horizontal derivative	THDR	$\sqrt{\left(\frac{\partial G}{\partial x}\right)^2+\left(\frac{\partial G}{\partial y}\right)^2}$	Blakely (1995)
Tilt angle	TA	$tan^{-1}\left(\frac{\frac{dG}{dz}}{THDR}\right)$	Miller and Singh (1994)
Tilt angle of total horizontal derivative	TAHG	$tan^{-1}\frac{\frac{\partial THDR}{\partial z}}{\sqrt{\left(\frac{dTHDR}{\partial x}\right)^2+\left(\frac{dTHDR}{\partial y}\right)^2}}$	Ferreira et al. (2011)

This study consists of 2 steps; theoretical and field study. A complex model was formed in the first step by using prisms in such a way that they best represent the study area. The edge detection methods were used to gravity anomaly of this model. The results of the used methods were compared by taking a section on the gravity anomaly. The residual gravity anomaly was calculated in the second phase of the study by using microgravity data collected in Bornova plain

(Izmir/Turkey). These edge detection methods were applied to the residual gravity map. In addition, the results of the methods were compared to each other and to the geology of the region along with those two sections taken on the map.

2. Theoretical Model Studies

Pamuk et al. (2017) were modeled along two N-S profiles using microgravity data in Bornova Plain and its surroundings (10). It is defined that along the profiles the average basin depth is approximately 400 m and the observed structure edges extend into the basin. In this context, synthetic model studies are planned by choosing similar parameters as possible and considering basin model to investigate the results of different boundary analysis methods. It was created the theoretical model for the effectiveness of the integrated edge detection methods using potensoft Matlab code (11). Fig.1a shows gravity anomaly composed of four prismatic bodies. Table 2 shows these prismatic bodies features. Four prisms were used in the synthetic model. Three of these prisms are at the same depth and one is at a different depth (Fig. 1b).

Table 2. The paramaters of vertical-sided prism models used for theoretical examples

	Coordinate (x,y,z)			Depth to top of the prism (km)	Depth to bottom of the prism (km)	Density (gr/cm^3)	Density Contrast (gr/cm^3)
	X(km)	Y (km)	Z (km)				
1st block	0	2	9.5	0	0.3	2.2	0.5
2nd block	2	8	9.5	0	0.3	1.6	1.1
3th block	8	12	9.5	0	0.3	2.0	0.7
4nd block	0	12	9.5	0.3	1.5	2.6	0.2

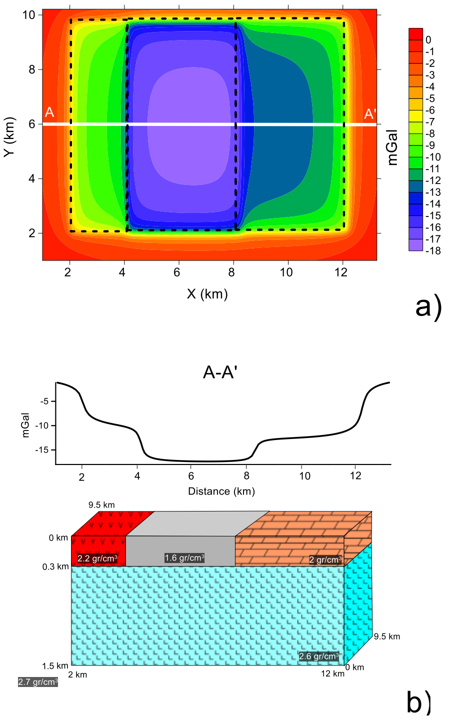

Figure 1. Representation of a) theoretical gravity anomaly maps (dashed line shows edge of prisms) b)the plan of the vertical prism models and A-A' cross section in theoretical gravity anomaly maps.

TA, THDR and TAHG methods were applied to the synthetic gravity map, respectively. Figure 2a shows the tilt angle of the gravity data. Tilt angle ranges from $+\pi/2$ to $-\pi/2$. The tilt angle is 0-radian value at the structural edges. This property defines the horizontal position of the structure. As the tilt angle is seen when the A-A' section is examined, 0-radian contour gives the edges of the structure. The edges of the structure were determined by the tilt angle. And Figure 2b shows the result of the THDR method, which effectively shows the edges of the structures at different depths. As it can be seen in the Figure 2b, the maximums of this method are above the structural edges. And it is at the minimum value at the centers of the structure. Fig. 2c shows the TAHG result of the gravity data. The edges of the structure became more dominant in this method. 0-radian values of the tilt angle give the edges of the structure. The structural edges in the 2nd, 4th, 8th and 12th km in horizontal and in the 2nd and 9.5th km in vertical were successfully obtained with this method.

3. Field Studies

3.1. Geology and tectonic of Study Area

The study area is the Bornova plain located at the east of the Izmir Bay (Figure 3). Bedrock is geologically defined as Upper Cretaceous aged Bornova complex for Izmir and its surroundings (12). The Bornova complex consists of the intercalation of sandstone/shale-calcareous shale. There are limestones, diabase blocks and conglomerate lenses inside the Bornova complex (13). Neogene aged lacustrine sedimentary take part in the upper part of the Bornova complex as inharmonious angularly. Respectively, Yamanlar volcanites to the surface and Quaternary aged alluvions on them take place as inharmonious (13,14) (Figure 4a). According to the geological studies, Miocene aged andesites and their derivatives are located at the north of the study area, and Neogene aged limestones at the south of it. The Delta accumulation features of Quaternary aged alluvions are observed, when it is considered the fact that their middle parts have depression area features (15). The alluvion unit has a feature of normal fault in the south, and it is bounded with İzmir Fault, which approximately 35 km in length and E-W trending, and Karşıyaka fault line in the north (15, 16). Moreover, alluvial fans are controlled by IFZ (İzmir Fault Zone) in the south and KFZ (Karşıyaka Fault Zone) in the north. The northern part of the gulf between Bayraklı and Karşıyaka is bounded with KFZ, which is an antithetic fault to IFZ and about 20 km in length (Fig. 4a) (15) (Fig. 4a).

3.2. Microgravity Studies

Microgravity measurements were carried out by Scintrex CG-5 gravity-meter as approximately 500 m sampling. The base station which's absolute gravity value is determined in Dokuz Eylül University Campus, was used as the main base station within measurement planning. All measurements were brought to term as connecting this station. Totally seven profiles were measured. Measurements were made as minimum 60 sec, 5-15 repeated reading to provide to get well tilt angle and low standard deviation values and the error amount also. Regarding corrections (latitude, height, terrain) were made and the Bouguer gravity map was obtained. A second-order polynomial trend analysis was applied to evaluate better the bottom geometry of shallow plain in the region where Bornova plain encounters with İzmir Bay. The regional effect was resolved by the obtained values from from trend analysis, then residual anomaly map was obtained (Fig. 4b).

The study area is generally bounded by East-West directional normal faults. The structural edges were obtained by applying the filters of TA, THDR and TAHG to the residual gravity anomaly belonging to the study area. Fig. 5a shows the simple form of TA filter containing 0-radian contour. Zero contours indicate the sudden lateral changes in the density of the structure. This map shows the basic structural edges of the region in different directions. Fig. 5b shows the results of the THDR filter. The maximum values obtained with this filter determined the edges of the structures with good and high resolution. The anomalies in the TAHG map were represented by sharp continuous peaks, and the structures were made more visible (Fig. 5c).

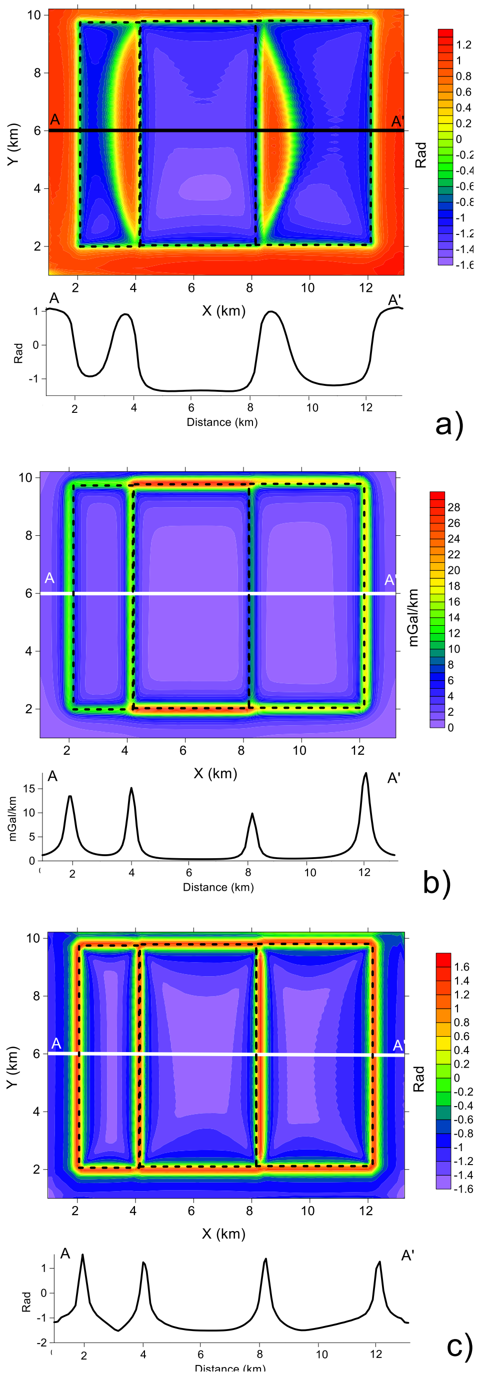

Figure 2. The gravity anomaly map and edge detection results a) TA-Tilt angle b) the THDR-the total horizontal derivative, c) TAHG-tilt angle of the total horizontal gradient.

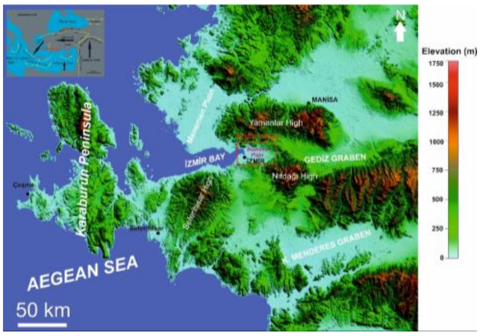

Figure 3. Site Location map of study area together with general morphology and uplift systems (Yamanlar high, Nif Dağı high and Seferihisar high).

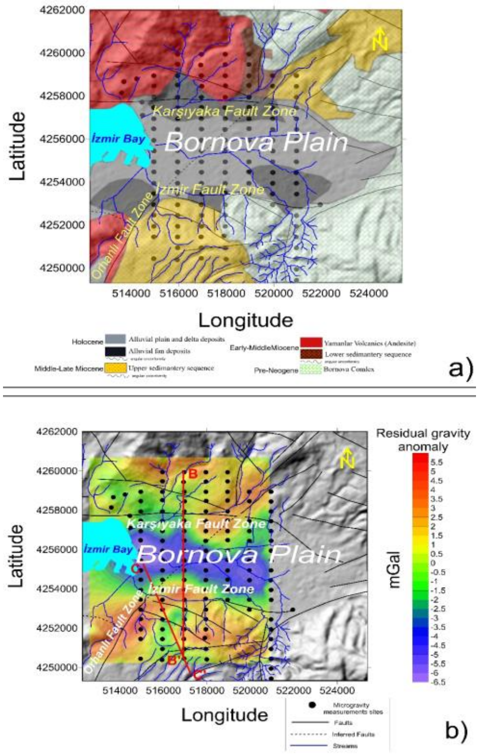

Figure 4. a) Geology map of the study area (modified from Uzel et al., 2012) b) Residual gravity anomaly map obtained by using 2nd degree trend analysis which subtracted from Bouguer gravity anomaly map of the study area.

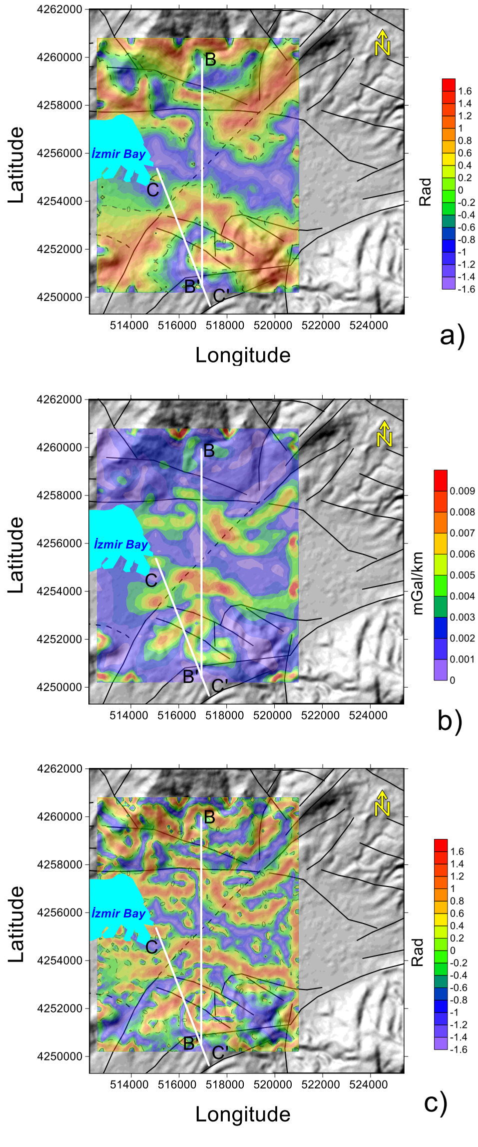

Figure 5. The gravity anomaly map and edge detection results a) TA (Dashed lines indicate the 0-radian contour) b) the THDR c) TAHG (Dashed lines indicate the 0-radian contour)

The region, of which there is approximately 400 m alluvion thickness between 2 and 6 km distance of B-B' profile, was characterized by low altitude and low gravity anomaly, when B-B' section, which was about 9 km in length, was examined (Pamuk et al., 2017). The areas outside this region have relatively higher topography and gravity values. The Karşıyaka and Izmir Fault zones were successfully obtained with the used edge detection methods. The THDR method gives the maxima values in these fault zones. These discontinuities were determined with 0-radian contours in the TA and TAHG methods. In addition, the possible structural edges were indicated by red arrows with the TA and TAHG methods. A total of 6 edges, included or not included in these fault zones, were found with the TAHG method. OHFZ (Orhanlı Fault Zone) could not be detected in the middle of the Gulf, which was interpreted as a possible fault by Uzel et al. (2012), with all the used detection methods (Fig. 6a).

The geological section, which was provided by Uzel et al. (2012), and the edge detection results were compared in the C-C' section, which was about 9 km in length. IFZ and the fault at the left of IFZ were successfully found with the three methods. The dominant edges of the structure were determined with the TAHG method. Five possible structural edges were successfully determined with the TAHG method, apart from the geological sections (Fig. 6b).

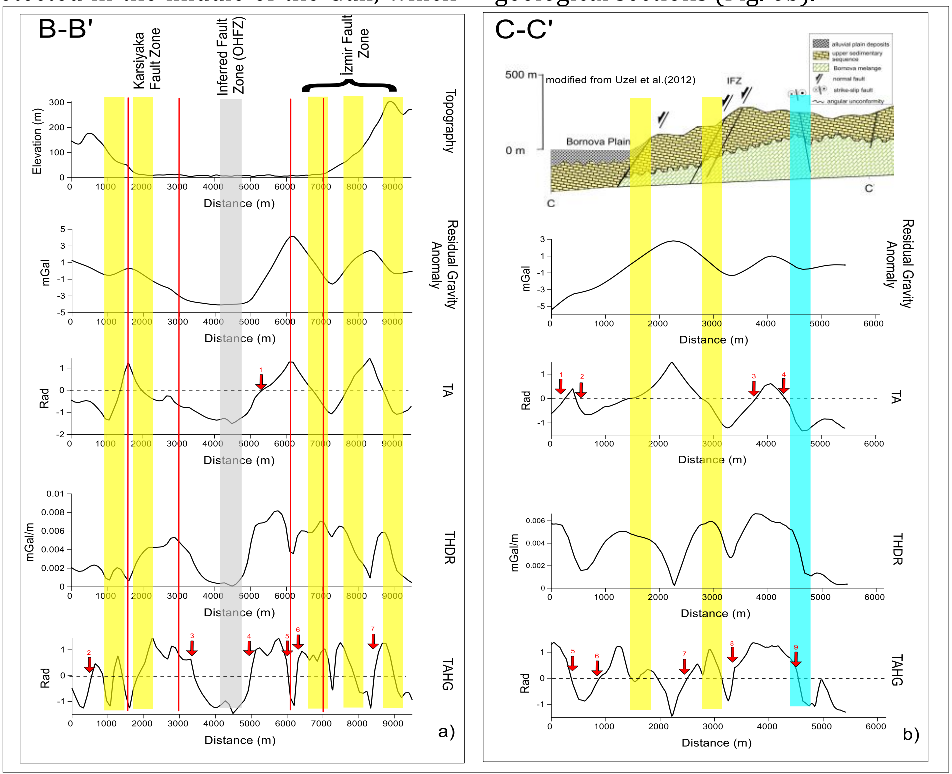

Figure 6. The Cross sections on topography map, the residual gravity anomaly map and edge TA, THDR, TAHG (Red lines indicate the edge of geological units; Yellow lines indicate the known fault zones; Blue lines indicate the strike-slip fault zone; Gray lines indicate the Inferred fault zone (OHFZ) Red arrow lines indicate the possible edges) a) B-B' cross section b) C-C' cross section

The TAHG results and the known and possible edges were compared in Figure 7a. The geological edges were able to be determined with 0-radian contours in general. Similarly, known faults were generally determined with the tilt angle method. Furthermore, the possible structural edges were shown with 0-radian contour (Fig. 7a). It was determined that the OHFZ had a continuation of about 700 m in the first region and about 850 m in the second region (Fig. 7a). However, the continuation of OHFZ could not be determined in the middle parts of the Gulf. It can be approximated from the tilt angle contours about the depth of the source (Salem, 2007; Akın et al., 2011; Dogru et al., 2017). While 0° value of tilt angle gives the edges of the source, half of the distance between the tilt angle contours (±-π/4 (0,785)) gives the upper structural depth(1,6,17,18). Approximate depth of the structural depth was tried to be determined at three selected points among the ±π/4 contours in the Figure 7b. The distances between the ±π/4 contours were determined by sectioning, and according to the results obtained in the study, which was made to determine the approximate depth of KFZ in the 1st section, approximate depth was determined as 110 m., approximate depth of OHFZ in the 2nd section was determined as 280 m, depth of the border shown in 3rd section between alluvial fan deposits and alluvion was determined to be approximately 80 m, and finally structural depth in 4th section, meaning the point that is selected as border of the structure, was determined to be approximately 293 m.

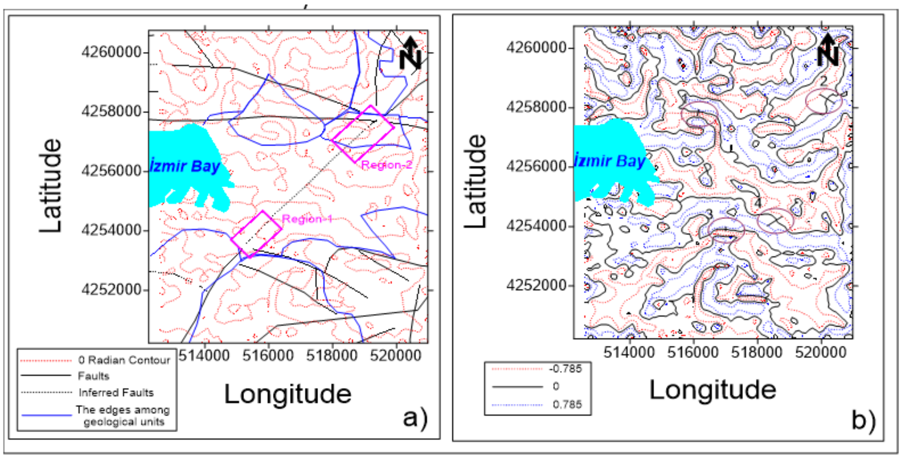

Figure 7. a) Comparison of TAHG results with the edges b) TAHG results dashed lines show the 0-radian contour of the tilt angle. blue lines are contours of the tilt angle for -π/4 radian and red lines are contours of the tilt angle for +π/4 radian.

4. Conclusion

Possible structural edges were tried to be determined by applying the methods of TA, THDR, and TAHG to the gravity data that was synthetically generated and collected with the field study.

- The structural edges were determined with 0-radian contours in the TA and TAHG methods.

- Possible edges were determined with the TAHG method by making the structural edges dominant with the TAHG method. The TAHG method also yielded successful results in the gravity data.

- The average depths of the structure were determined at different regions specified by calculating the half of the distance between the tilt angle contours of $\pm\pi/4$. While the average depth of the KFZ in the region is 110 m, the average depth of the OHFZ was obtained as 280 m.

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