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CALCULATION ALGORITHM AND DIGITAL MODELING OF THE FULL NORMALIZED GRAVITY GRADIENT

Isgandarov E.H.

Azerbaijan State Oil and Industrial University Azerbaijan
34, Azadlig ave., Baku AZ1010: elton_iskender@mail.ru

Keywords: *algorithm, block-diagram, gravity anomaly, full normalized gradient, gravity model, digital modeling, reservoir type anomaly*

Summary. The paper is devoted to the problem of constructing an algorithm for computing and digital modeling of the full normalized gradient of the gravity anomaly, the solution of which plays an important role in gravity exploration for the geological interpretation of the observed anomalies. To identify density inhomogeneities of rocks, which may be associated with structural features as well as hydrocarbon deposits in the section, methods for calculating gradients and higher derivatives of gravity anomalies are widely used. The paper describes an algorithm developed at the Department of Geophysics of Azerbaijan State Oil an Industry University (ASOIU) for calculating the full normalized gradient of gravity anomalies, used to identify and localize areas of density heterogeneities along the studied section. This algorithm and the corresponding FORSE-FORTRAN program allow the calculation of the values of the full normalized gradient of the gravity anomaly by analytical continuation into the lower half-space. Muradkhanli field was selected as the studied model, in the context of which volcanic-sedimentary sediments of the Mesozoic take part, that are well displayed in the gravitational field. Using modern graphical programs and developed applied algorithms, the profile values of the full normalized gradient of the gravity anomaly of the gravitational field of the Muradkhanli rising are calculated. Using the SURFER program, digital modeling of the full normalized gradient of the gravity anomaly is performed, which gives the most complete and a visual representation of the location of anomalous geological objects and oil and gas fields.

Introduction

In the search, exploration and study of the geological structure of promising oil, gas and ore bearing areas, the gravimetric exploration method is of great importance, which is based on studying the distribution pattern of gravitational fields created by individual structural uplifts that have an excess density of rocks composing it. At the stage of quantitative interpretation of gravimetric data, a very important problem is also solved – modeling of gravitational anomalies, which is of great significance in the geological interpretation. Currently, this problem is being solved in the form of digital modeling using modern graphic programs in two-dimensional and three-dimensional versions based on the results of computer calculations of the observed and theoretical gravitational fields using developed algorithms and programs, which provides the most complete picture of the shape, depth and size of the desired geological objects and oil and gas fields.

A direct search for oil and gas deposits in Azerbaijan is currently becoming particularly relevant in connection with the use of Canadian-made CG5 high-precision digital gravimeters in gravity practice, the accuracy of which reaches 0.001 mGal, which fully provides the possibility of identifying weak local anomalies associated with oil and gas deposits. In the literature, these anomalies are also called “Reservoir Type Anomalies” (RTA). Quite a few studies have been devoted to the study of weak local gravitational anomalies associated with hydrocarbon deposits (Цимельзон и др., 1984). Various methods have been developed for transforming high-precision gravity data, among which the Berezkin method of full normalized gradient of gravity is especially popular (Березкин, 1988). The full normalized gradient method and its modifications are currently widely used (Aydin, 2007; Aydin and Kadirov, 2023). Of great interest are the works of Fedi and Florio (2001), devoted to identifying source boundaries using horizontal gradients, Sarsar Naouali et al. (2011), devoted to searching for diapiric structures based on gravity survey data and Kadirov et al. (2023), which proposes the idea of using the gravity gradient tensor based on satellite gravimetric survey data together with ground-based data in solving geodynamic problems and detecting oil and gas deposits. This explains the relevance of scientific research conducted in this direction.

The purpose of this research is to describe an algorithm for calculating the full normalized gradient of the gravity anomaly and digital modeling of the profile values of the full normalized gradient of the gravity anomaly of the gravitational field of the Muradkhanli rising in the eastern part of the Middle Kura depression known in Azerbaijan in the oil and gas ratio.

Means and methods: For many years, the Department of Geophysics has been developing algorithms, programs and the corresponding methodology for processing profile and areal data of high-precision gravimetric prospecting in order to isolate RTA (Isgandarov, 2023a,b; Искендеров, 2005, 2011, 2018, 2019). We propose a graph for processing both analog and digital gravimetric data using developed algorithms and programs. The basis of these algorithms includes various methods for transforming gravimetric data with increased sensitivity: methods of higher derivatives of the potential of gravity, calculation of dispersion, and the full normalized gradient of gravity of Berezkin. The results of processing model and actual gravimetric data are presented in a modern graphical interface. Below there is the block diagram of an algorithm for calculating the full normalized gradient of the gravity anomaly developed at the department (Fig. 1). According to this algorithm, the following data is first entered:

NP, M are the profile number and the number of nodal points; DX, DDX are the step between points along the profile and the step of outputting values to the printing device, in km;

XN, XZL are the beginning and end of the integration base on the profile, in km;

ZH, ZMAX, DZ are the initial, maximum depth of the analytic continuation and their step.

FOR is the format ratio;

NH, NMAX, ND are the initial, maximum number of harmonics and their step of change.

After entering the data, the base is calculated and a linear regional background is removed. Then, in three cycles, according to the change in the number of harmonics, the integration base, and the depth of the analytic continuation, the values of the full normalized gradient of gravity into the lower half-space are calculated by the Berezkin method. The results are printed out as node points of the map along the section.

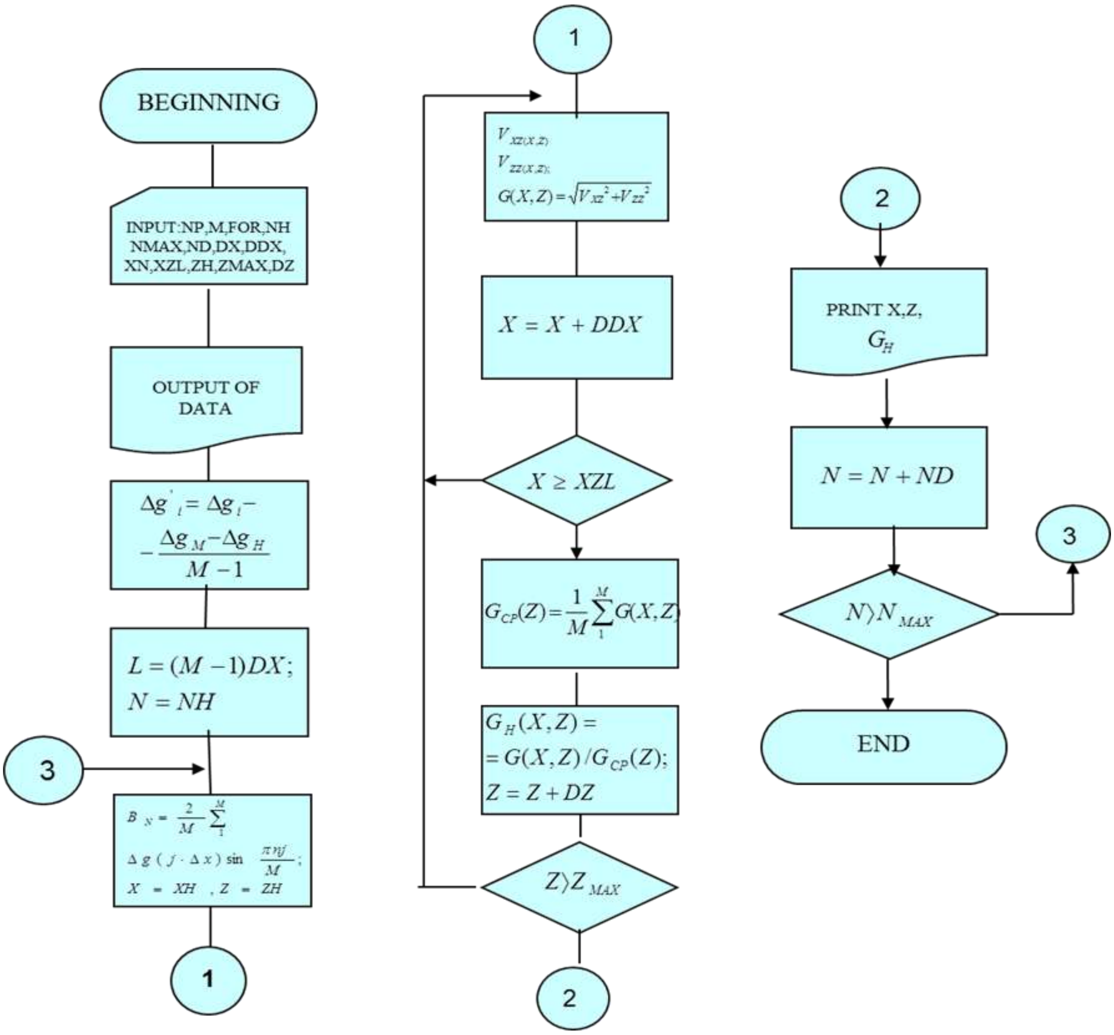

Fig. 1. Block-diagram of the algorithm GNORM

The Muradkhanli rising in the eastern part of the Middle Kura Depression (Fig. 2.), which is associated with an industrial oil and gas field, was chosen as a model. The structure itself is distinguished by its large size (6.5 x 8.7 km) and is tectonically represented by a dome-shaped fold along the Upper Cretaceous, the structure of which is complicated by discontinuous disturbances of various lengths and amplitudes (Салманов, Юсифов, 2013). In the section of the Muradkhanli rising, Mesozoic volcanogenic sedimentary deposits are involved, which have an excess density of about 0.2 g/cm^3. It should be noted that the rise of Muradkhanli was first noted on maps of local gravity anomalies, constructed according to the data of gravity exploration.

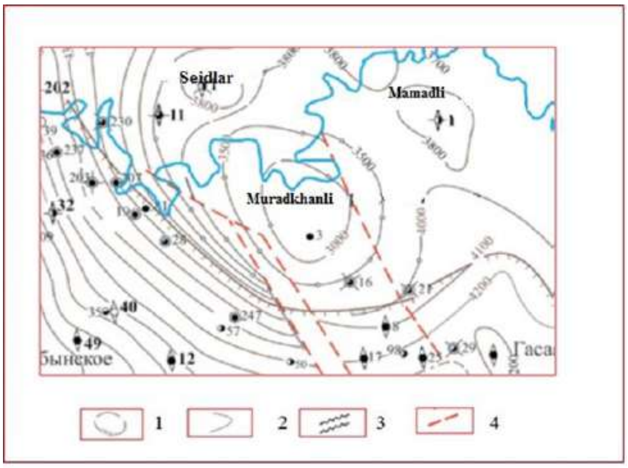

Fig. 2. The rise of Muradhanli
Conv. Designator: 1 – structures prepared by seismic exploration; 2 – contours along the surface of the Upper Cretaceous; 3 – zone complex seismic information, associated with violations according to drilling; 4 – violations according to drilling

Results

Based on seismic data, we first performed a digital simulation of the Muradkhanli structure and compiled a structural model of the Muradkhanli rising in simplified form using the SURFER graphics program (Fig. 3). Then, according to detailed field gravimetric work data at the Geophysics Department, various transformations of the gravitational field were performed using a computer, including the method of averaging with a radius of 20 km (Δg_{20} local gravity anomalies, Искендеров, 2018). As you can see, the rise of Muradkhanli is displayed by the local maximum of gravity with the amplitude of about 4.5 mGal (Fig. 4). Based on the profile data of gravity exploration (the values of the gravity anomaly in the Bouguer reduction), we prepared the initial data in accordance with the algorithm, and then these data were processed using the appropriate GNORM program to calculate the values of the full normalized gradient of the gravity anomaly (G_{fng}, dimensionless quantity). Then, using the SURFER program (Силкин, 2008), G_{fng} values were digitized according to the profile section and a map of the full normalized gradient of the gravity anomaly was constructed using the resulting grid file. In the beginning, it was necessary to calculate the optimal number of harmonics in the Fourier expansion. For this purpose, a priori drilling data on the location of a known oil reservoir were used. The results of calculation and digital modeling of the values of the full normalized gradient of the gravity anomaly for selection of the optimal number of harmonics are shown below (Fig. 5). The optimal number of harmonics in accordance with the drilling data turned out to be 17. After that, the values of the full normalized gradient of the gravity anomaly with the optimal number of harmonics were calculated and digital modeling of the Gfng section was performed. The section map of the full normalized gradient and the model of gravity anomaly curve are shown below (Fig. 6-7). As you can see, the deposit of oil lying at a depth of about 3 km (horizontal coordinate about 7.5 km) is characterized by a minimum of the full normalized gradient of gravity (Berezkin, 1988), outlined by two maxima on the left and right (horizontal coordinate about 6.5 and 8.5 km). To the left of this minimum (horizontal coordinate about 5.5 km) is clearly fixed another minimum gravity that may be associated with another oil and gas field.

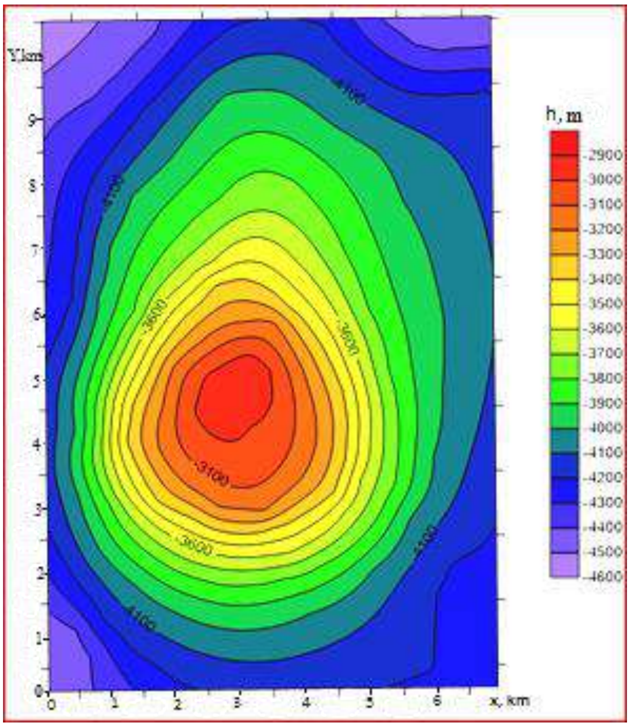

Fig. 3. Digital model of Muradhanli structure (in the contours of depths on the surface of the Cretaceous deposits)

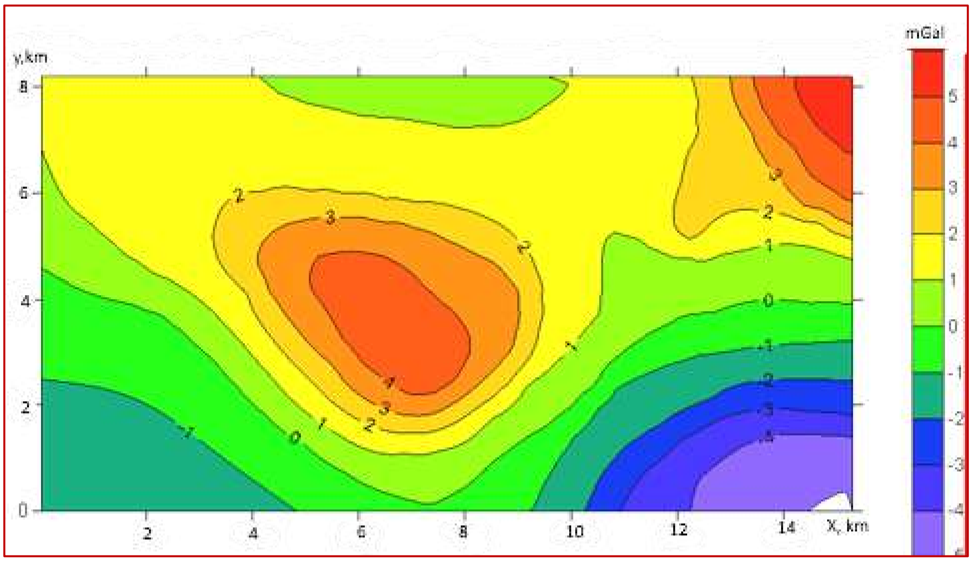

Fig. 4. Δg_{20} local gravity anomalies map of Muradkhanli area (in units mGal)

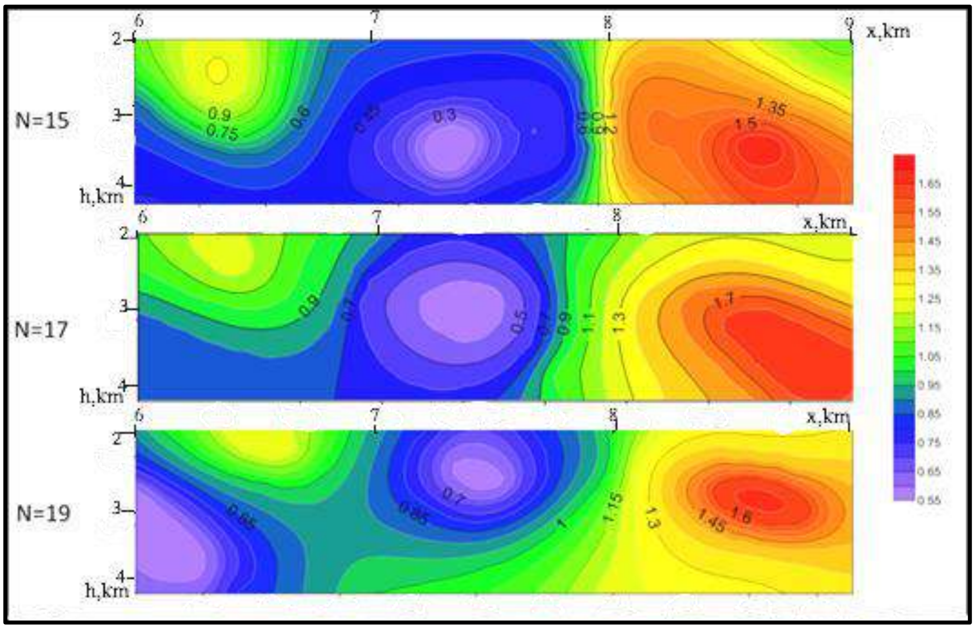

Fig. 5. Selection of the optimal number of harmonics

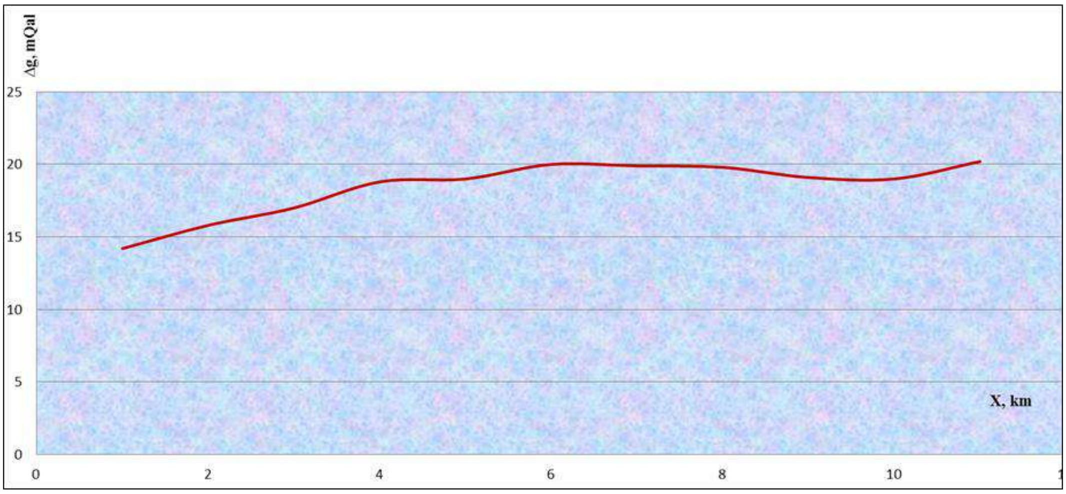

Fig. 6. The model curve of Bouguer gravity anomaly (Muradhanli maximum)

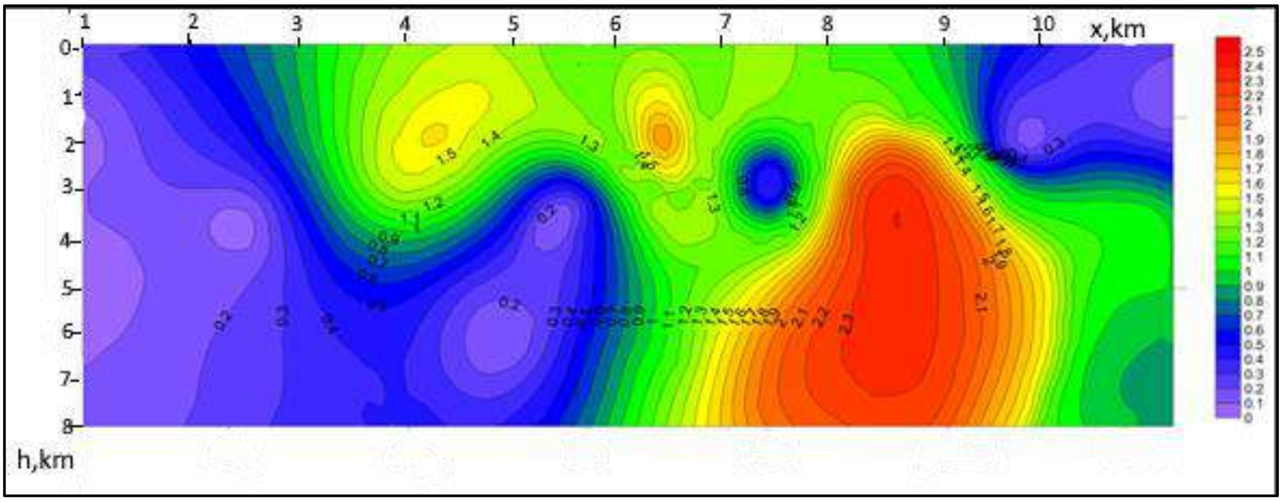

Fig. 7. Digital model of the map of the full normalized gradient of gravity field (Muradhanli maximum)

Conclusions

1. The block diagram of GNORM algorithm for calculating the full normalized gradient of the gravity anomaly in the profile version is presented. The GNORM program is implemented in the WINDOWS system using the FORCE FORTRAN compiler.

2. In the light of new geological and geophysical data, seismic, drilling, and gravity exploration data on the structure of the Mesozoic deposits of the Muradkhanli deposit are analyzed. According to the GNORM program software, the gravitational field was transformed by the method of the full normalized gradient of gravity along the profile crossing the Muradkhanli rise.

3. A digital simulation of the gravitational field of the Muradkhanli area in the profile version using the SURFER program has been performed, which gives the most complete two-dimensional representation of the studied geological section. On the section of the map of the full normalized gradient, the minimum of the full normalized gradient is noted, which can be associated with an oil and gas deposit.

4. The proposed algorithm for calculating the full normalized gradient of the gravity anomaly and the results of digital modeling are recommended for practical use in order to identify weak local anomalies associated with oil and gas deposits.

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АЛГОРИТМ ВЫЧИСЛЕНИЯ И ЦИФРОВОЕ МОДЕЛИРОВАНИЕ ПОЛНОГО НОРМИРОВАННОГО ГРАДИЕНТА СИЛЫ ТЯЖЕСТИ

Искандаров Э.Г.

Азербайджанский государственный университет нефти и промышленности, Азербайджан
AZ1010 Баку, просп. Азадлыг, 34: elton_iskender@mail.ru

Резюме. Статья посвящена проблеме построения алгоритма вычисления и цифрового моделирования полного нормированного градиента аномалии силы тяжести, решение которой играет важную роль в гравиразведке для геологической интерпретации наблюдаемых аномалий. В настоящее время для выявления плотностных неоднородностей горных пород, которые могут быть связаны со структурными неоднородностями, а также с залежами углеводородов в разрезе, широко используются методы расчета градиентов и высших производных гравитационных аномалий. В статье описан разработанный на кафедре геофизики АГУНП алгоритм расчета полного нормированного градиента силы тяжести, который используется для выявления и локализации областей плотностных неоднородностей по изучаемому разрезу. Этот алгоритм и соответствующая FORSE-FORTRAN программа позволяют путем аналитического продолжения в нижнее полупространство рассчитывать значения полного нормированного градиента. В качестве изучаемой модели было выбрано месторождение Мурадханлы, в разрезе которого принимают участие вулканогенно-осадочные отложения мезозоя, хорошо отображаемые в гравитационном поле. С использованием современных графических программ и прикладных алгоритмов, разработанных на кафедре геофизики, рассчитаны значения полного нормированного градиента вдоль профиля поднятия Мурадханлы. Также с помощью программы SURFER выполнено цифровое моделирование полного нормированного градиента сила тяжести, что дает наиболее полное и наглядное представление о местоположении аномальных геологических объектов и месторождений нефти и газа. Представленные алгоритмы и программы могу быть использованы для обработки и интерпретации высокоточных профильных гравиметрических наблюдений для локализации местоположения структурных неоднородностей, а также скоплений нефти и газа в разрезе изучаемой площади исследования.

Ключевые слова: *алгоритм, блок-схема, аномалия силы тяжести, полный нормированный градиент, гравитационная модель, цифровое моделирование, аномалия типа залежи*

AĞIRLIQ QÜVVƏSİNİN TAM NORMALLAŞDIRILMIŞ QRADİENTİNİN HESABLAMASI ALQORİTMİ VƏ RƏQƏMSAL MODELLƏŞDİRİLMƏSİ

İsgəndərov E.H.
Azərbaycan Dövlət Neft və Sənaye Universiteti (ADNSU), Azərbaycan
AZ1010, Bakı, Azadlıq prosp., 34: elton_iskender@mail.ru

Xülasə. Məqalə ağırlıq qüvvəsinin müşahidə olunan anomaliyaların geoloji şərhi üçün qravikəşfiyyatda həlli mühüm rol oynayan qravitasiya anomaliyasının tam normallaşdırılmış qradientinin hesablanması və rəqəmsal modelləşdirilməsi alqoritminin qurulması probleminə həsr edilmişdir. Hal-hazırda, strukturların qeyribircinsliyi ilə, eləcə də kəsilişdəki karbohidrogen yataqları ilə əlaqəli ola süxurların sıxlıq qeyribircinsliyini müəyyən etmək üçün qradiyentin və ağırlıq qüvvəsinin anomaliyalarının daha yüksək törəmələrinin hesablanması üsullarından geniş istifadə olunur. Məqalədə ADNSU-nun Geofizika kafedrasında işlənmiş tam normallaşdırılmış ağırlıq qüvvəsinin qradiyentinin hesablanması alqoritmi təsvir olunur ki, bu alqoritm tədqiq olunan kəsiliş boyunca sıxlığ qeyribircinslik sahələrini müəyyən etmək və lokallaşdırmaq üçün istifadə olunur. Bu alqoritm və müvafiq FORSE-FORTRAN proqramı aşağı yarım fəzaya analitik davam etdirərək tam normallaşdırılmış qradientin qiymətlərini hesablamağa imkan verir. Tədqiq olunan model kimi Muradxanlı yatağı seçilmişdir ki, onun kəsilişində qravitasiya sahəsində yaxşı əks olunan mezozoy vulkanogen-çökmə çöküntüləri iştirak edir. Geofizika kafedrasında hazırlanmış müasir qrafik proqramlar və tətbiqi alqoritmlərdən istifadə etməklə Muradxanlı qalxımının profili üzrə tam normallaşdırılmış qradiyentin qiymətləri hesablanmışdır. Həmçinin, SURFER proqramından istifadə etməklə, anomal geoloji obyektlərin və neft-qaz yataqlarının yerləşməsi haqqında ən dolğun və aydın mənzərəni verən tam normallaşdırılmış qradiyentinin rəqəmsal modelləşdirilməsi aparılmışdır. Təqdim olunan alqoritmlər və proqramlar tədqiqat sahəsinin kəsilişində struktur sıxlığ qeyribircinsliklərin, eləcə də neft və qaz yığılmalarının yerini lokallaşdırmaq üçün profil boyunca yüksək dəqiqlikli qravimetrik müşahidələrini emal və interpretasiya etmək üçün istifadə edilə bilər.

***Açar sözlər*:** *alqoritm, blok-sxem, ağırlıq qüvvəsinin anomaliyası, tam normallaşdırılmış qradiyent, qravitasiya modeli, rəqəmsal modelləşdirmə, yataq tipli anomaliyası*