Research on the detection effect of microgravity method in urban mined-out area

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Abstract. The mined-out area is a potential geological hazard for urban safety. In particular, there are many mined-out areas in the Longgui nitrate mine in Guangzhou, which poses a serious threat to the safety of large-scale buildings in the city. Therefore, it is necessary to find out its specific spatial distribution location and center depth information. The micro-gravity detection method uses the residual density inversion and the re-focus weighted inversion method to identify the spatial distribution of urban underground goaf by observing the weak change of gravity field in the area. The microgravity detection method combined with the effective processing and inversion interpretation method can realize the delineation of the specific distribution range and spatial distribution form of the cave in the goaf.

1. Introduction

The urban goaf has a significant impact on the prevention of geological hazards such as urban building construction, urban underground space utilization and development, and underground pipeline engineering. The detection and identification of the goaf is the key link of building site selection, urban subway passage construction, and urban geological prevention and control. The interference in the urban area is relatively large, which increases the difficulty of detection. The commonly used electrical methods, seismic methods, and electromagnetic sounding methods cannot effectively solve this problem. Micro-gravity method technology is relatively less disturbed, which can eliminate shallow surface and ground interference. Combined with effective inversion and imaging processing technology, it can clearly detect and identify the location and spatial distribution of goafs in urban areas. Microgravity detection technology has been widely used in goaf or goaf caverns around the
world [1-9]. A high-precision gravity instrument CG-5 is used, with its resolution of 0.01 mGal, which ensures the successful realization of microgravity measurement.

2. Geological condition
The goaf is located in the area of Yongtaizhuang and Gaoqiaozhuang on the northern outskirts of Guangzhou. A set of lower Tertiary clastic rocks dominated by river and lake facies are deposited, and the basement and periphery are composed of Paleozoic, Mesozoic, and Yanshanian granites. The mining area is covered by the Quaternary (Q) in a large area, and the lower Tertiary Buxin Formation (E1-2b) and Xibu Formation (E2x) strata are only seen in the borehole.

The upper part of the salt layer in the mining area is mostly dominated by calcareous rocks, which easily cause ground fissures and ground subsidence. Especially after the formation of the mined-out area, the mineral salts will further dissolve and soften, and the top rock cavity and interlayer will easily collapse, posing a great threat to urban safety.

3. Physical property analysis of goaf
The author statistically analyzed the physical parameters of the goaf (Table 1). The quaternary thickness of the goaf is between 24-30 m. The average density of the quaternary layer is 1.65 g/cm³, and the average density of the lower tertiary system is 2.55 g/cm³; the density of the salt mine is 2.25 g/cm³ (stone salt and anhydrous thenardite) and 2.69 g/cm³ (calcium Glauber's salt), the average density of the surrounding rock is 2.55 g/cm³, and the brine density in the goaf is 1.28 g/cm³. Therefore, the density difference produces microgravity anomalies, which provides a physical basis for microgravity to distinguish the goaf of salt mines.

| geologic period | stratigraphic unit | lithology | Number of samples | density (g/cm³) | Average density (g/cm³) |
|-----------------|-------------------|-----------|-------------------|-----------------|------------------------|
| Quaternary Q    | sandstone         | 8         | 2.55              |                 | 2.57                   |
|                 | siltstone, mudstone | 13        | 2.56              |                 |                        |
| Sibu Formation  | E2x^2             |           |                   |                 |                        |
|                 | First             | mudstone  | 8                 | 2.59            |                        |
|                 | E2x^1             |           |                   |                 |                        |
| Lower Tertiary  | E1-2b^3           |           |                   |                 |                        |
| Buxin Formation | Top               | Mortar Rock | 7               | 2.51            |                        |
|                 | Salt              | marlile   | 4                 | 2.42            |                        |
|                 | section           | nagefluih | 2                 | 2.22            |                        |
|                 | Bottom            | salt rock | 4                 | 2.17            |                        |
|                 |                   | Gray mudstone | 6               | 2.55            |                        |
|                 |                   | marlile   | 7                 | 2.60            |                        |
|                 |                   | marlile   | 1                 | 2.53            |                        |
|                 |                   | Gray mudstone | 4             | 2.63            |                        |

4. Microgravity detection inversion results and effect analysis
4.1. Principle of microgravity
The microgravity method takes the difference in density values between underground media as its physical basis, and solves geological problems by studying the value, range, and law of gravity acceleration changes caused by local density unevenness. The microgravity method is not restricted by
human interference such as electromagnetic fields, grounding conditions, and the size of the work site. In addition, the microgravity method has the advantages of simple, low cost, high efficiency, and small interference, which can make up for the deficiencies of other geophysical methods.

With the widespread introduction and frequently use of micro-gal-level high-precision gravity instruments, the measurement accuracy of the instrument has been greatly improved, which can enhance the discrimination ability of tiny detection objects and the recognition ability of low-slow weak anomalies.

4.2. Characteristics of gravity anomaly in goaf

Through data processing, we obtain the Bouguer gravity anomaly data, and draw the residual Bouguer gravity anomaly contours (Figure1). The contour map of the residual anomalies of Bouguer gravity reflects the complex density difference information in this area. The results show that the tectonic trend of the area is northeast, the magnitude of the Bouguer anomaly is about 1.6 mGal, while the anomaly amplitude of the Bouguer gravity anomaly is about 0.500 mGal in the goaf, and the variation of the anomaly amplitude is relatively small. The size of the anomaly gradually increases from the southwest to the northwest, manifested by the low gravity of the salt mining area and basement, but high on the southeast and northwest sides.

Microgravity anomaly features obviously reflect two problems: low gravity anomaly in basement structure and low gravity anomaly in goaf. The density of the mined-out area is obviously smaller than that of the stratum, and it shows a low value on the Bouguer gravity anomaly. The remaining anomaly of the whole goaf forms a gravity low anomaly area on the plane, which corresponds well to the location of the salt mine mining well (Figure 1).

![Figure 1. Contour map of the residual gravity anomaly](image)

Based on the map of different gravity interpretation results, the plane position of the goaf is deduced, and the result corresponds to the 34 different microgravity low anomaly traps in Figure 2.
The anomaly characteristic of the gravity field indicates that the whole gravity low anomaly trap is the reflection of the base of the basin and the Yongtaizhuang syncline. In the southwest of the regional field, there is a north-east-east Sanyuanbian-Zhongmutian-Taihezhuang negative anomaly trap with an abnormal amplitude of about 0.150mGal, the anomalous value varies from -13.800 to -13.950 mGal, and it goes northwest along the main axis. The tilt trend indicates that the Yongtaizhuang syncline was squeezed to form a complex structure in the south near Zhongmutian, which is consistent with the geological view that the Yongtaizhuang syncline's southward and northward depressions are "saddle-shaped structure ".

4.3. 3D residual density inversion
The gravity observation anomaly is mainly caused by the uneven distribution of the density in the underground 3D space, and the 3D density inversion plays an irreplaceable role in the interpretation of gravity data. Totally, 64481 residual density data are obtained by 50×50 mesh calculation. The model is divided into 20 layers and the inversion depth is 1 km. A total of three inversion iterations were performed, and the final inversion mean square error was 0.010 mGal.

![Figure 2. Gravity residual density 3D inversion and interpretation](image)

The 3D inversion results were obtained by selecting different parameter contrasts (Figure 2). The residual density critical value -0.003 and the high and low region proportion factor were selected as -0.5, respectively. The mass missing part of the residual density is the location of the goaf, with depths ranging from about 390 m to 650 m underground. It is concluded that the gravity residual density 3D inversion can completely reflect the fine information such as location of goaf, buried depth of center and spatial distribution. This shows that microgravity technology has an irreplaceable role in the detection and identification of the goaf.

4.4. Refocus weighted inversion
If the underground space is divided into cuboid units with equal size, tight arrangement and uniform density, the gravity gradient tensor observed by each observation point and the density of the unit body can be expressed in linear relation. In the process of focused inversion, in order to obtain the density distribution consistent with the real situation, it is necessary to determine the boundary range
of the model parameters according to the prior information to ensure that the negative density value or
the non-real over-density value in the inversion process is constrained to a reasonable range.

It can be seen in the interpretation diagram of gravity anomaly inversion (Figure 3, 4) that the
location of the mined-out area compared with the surrounding rock shows an obvious low gravity
anomaly. From the 3D inversion results, it can be concluded that the burial depth of the cave is
between 500 m and 800 m underground, the X-direction width range is 1700-2400 m, with a total
length of 700 m, while the Y-direction extends from 1900 m to 2800 m, and the total length is about
900 m. The results are basically consistent with those of residual gravity anomaly inversion and
residual density inversion.

5. Conclusion
The microgravity detection method recognizes and detects the underground space by observing the
weak changes of the gravity field in the study area. In this paper, the microgravity detection method is
applied to the mined-out area of Longgui Saltpeter Mine in Guangzhou, and the following conclusions
can be drawn.

(1) The basis of microgravity method is that there are differences in density between goaf and
surrounding rock, especially in the case of rock mass density change caused by human activities. (2)
The microgravity method is suitable and effective for the urban goaf detection, especially in the large-
area goaf deformation boundary, which can greatly reduce the analysis and calculation of goaf
boundary. (3) Based on the microgravity anomaly information, we found out the location of the
basement and the Yongtaizhuang syncline low gravity anomaly area, and accurately identified the
plane position accurately according to the gravity anomaly distribution of the goaf. The microgravity
method can also identify the gravity anomaly caused by the shallow surface pipeline in the city. (4)
Various gravity inversion methods have shown that the goaf is mainly distributed between 390m and
650m underground, the central buried depth of the goaf is about 490m, and very few parts are close to
the shallow surface or deeper underground.

The application of microgravity method in the detection and identification of goaf and urban
underground cavities is good, which can provide a powerful technical support for the prevention and
treatment of urban geological hazards.
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