GEOPHYSICS, VOL. 65, NO. 2 (MARCH-APRIL 2000); P. 421–425, 6 FIGS.

Case History

The 3-D geometry of the Linglong granitic complex from 2-D gravity forward modeling, Shandong Province, east China

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ABSTRACT

The 3-D geometry of the Linglong granitic complex, Shandong Province, east China, is derived from 2-D gravity forward modeling constrained by geological data. A study of the geometry of the granite body at depth is particularly significant to better understand emplacement mechanisms and to guide gold exploration. The geometry of the granitic complex is analyzed using 2-D gravity forward modeling, constrained by the outcrops of the granites along each modeled profile. Anomalies along the profile were modeled using an interactive program derived from 2-D forward-modeling techniques. The results show the Linglong granitic complex is a sheet-like body of 3100 km^2 in areal extent and a maximum thickness of 8 km. It is not a deeply rooted batholith as previously inferred.

INTRODUCTION

The Linglong granitic complex (Linglong GC) is a rather large granitic body famous in China for hosting the largest gold field. It is a north–northeast-trending elongate body approximately 100 km long and 30 km wide exposed in northeast Shandong Province, surrounded by the Archean Jiaodong Group, the Early Proterozoic Fenzishan Group, and the Late Proterozoic Penglai Group and covered partly by Cretaceous and Late Neogene sedimentary units (Figure 1). Jurassic tectonic events produced a series of north–northeast and northeast thrusts, along which magmatic activities developed, followed by the emplacement of the Linglong GC, which consists of Linglong granite (170–145 Ma), Guojiadian granite (170–145 Ma), Cuizhao granite (possibly Triassic), and Guojialing granodioric (140–135 Ma) plutons (Mao, 1983; Hu et al., 1987; Xu, 1991; Wan, 1992; Chen et al., 1993).

Geological and geochemical research on the main characteristics, petrogenesis, and evolution of the Linglong GC over the last 60 years (Mao, 1983; Sang, 1984; Li et al., 1986; Hu et al., 1987; Wang et al., 1988; Xu, 1991; Chen et al., 1993) has generated two points of view on its petrogenesis. During the 1980s most granite researchers suggested that the Linglong GC was a result of in-situ melting of metamorphic rock (Sang, 1984; Li et al., 1986). However, in the 1990s this view shifted toward a model of migration and emplacement of granitic magma (Mao, 1983; Xu, 1991; Chen et al., 1993).

Determining the 3-D geometry of the granite bodies has important implications for better understanding emplacement mechanisms and for guiding mineral exploration. Among geophysical techniques, the gravity method is the best tool to interpret the 3-D shape of the plutonic bodies (Audrain et al., 1989; Lyons et al., 1996; Améglio et al., 1997). Owing to the large negative density contrast (-0.14 g/cm^3) between the Linglong GC and surrounding rocks comprised of the Early Proterozoic Fenzishan Group and the Archaean Jiaodong Group, a clear correlation exists between the local gravity low on the Bouguer gravity anomaly map and the Linglong GC outcrops. Therefore, the gravity data play an important role in delineating the Linglong GC at depth and offer an opportunity to constrain the shape of the pluton floor.

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Gu et al. (1992) reported the first interpretation of the shape of the Linglong GC from gravity inversion. This report proposes that the Linglong GC likely is a sheet-like body. Our study represents the first thorough investigation of the structure of the Linglong GC. Our recent geological and geophysical work builds on the preliminary work by the Shandong Institute of Geophysical and Geochemical Exploration (SIGGE) in an attempt to better establish the shape of the pluton floor.

The effectiveness of gravity interpretation of the granite structure depends mainly on separating the gravity anomaly attributable to the granitic body from the Bouguer gravity anomaly. Comparing the Bouguer gravity anomaly map with the geological map shows that the local negative gravity anomaly is caused by the Linglong GC. However, the local gravity anomaly from the Linglong GC is masked by regional background produced by deep structures whose trend is unclear. In addition, the gravity anomaly caused by the Linglong GC does not differ greatly in frequency from that produced by other anomalous bodies, so it is very difficult to completely separate the gravity anomaly attributable to the Linglong GC from the Bouguer gravity anomaly using methods based on spectrum analysis. Therefore, the geometry of the granitic complex is studied by using 2-D gravity forward modeling on parallel cross-sections constrained by the outcrops of the Linglong GC.

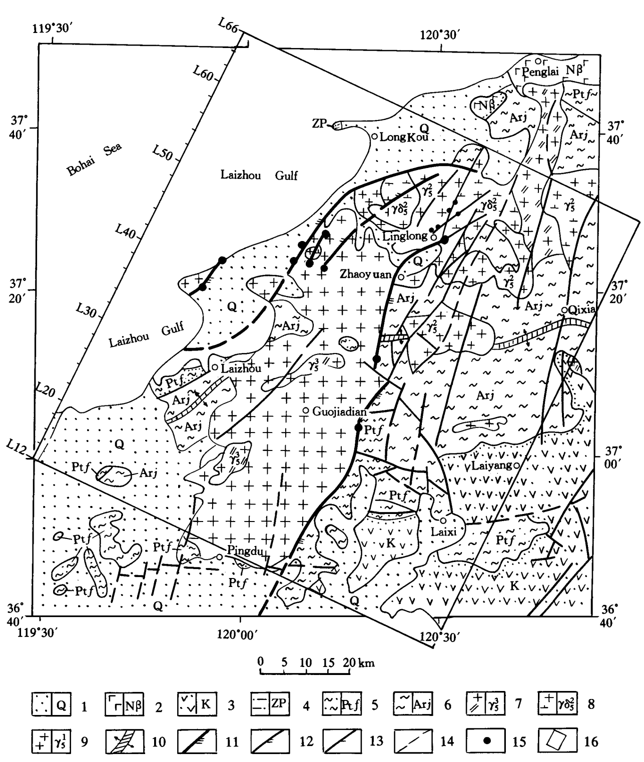

FIG. 1. Map of regional geology in northwest Jiaodong, Shandong Province, eastern China (modified from SIGGE). 1 = Quaternary; 2 = Neogene; 3 = Cretaceous; 4 = Late Proterozoic Penglai Group; 5 = Early Proterozoic Fenzishan Group; 6 = Archaeozoic Jiaodong Group; 7 = Granite-porphyry, Sichuan tectonic event (135–100 Ma); 8 = Guojialing granodiorite, Yanshan tectonic event (145–135 Ma); 9 = Linglong granite, Yanshan tectonic event (170–145 Ma); 10 = axis of complex anticline in Qixia; 11 = major transcompressive fault zones; 12 = secondary transcompressive fault zones; 13 = northeast-trending reverse fault; 14 = faults inferred from geological data; 15 = gold deposits; 16 = area for gravity modeling.

Gravity profiles oriented perpendicular to the elongate trend of the Linglong GC were drawn, and the limit of granite outcrops along each section served as a surface constraint for the model. Each anomaly along the profile was modeled using an interactive 2-D forward modeling program. The application of this method to all the cross-sections allowed construction of a 3-D diagram displaying the geometry of the Linglong GC. A map of the inferred thickness of the modeled source body was also constructed. With this detailed work, we established that the Linglong granitic complex is a sheet-like body and not a deep batholith, as previously proposed.

GRAVITY DATA

The gravity measurements were conducted by the SIGGE in 1982 and 1993 and by the Shandong Geological Brigade No. 2 in 1981 and 1982. Measurements were taken along a square mesh with a spacing of approximately 2 km. The Bouguer gravity anomaly map in this area (Figure 2) was compiled from the original map provided by the SIGGE.

The elevation at each gravity station was measured using a precise baroaltimeter, and the precision of the elevation was better than 1.704 m. The studied region is characterized by smooth topography and subdued relief with plains and small hills. The elevation is typically <100 m, except for an area of about 100 km^2 in the northeast corner of the study area, which presents an elevation around 400 m. Obviously, the gentle topography in the region is beneficial to gravity research.

Density measurements were also carried out by the SIGGE between 1982 and 1986. The average density values for each rock type are as follows (in g/cm^3): Quaternary, 1.74; Tertiary, 2.31; Cretaceous, 2.62; Early Proterozoic Fenzishan Group, 2.79; Archaeozoic Jiaodong Group, 2.81. The Linglong GC was assigned a density of 2.66, and the density variations within the Linglong GC are from 0.01 to 0.02. Thus, the average density contrast between the Linglong GC and surrounding metamorphic rocks is about -0.14 g/cm^3, which generates a distinct negative gravity anomaly.

The Bouguer gravity map (Figure 2) shows a pronounced anomaly of about -18 mGals in relative amplitude and with a minimum of -8 mGal at Guojiadian and adjacent areas. This anomaly is elliptical in shape with a major axis trending north–northeast in the south, changing to an east–west trend north of Zhaoyuan, and a north–south trend north of Qixia county. Two north–northeast gravity gradient zones exist on the two sides of the large negative anomaly. The eastern zone coincides with the Zhaoyuan–Pingdu fault, and the western zone reflects the contact between the pluton and surrounding rocks.

Comparison of the Bouguer gravity map (Figure 2) with the geological map (Figure 1) shows a large closed negative gravity anomaly with axes trending north–northeast, east–west, and north–south that coincides with the exposed part of the Linglong GC. It can be concluded from this coincidence and the density contrast between the granite pluton and the surrounding rocks that the negative anomaly is caused predominantly by the Linglong GC. Consequently, it is possible to interpret the shape of the granite bodies from the gravity anomalies.

2-D GRAVITY MODELING

The main problem in gravity data processing and interpretation is the separation of the anomalies resuting from the body of interest and the Bouguer anomalies. Although the local negative gravity anomaly is caused mainly by the Linglong GC, it is almost impossible to recognize the limits of the negative anomalies attributable solely to the complex. Therefore, a 3-D gravity inversion method cannot resolve the problem easily.

A gravity profile with the outcrops along a direction perpendicular to the north–northeast trend of the negative anomaly through Guojiadian shows a close correlation between the local gravity lows and highs and the outcrop distribution of densities of the various rock types (Figure 3). The gravity low centered at Guojiadian must be caused by the Linglong GC. Obviously, the negative anomaly centered at Gaojiadian with an upper limit of about 25 mGal can be regarded as that primarily resulting from the granite. The limit of the granitic outcrop (Figure 3a,b) along this profile constrained the surface limit of the model. This anomaly is modeled using an interactive program derived from 2-D forward-modeling techniques to illustrate the shape of the pluton on the cross-section.

Digital input of a series of 28 equally spaced gravity profiles, labeled L12, L14, . . . , L66 and drawn perpendicular to the north–northeast major trend of the Linglong massif yielded a gravity-anomaly data set for the interpretation (see Figure 2). These 28 gravity profiles through the pluton were modeled using the program, with the limits of the granite outcrops along each profile serving as a surface constraint for the shape of the low-density body (see Figure 1). The program first built a rectangular shape based on the limits of the outcrops and some extension of the body at depth. Each point that defined the shape

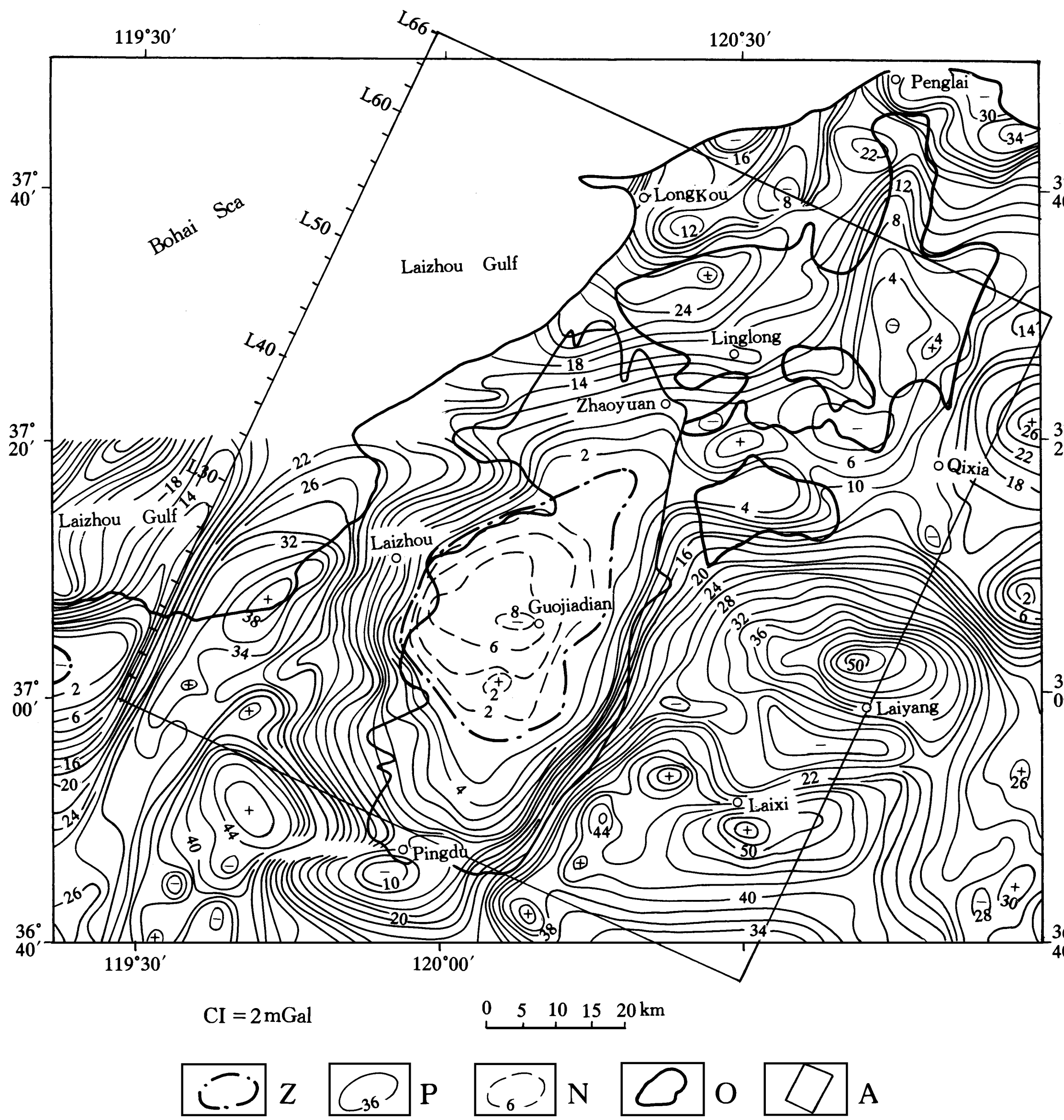

FIG. 2. Bouguer gravity anomaly map in northwest Jiaodong, Shandong Province, east China (compiled after SIGGE). Z = zero anomalies; P = positive anomalies; N = negative anomalies; O = outcrops of Linglong granitic complex; A = area of gravity modeling.

of the structure was modified by hand. The program computed the modification to the calculated fields and automatically drew the resulting anomaly. By successive modification of the model shape, the computed anomaly was fit to the observed anomaly. The computed structure was built iteratively by making one or several bodies, each of them having the same imposed density contrast (-0.14 g/cm^3) relative to a uniform surrounding. On each profile, the regional effect was automatically removed as being a constant value based on the amplitude of the observed anomaly compared to that of the computed anomalies. Interpretation of the successive profiles using this method allowed the definition of a synthetic diagram based on the compilation of the series of cross-sections (Figure 4). Figure 5 displays two cross-sections along the L30 and L60 profiles, which illustrate the geometry of the pluton floor in detail. The data were interpolated in between the series of cross-sections to construct a contour map of body thickness (Figure 6).

Figures 4 and 6 show that a maximum thickness of approximately 8 km is reached near the center of the body. The pluton floor shallows to about 2 km thick to the north–northeast in the area of gold mineralization. The Linglong GC extends westward beneath the country rocks in the form of a gently dipping sheet (Figure 4). Current research on the anisotropy of magnetic susceptibility as well as structural field work suggests that this western sheet may have been a feeder zone, controlled by crustal faults, for the main body of the Linglong GC. In general, we can conclude from our results that the Linglong GC is a sheet with a maximum thickness of about 8 km and an areal extent of about 3100 km^2 and not a deeply rooted batholith, as inferred by many geologists in China.

CONCLUSION

Gravity modeling plays an important role in deciphering the 3-D geometry of the Linglong GC, leading to a better data set to interpret the emplacement mechanisms and the extent of the gold deposits associated with this granite complex. Two-dimensional interactive gravity forward modeling is very simple, visual, and effective to infer the bulk shape of granite bodies at depth, with the aid of the geological constraints as well as density measurements, which are necessary to minimize inherent ambiguity in gravity interpretation. The methods described in this paper are most effective in the special case of the Linglong granite complex, which is characterized by a gently undulating terrain, a pronounced density contrast between the pluton and the surrounding rock, and small variations in density within the granites.

The gravity modeling has defined the shape of the Longling GC and uncovered a west-dipping sheet that may have been the magma feeding zone for the main body, as inferred from structural and magnetic anisotropy work. Therefore, the gravity modeling furthers our understanding of the emplacement mechanisms of large granite bodies and provides a guide to

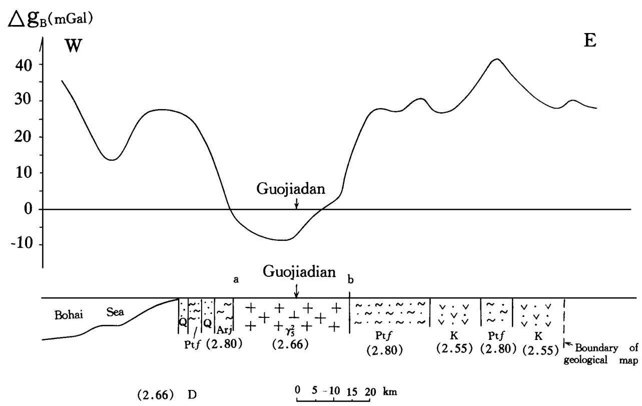

FIG. 3. Integrated gravity and geology profile along L30. D = density, g/cm^3.

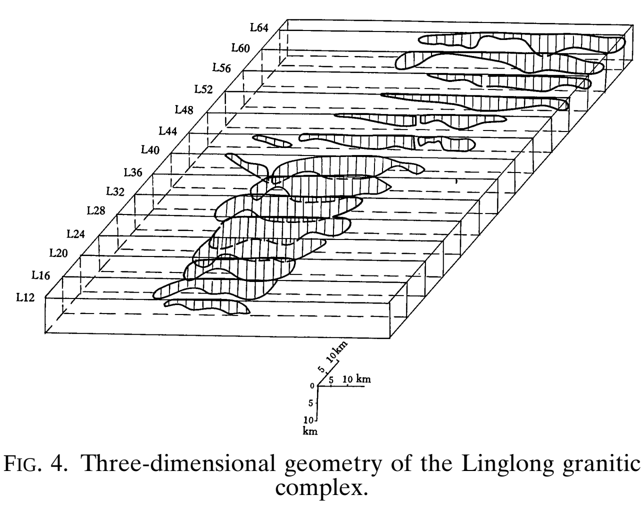

FIG. 4. Three-dimensional geometry of the Linglong granitic complex.

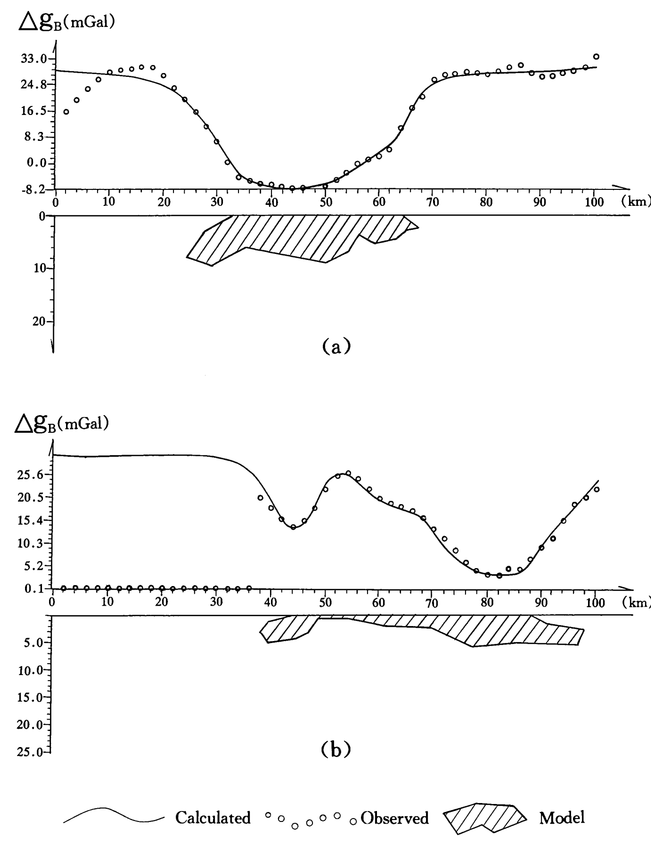

FIG. 5. Two-dimensional gravity forward modeling along L30(a) and L60(b) profiles; $\Delta g_B = 0$ means there is no observed anomaly in this area (see Figure 2).

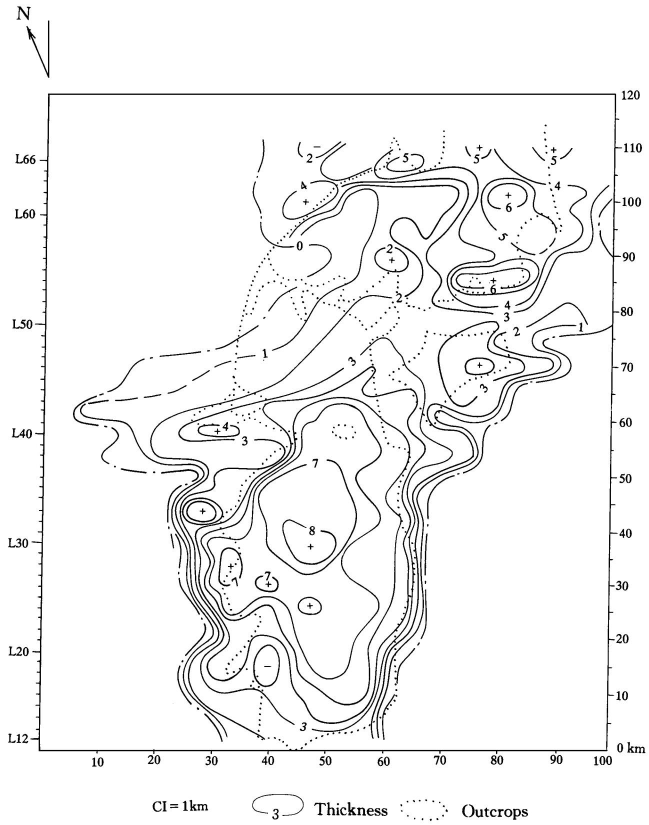

FIG. 6. Thickness of the Linglong granitic complex estimated from gravity data.

exploration for gold deposits associated with this granite complex.

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