On Geophysical Background of Superlarge Deposits in the Chinese Continent

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Abstract Based on the study of tens of geophysical profiles (seismic, geothermal flow and magnetotelluric sounding profiles) and 3-D shear wave velocity structures of the Chinese continent and its neighbouring regions, this paper describes the 3-D crustal and upper mantle structures and discusses briefly the deep geophysical background of superlarge ore deposits in the Chinese continent. Superlarge deposits are usually very few in number, but they are distributed still in certain forms such as "point", "zone" and "area". Most of the large-, medium- and small-sized deposits occur near the margins of different tectonic units; while the superlarge endogenic polymetallic deposits occur mostly in thinned mantle lithosphere, uplifts of the asthenosphere (vertical low-velocity zones) and the transformation zones of lateral inhomogeneity (weak zones) in the upper mantle. The superlarge endogenic polymetallic deposits are almost unevenly distributed in three major ore zones in China, corresponding to the boundaries of inhomogeneous regions in the asthenosphere.

The authors argue that the lithospheric structure is to some extent in agreement with the geotectonic units, suggesting that the crust structure is influenced and restricted by the lithosphere, and that the crust and upper mantle both exhibit low-velocity nature. Therefore, vertical low-velocity zones of seismic waves are considered to be a favourable environment for endogenic polymetallic ore belts.

Key words: Chinese continent, superlarge deposits, mantle lithosphere, asthenosphere

1 Introduction

Seeking for superlarge ore deposits has become an important trend in the exploration of mineral resources in the present age. The International Union of Geodesy and Geophysics (IUGG) put forward the project "Study of the global background of superlarge ore deposits" in 1987 as one of the most important frontier subjects in geosciences of the 1990s. In 1995 IGCP (International Geological Correlation Programme)-354 (1995-1999) was formulated by the IUGS and coordinated by the Institute of Mineral Deposits, subordinate to the former Ministry of Geology and Mineral Resources. As a part of this programme, the study made a marked progress during 1995-1996. A number of new ideas were proposed, which provided a significant basis in further prospecting for superlarge ore deposits in China.

Based on the data of more than 10 geophysical profiles and 3-D velocity structures of shear waves of the Chinese continent and neighbouring regions (Chen et al., 1991a, 1991b; Zhuang et al., 1991; Song et al., 1992; An et al., 1993), the crustal and upper mantle structures and deep geophysical background of superlarge deposits in the Chinese continent are discussed.

2 Structures of Asthenosphere, Mantle Lithosphere and Crust

2.1 Structure of asthenosphere

The asthenosphere is a weak zone characterized by low density (3.20 g/cm^3 on average), relatively low velocity, high temperature and frequent convection. S-wave velocity analysis reveals that S-wave velocity structures (both seismic velocity and asthenospheric thickness) varied greatly between the *continental* and marine asthenosphere in China. The wave velocity of the former is >4.00 km/s (4.00– 4.70 km/s), while that of the latter <4.00 km/s (3.90–4.00 km/s). Their boundary runs roughly along the Chinese coastline. Based on the velocity structure of shear waves, the asthenosphere of the Chinese continent can be divided into two belts and three regions. The two belts refer to the N-S-trending thick low-velocity belt (around 102°E) and the Qilian-Qinling thick low-velocity belt. The velocity ranges from 4.10–4.20 km/s and the thickness is larger than 160 km for the both belts. Bounded by these belts, there are three regions, i.e. the northern thick low velocity region (north of 40°N) with a velocity of 4.10–4.20 km/s and thickness larger than 150 km; the southwestern medium-thick high-velocity region with a velocity of 4.50–4.60 km/s and thickness of 100–140 km; and southeastern medium-thick high-velocity region with a velocity of 4.25–4.45 km/s and thickness of 60–70 km. The first region can be further divided into three parts: the Tianshan–Junggar area, northeastern area and North China area, while the southern region can be divided into the northern and southern parts. Some of these belts and areas match well with metallogenic domains, e.g. the northern thick low-velocity area corresponding to the Palaeo-asiatic metallogenic domain, the southeastern high-velocity area corresponding to the Tethyan metallogenic domain and the Qilian-Qinling low-velocity belt corresponding to the Qinling-Qilian-Kunlun metallogenic domain. In other words, these areas or belts have comparatively homogeneous asthenospheric struc-tures. A striking difference can be seen between the eastern and western parts of the asthenosphere of the Chinese continent. The eastern part corresponds to the west marginal-Pacific metallogenic domain, featuring inhomogeneous asthenosphere. The region to the north of the Qinling-Dabie line has a large thickness and low velocity; while the region to the south is just opposite, which is thinner and has a higher velocity. Only the Precambrian metallogenic domain bears no evident correspondence with the asthenospheric division, which crosses the boundaries between asthenospheric divisions and assumes noticeable inhomogeneity.

China's three belts of superlarge ore deposits are closely related to the boundaries of asthenospheric divisions, where dozens of superlarge ore deposits are almost evenly distributed.

2.2 Structure of mantle lithosphere

The lithosphere is composed of crust and mantle lithosphere. The latter lies beneath the former and is the hardest layer in the lithosphere. It is the major stress-guiding zone of lithological plates and has an average density of 3.30 g/cm^3. The variation of thickness of the mantle lithosphere is not necessarily in agreement with that of the crust. The litho-logical structure of the Chinese continent and its adjacent regions can be constructed by means of analysis of S-wave velocity structures. Remarkable difference in S-wave velocity structure is shown between the continental and the marine mantle lithosphere in China (Fig. 1). Since the velocity data were collected on a 4°×4° grid, the thickness values of the mantle lithosphere shown in this figure may not be exact, but the relative variation is evident.

The marine mantle lithosphere has a wave velocity less than 4.40 km/s (4.20–4.40 km/s), while that of the mantle lithosphere of the Chinese continent larger than 4.40 km/s (4.40–4.70 km/s). Their boundary runs roughly along the Ryukyu Islands. In view of the velocity inhomogeneity, the mantle lithosphere of the Chinese continent can be divided into two belts and three regions as was done in the case of asthenosphere. The N-S-thending thin low-velocity belt (around 102°E) with a velocity of 4.40–4.50 km/s and thickness of 20–40 km; the Qilian-Qinling thin low-velocity belt with a velocity of 4.40–4.50 km/s and thickness of 20–30 km. Separated by these two belts, there are three mantle lithospheric regions: the northern region, featuring low-velocity (4.40–4.50 km/s) and large thickness (50–70 km) with high-velocity measured in some places such as the Tianshan Mountains and Alxa block; the southwestern thick high-velocity region with a velocity of 4.55–4.70 km/s and thickness of 50-70 km; and the southeastern thick high-velocity region with a velocity of 4.55–4.70 km/s and thickness of 40-70 km. The agreement between the mantle lithosphere and the asthenosphere in velocity structure indicates that the inhomogeneity of the asthenosphere affects the deformation features of the overlying lithosphere.

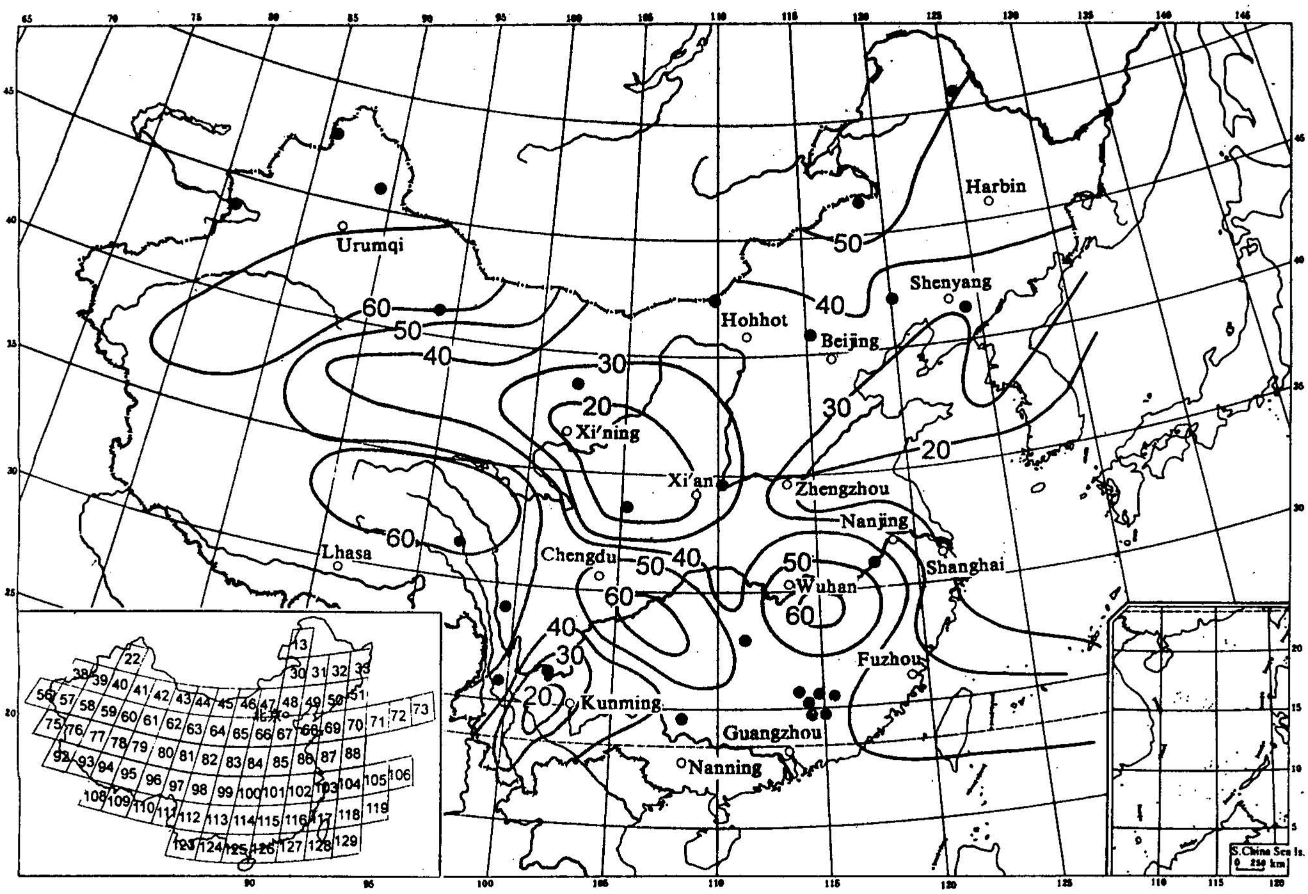

Fig. 1. Thickness of the mantle lithosphere in the Chinese continent (in km).
Superlarge deposits (•) occur mainly in the thinned mantle lithosphere.

2.3 Structure of crust

More striking inhomogeneity and complexity are assumed in the crustal structure, but similar structural characteristics can be recognized to some extent. The form of the Moho is related to large-scale tectonic deformation and the intracrustal low-velocity and high-conduc-tivity layers have control of the features and depths of deformation. Three areas demarcated by a N-S belt characterized by steep variation in crust thickness (around 102°E) and the latitude of 40°N are in agreement with the divisions of the upper mantle. The northern part has a crust with a medium thickness (32–48 km) and the southwestern part has a thicker crust (50–70 km). The crust of the southeastern part is relatively thin (30–40 km) except for a few places in the Yangtze block where the crust might be thicker.

3 Case Histories in the study of Geophysical Background of Superlarge Ore Deposits

3.1 Xicheng lead-zinc ore belt

This ore belt consists of four major metallogenic provinces and two superlarge Pb-Zn ore deposits, i.e. the Changba-Lijiagou Pb-Zn deposit and the Bijiashan Pb-Zn deposit in Gansu Province. Tectonically, the Xicheng ore belt belongs to the passive margin of the northern Yangtze block. The major metallogenic epochs were mainly in the Middle Devonian. The Changba superlarge Pb-Zn deposit is obviously a stratabound one, stretching E-W and controlled by the Danfeng and Shanyang fault zones. A host of ore-forming metallic elements such as Pb, Zn, Ag, Hg, Sb and Au were carried by submarine hydro-thermal

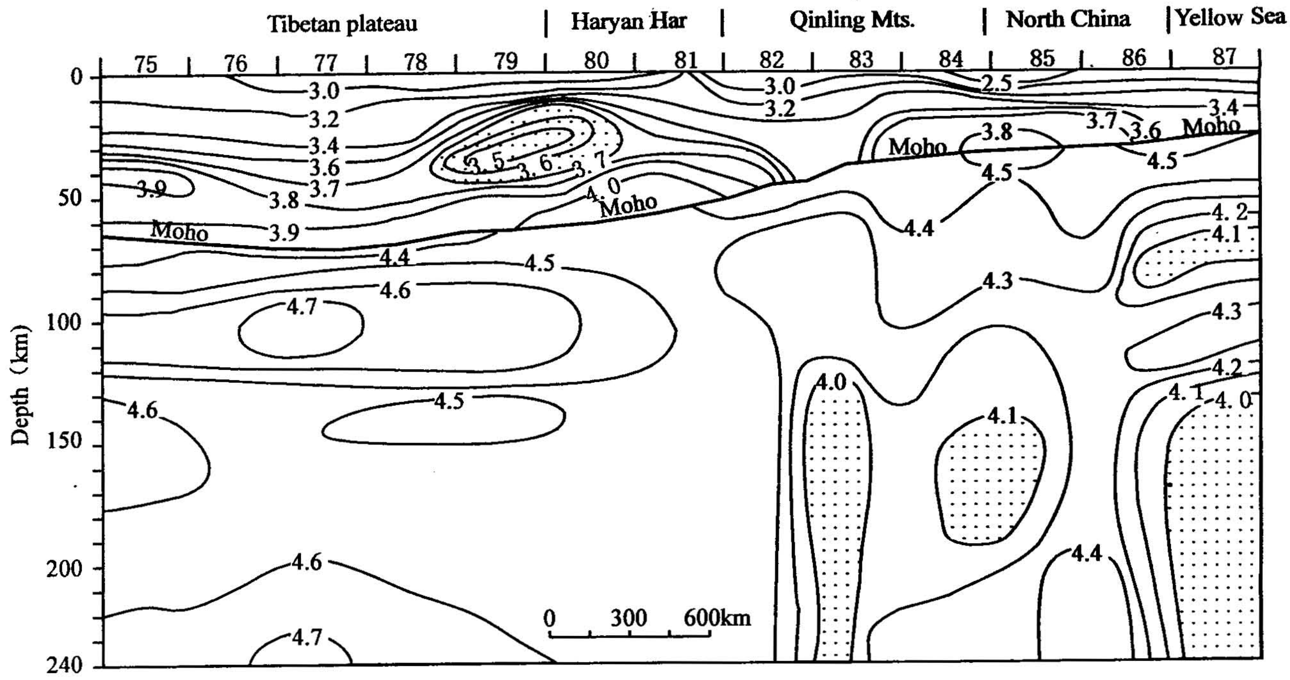

Fig. 2. S-wave velocity model of the crust and upper mantle (in km/s) (Refer to the sheet division in Fig. 1 for the location of this section).

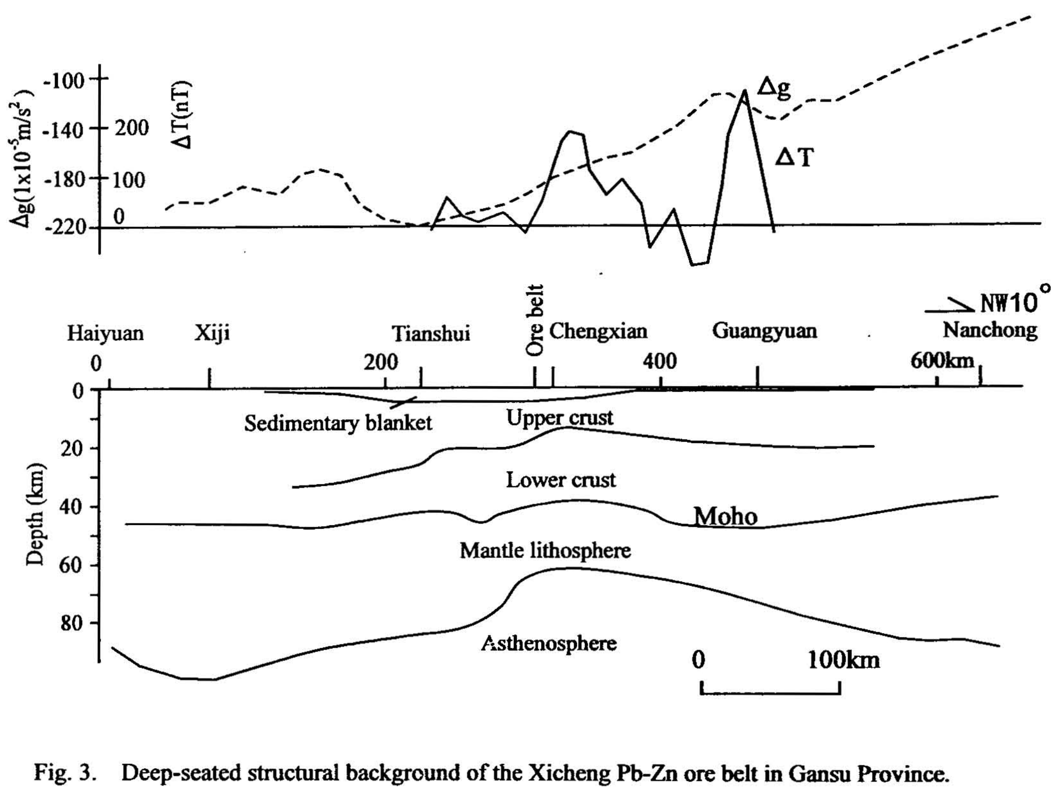

Fig. 3. Deep-seated structural background of the Xicheng Pb-Zn ore belt in Gansu Province.

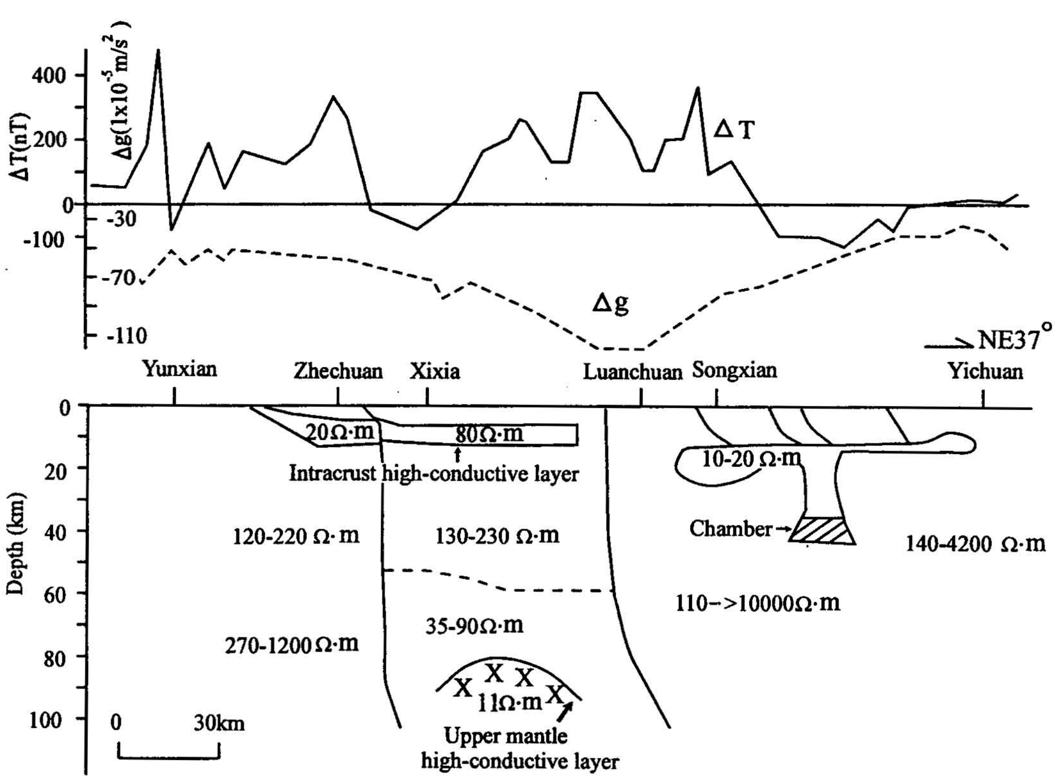

Fig. 4. Magnetic and gravity profiles and inferred electric structure.

solutions and flew upwards to sea-floor sedimentary basins to become hot brine, eventually forming superlarge massive sulphide Pb-Zn deposits hosted in sedimentary rocks in the middle Qinling region (Pei, 1995). The Changba-Lijiagou superlarge Pb-Zn deposit in the western Qinling area experienced rifting during the Caledonian, Hersynian and Indo-Chinese epochs, thus causing accumulation of a great volume of ore solutions. In the southern and northern parts of the ore district outcrop intermediate-acidic rockbodies, but they are not definitely associated with mineralization. The huge heat energy and ore metals for the mineralization most likely stemmed from the depths.

From the S-wave velocity structure of the crust and upper mantle (sheet 82 in Fig. 2 and Fig. 3) (Dong, 1988; Zhang et al., 1993) one can see that the Xicheng ore belt is located in the thinned segment of the mantle lithosphere and the uplift of asthenosphere. This position is at the boundaries not only between the northern and southern, but also between the eaten and western deep-seated structures. To the west there is the high-velocity Himalayan mantle lithosphere, which is rigid and extremely thick with a velocity of 4.40–4.70 km/s, while to the east the low-velocity North China mantle lithosphere, which is relatively soft and thin with a velocity of 4.30–4.50 km/s. The mantle lithosphere in the N-S-trending belt was notably thinned, where the well-developed asthenosphere has a low average velocity. On the MT profile (Fig. 4), a high-conductivity layer is seen between Xixia and Luanchuan in the Qinling fold system and the depth there is 83 km. One can also see an uplift there, which is characterized by thinned mantle lithosphere.

3.2 Kang-Dian (Xikang-Yunnan) axis metallogenic belt

This metallogenic belt lies in the Yangtze paraplatform and there occur many superlarge ore deposits, such as the Panzhihua, Taihe, Baima and Hongge V-Ti magnetite deposits in Sichuan Province. These

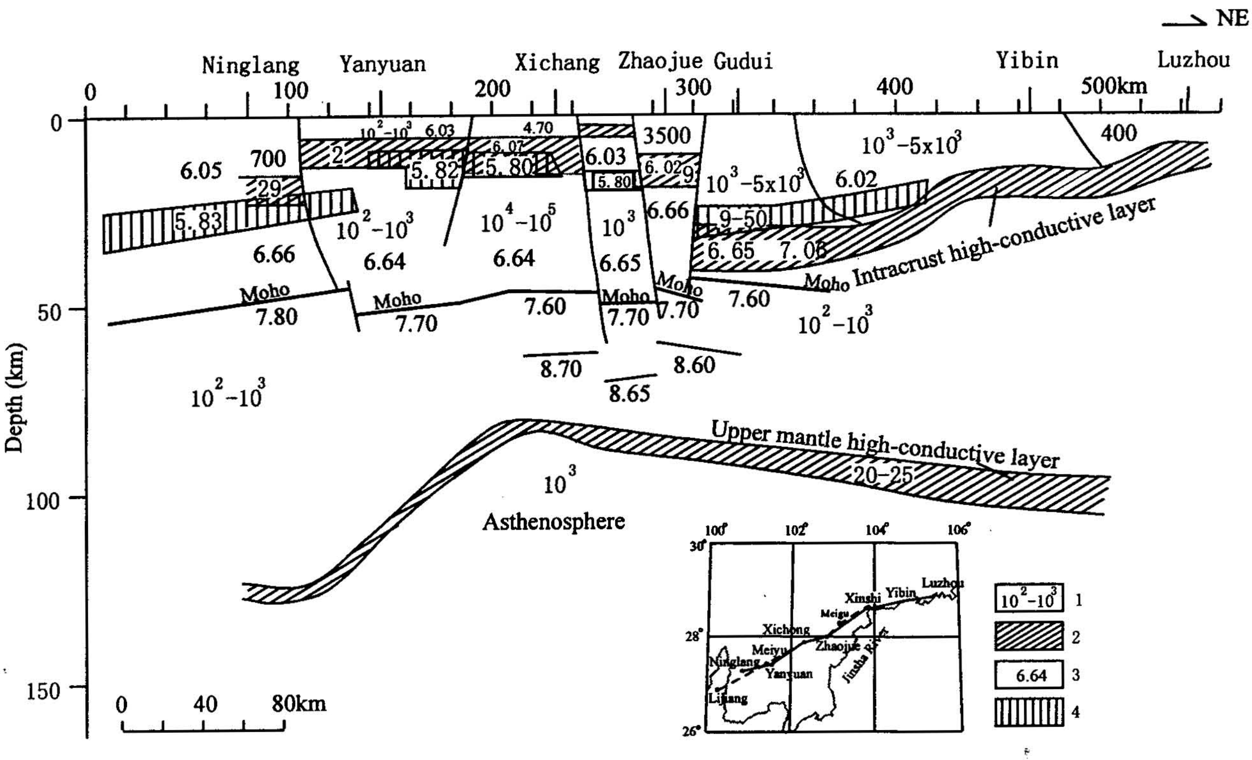

Fig. 5. Electrical structure and P-wave structure of the lithosphere in the Ninglang-Luzhou area.

1. Resistivity (in Ω·m); 2 high-conductive layer; 3. velocity of P-wave (in km/s); 4. low-velocity layer (in km/s).

deposits are mainly distributed around Xichang and Dukou. This area was once an old continental nucleus in the Archaeozoic and rifting took place when the crust was split in the Palaeoproterozoic. The crystalline basement consists of the early Proterozoic-Archaeozoic Kang-Dian complex and the middle Proterozoic folded basement includes the Yanbian, Huili and Kunyang Groups. The Panzhihua, Baima, Taihe and Hongge rockbodies all appear as huge stratified basic-ultrabasic intrusions with large V-Ti magnetite deposits occurring at their bottoms, whose ages are between 300 million a and 200 million a B.P. and which are the product of crystallization of alkali peridotitic magmas. The mineralization took place in mafic or ultramafic rocks of the old land blocks and the occurrence of the rockbodies was controlled by a N-S-striking deep fault zone. The deep fault zone dips steeply and reaches the asthenosphere, cutting the mantle lithosphere. Repeated faulting events caused pulsating invasion of the magmas and controlled the distribution of the rockbodies. During the relatively stable tectonic stages, magmas intruding in the uppermost layer were subjected to thorough differentiation so as to concentrate ore-forming compositions. In this case, the mobile deep-seated fault structure and ore-bearing mantle-derived magmas are the basic geological condition for the ore formation (Pei and Wu, 1993).

The S-wave velocity structures of the study area show that the Kang-Dian axis metallogenic belt is located in the N-S-trending thinned mantle lithosphere and the uplift in the upper mantle, where the crust is 53 km thick and the average crustal velocity is comparatively large (3.60–3.63 km/s). The lower crust here is relatively thick with a low velocity (4.30–4.40 km/s). The asthenosphere of this area (67–74 km in depth) is obviously deeper than areas on its two sides. This N-S-trending belt shows an abrupt change of crustal structure between the eastern and western parts of the Chinese continent. P-wave data show that low-velocity (high-conductivity) layers are well developed and at small depths. Fractured structures and fairly steep faults are characteristic of this metallogenic belt, thus favourable for the upward invasion of magmas (Figs. 5 and 6) (Li and Jin, 1987). This belt has very small Pn values (7.6–7.7 km/s) and thus belongs to an anomalous mantle zone. Seismic sounding data show that the crust has a two-layered structure, that is, a 10 km thick low-velocity layer exists persistently in the middle crust and the lower crust is greatly thickened. The uplift of the high-conductive layer in the upper mantle indicates the rise of the upper mantle and thinning of the mantle lithosphere. The difference of the mantle at different loci results in uneven distribution of the ore deposits in the overlying crust. This belt also features high heat-flow values and the change of mantle heat flows, carrying certain amounts of thermal energy, stimulated various mineralizations, thus serving as one of the favourable ore-controlling conditions.

4 Discussion and Conclusions

The two thinned mantle lithospheric belts readily ascertained in the Chinese continent are in accordance with the N-S-trending low-velocity belt (around 102°E) and the E-W-trending Qilian-Qinling low-velocity belt. They divides the crust and mantle of the Chinese continent into two belts and three regions, which provide a favourable environment for the mineralization. The N-S-trending thinned mantle belt is linked with metallogenic belts of Fe, Cu, Sn, W and rare metals in the Kang-Dian axis region; whereas the E-W-trending belt corresponds to Fe, Cu, Ni, Co, Au and Ag ore belts of the Qilian-Qinling fold system. These two belts have some common characteristics in controlling metallogenesis and are both associated with Fe and Cu and polymetallic ore belts originating from mantle-derived ore solutions. The vertical shear-wave low-velocity belts in the thinned mantle lithosphere and uplifts of the upper mantle serve as a passage way for the upward flow of mantle substances; while the vertical shear-wave low-velocity belts are the boundaries between tectonic regions and also gravity gradient zones and deep-seated fault zones. Uplifting of the upper mantle, thinning of the mantle lithosphere and the upward intrusion of the upper mantle magmas along the vertical S-wave low-velocity belt made the lower crust melted to form structural mobile belts. Ore-bearing solutions migrated along the deep-seated faults to provide sufficient amounts of ore-forming substances. Basic and ultrabasic rockbodies and ophiolite suites are distributed along the vertical S-wave low-velocity belts in addition to some intermediate and acidic rocks. This is favourable for the formation of superlarge deposits of Cr, Ni, Cu, Pb-Zn, Ag and Fe and related polymetallic ores.

To sum up, the geophysical ore-controlling factors of superlarge polymetallic deposits (related to mantle-derived substances) can be summarized as follows.

1. Gravity and magnetic anomaly belts reflecting regional structures in different directions and the intersections of these belts.
2. Deep-seated faults and their intersections, inferred based on the data obtained by means of gravity, magnetic, MT, seismic sounding and geothermal surveys.
3. Weak zones in the crust and upper mantle (vertical low-velocity belts in the geophysical filed).
4. Thinned positions of the mantle lithosphere.
5. Uplifts in the asthenosphere and transformation zones of lateral inhomogeneity of the crust and upper mantle (low-velocity zones). Anomalous mantle (Pn<8.0 km/s) usually exists in such areas.
6. Uplifts in intracrustal high-conductive layers (synchronous with mantle uplifts), where the crust opened to form channels for the rise of magmas.

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