Progress and records in the study of endogenetic mineralization during collisional orogenesis

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Abstract To develop and perfect the theory of plate tectonics and regional metallogeny, metallogenesis during collisional orogenesis should be thoroughly studied and will attract increasing attention of more and more scientists. This paper presents the main aspects of research and discussions on metallogenesis during collisional orogenesis after the development of plate tectonics, and accordingly divides the study history into two stages, i.e. the junior stage during 1971—1990 and the senior stage after 1990. Beginning with the negation of mineralization in the collision regime by Guild (1971), the focus of study was put on whether there occurred any mineralization during collisional orogenesis at the junior stage. At the senior stage, which is initiated by the advance of metallogenic and petrogenic model for collisional orogenesis, scientists begin to pay their attention to the geodynamic mechanism of metallogenesis, spatial and temporal distribution of ore deposits, ore-forming fluidization, relationship between petrogenesis and mineralization in collisional orogenesis, etc. Abundance of typical collisional orogens such as Himalayan, China has best natural conditions to study collisional metallogenesis. Great progress in the study of metallogenesis during collisional orogenesis has been made by Chinese geologists. Therefore, we hope that the Chinese geologists and Chinese governments at various levels to pay more attention to the study of collisional metallogenesis. Some urgent problems are suggested to be solved so as to bring about breakthroughs in the aspects concerned.

Keywords: collisional orogenesis, metallogenesis, study history, progress, frontier.

The purposes of this paper are: (i) to explore together with their colleagues the rules of development of science with an attempt to correctly choose the orientation of research and relevant problems in the future or even in the whole life so as to make contributions with twice the result with half the effort to the scientific cause; (ii) to commemorate those pioneer scientific workers who have made great contributions to the development of scientific cause and encourage their followers; (iii) to expound China's progress in research on the metallogenesis during collisional orogenesis and the obvious advantages of natural conditions; (iv) to appeal the functional departments and colleagues to pay increasing attention to the study of metallogenesis during collisional orogenesis so as to gain more and more in the study of collisional metallogenesis; and (v) to offer a few commonplace remarks by way of introduction so that others may come up with valuable opinions.

To achieve these goals, this paper analyzes first the trend of development of the discipline and on this basis expounds that the metallogenesis during collisional orogenesis is an important scientific problem of common interest. By tracing the study history, the authors describe in detail how previous scientific workers raised the problems and what importance they attached to them, as well as how they chose the objects of study and how they made achievements in research. According to the historic facts, we divided the study history of metallogenesis during collisional orogenesis into two stages, the junior stage and the senior stage and also briefly described the characteristics of each of the stages (e.g. the grounds for the division). Finally the authors put forward a number of problems to be further studied.

1 Importance of the study on collisional metallogenesis to the development of earth sciences

(i) A key to perfect plate tectonics. The development of Plate Tectonics is a century revolution in earth sciences. Scientifically illustrating the structure of lithosphere and the origin of tectonic deformation not only stirs up tight combination among various branches of earth sciences, but permeates intersectly with other disciplines of modern sciences. In the combination and permeation with the different branches of earth sciences and other sciences, plate tectonics is widely proved, accepted and used; and more and more evidence and content of it are obtained. Hence it becomes more vigorous.

Undoubtedly, to look for supporting to plate tectonics from metallogeny or spatial distribution of mineral resources, geologists engaged in tectonic and structural geology should study or discuss the characteristics of ore deposits and their metallogenic mechanism at plate boundaries and inner plates[1—6]. As a kind of plate boundaries, the collision orogenic belt, paleo-geosuture, must be a research focus. Therefore the study of collisional metallogenesis is necessary to the development and perfection of plate tectonics.

(ii) A key to developing regional metallogeny and economic geology. Plate tectonics, the most fundamental theory of modern earth sciences, is also widely used by economic geologists to study regional mineralizations and to improve economic geology[5—13]. In the past three decades, the foci and significant advancements in the research field of mineral deposits are the results of the utilization of plate tectonics. Important models, such as those for porphyry copper deposits, for Kuroko-type massive sulfide deposits, for greenstone-type gold deposits, and for nickel-copper deposits, were established by employing plate tectonics to economic geological studies.

The movement or/and interaction of plates includes four styles, diverging, transforming, subducting and colliding. Intensive mineralizations should occur at these four kinds of plate movements or boundaries. As well known, plate tectonics developed from the study of oceans and continental margins. Mineralizations in oceans and at continental margins have been first studied by appealing to plate tectonics. Since the 1960s, mineralizations in divergent and B-subducting regimes have become research foci in solid earth sciences, and have been understood profoundly. The spatial distributions and metallogenic mechanism of some important types of mineral deposits, e.g. chromite deposits, nickel-copper deposits, diamond-bearing kimberlite pipes, porphyry copper deposits and massive sulfide deposits, have been clearly discovered[13].

It is emphasized that hardly had the geological study of subducting regime gotten breakthrough when the porphyry copper deposit model was proposed by Sillitoe[7], and that the long-term upsurge in exploration for mineral deposits was consequently aroused in the circum-Pacific rim. Relatively, geological process in collision environment was concerned late. The knowledge about collision is very poor, which obstacles us to deal with collisional metallogenesis and its related problems. The mineralizing regularities and the characteristics of related geological process in collisional environment are still unclear up to date[3]. However, to understand the collisional metallogenesis and related petrogenesis and fluidization are essential to developing modern economic geology, petrology and geochemistry as well as to perfecting plate tectonics. Hence it is a great topic open to all the tectonic geologists, petrologists, geochemists and economic geologists.

(iii) An inevitable result of the landing of plate tectonics. The birth of plate tectonics and its successfully application to other related domains of earth sciences encourage scientists impatiently to employ it to study Precambrian and inner continent geological processes and metallogeneses, i.e. so-called "landing" and "restoring ancient", respectively. It should be imagined that some difficulties or disappoints be encountered when plate tectonics is used to cope with geologic problems of inner continents since plate tectonics stemmed from the oceans and continental margins. For instance, a number of geologists use the porphyry copper deposit model for oceanic subduction to interpret the formation and distribution of mineral deposits within ancient intracontinental collision orogens[8—10, 14,15]; most of the Chinese economic geologists prefer to use mineral deposit models for arc environment to explain the formation of large-scale granitoids and mineralization in Southeastern China orogens, Qinling-Qilian-Altin-Kunlun Mountains, and Tianshan-Mongolian-Xing'anling orogenic belt. Now we see that all these explanations are not satisfactory as expected.

It is widely agreed that models or theories suitable to ocean and continental margins cannot be inflexibly applied to inner continents. Since the 1980s continental geology has become a frontier of solid earth sciences and the collisional orogenic belts have drawn even more attention of geologists. Chinese geologists have laid their stress on the collisional orogenic belts such as Qinling-Dabie, Southern China, Mongolian-Xing'anling, Sangjiang-Tibet, Tianshan and Altay, and have made great progress.

A series of breakthroughs in geology of collisional orogens resulted from a large amount of research in the past three decades. Structural geometry, orogenic mechanism and geodynamic process of collisional orogens have been understood profoundly. These results will be immediately utilized by tectonic and economic geologists to study collisional metallogenesis. Therefore we can expect that the 1980s' progress in geological study of collisional orogens will result in breakthroughs in the study on collisional metallogenesis and in exploration upsurge in collisional orogens in the late 1990s and thereafter, just like the achievements in geological studies of B-subducting and diverging regimes in the 1960s leading to breakthroughs in metallogenic study and prospecting upsurge in corresponding environments in the 1970s.

In summary, study of collisional metallogenesis is indispensable to land the plate tectonics or to develop continental geodynamics.

2 Historical records related with the study of metallogenesis during collisional orogenesis

In order to clearly disclose the progress in the study of metallogenesis during collisional orogenesis, the authors present the research events and understanding which are considered to be relatively important.

In 1971, Guild[5] clearly pointed out that in continental collision the two plates could not subduct deeply because of their buoyancy and at the same time, the force was dispersed by strong rupturing. Such collisional events would not lead to the formation of igneous rocks, and hydrothermal deposits are obviously absent.

In 1972, Guild[6] denied again at the 24th International Geological Conference the possibility of metallogenesis in continent-continent collision regime. He held that there were widely distributed the post-Eocene metallogenic provinces in some locations of the Tethysian belt between the Eurasian Continent and the Gondwana Land, and however almost no endogenetically metallogenic province has been reported in other locations. Mineralization seems to be related with the generation of calc-alkaline magmas at the subducting site of oceanic crust that was formed as a result of spreading of the Tethysian Sea. At the last stage of continental collision the two plates would not subduct further and therefore neither magma nor endogenic mineralization would occur.

In 1974, Strong[8] compiled the book "Metallogeny and Plate Tectonics" to explore the distribution of ore deposits in New Finland and introduce the relationship between plate tectonics and metallogeny. Unfortunately, little room was given to metallogenesis during collisional orogenesis. Mitchell[14] found that tin mineralization in Western Europe could not be well interpreted with the model of oceanic subduction. He considered that in southwestern England the granites and relevant tin mineralization were related with magmatism in post-collision tectonic settings. Chappell and White proposed the classification scheme of S-type and I-type granites[16], thus providing the theoretical grounds for distinguishing granites formed in subduction regime from those emplaced in collision-orogenic regime and for the study of metallogeny concerned.

In 1975, Bromley[15] launched a strong challenge against Mitchell who had related tin mineralization in Western Europe with magmatism in collision-tectonic settings, and he held that the formation of ore deposits was genetically connected with oceanic crust subduction.

In 1976, Mitchell et al.[17] considered the Conwall Sn-Cu-U deposit which was spatially associated with Sn-bearing granites in Western Europe was formed in the collisional orogenic environment.

In 1977, Wright[9] compiled the collections entitled "Mineral Deposits, Continental Drift and Plate Tectonics" in which three papers pertaining to metallogenesis during collisional orogenesis were included, two of which denied the hypothesis of metallogeny in collision orogenic regime.

In 1978, Kovalev[4] considered that collision orogenic belts may be the loci of formation of Au, Sn, U, barite and oil/gas deposits. He also pointed out that it is far from enough with respect to the study of collisional belts, especially the mineralizations.

In 1980, Xu et al.[18] proposed a classification scheme for syntexis and transformation granites, relating the syntectic granites with subduction orogeny and the transformed granites with the mobilization and melting of continental crust materials.

In 1981, Mitchell and Garson[10] proposed the relations between Sn or U mineralization in Himalaya, Southeast Asia, southwestern England, Portugal, Namibia and Central France and collisional processes. However, the authors failed to have related metallogeny with collision orogenic mechanism.

In 1982, Miyashiro et al.[3] clearly pointed out in the book *"Orogeny"* (its Chinese version was published in 1986) that continental collision at least caused low-grade regional metamorphism, but whether it could lead to moderate or high-grade regional metamorphism is still uncertain. Little has been known about the character of collision-induced magmatism.

In 1984, Sawkins[11] agreed that the tin-tungsten and uranium deposits in Western Europe (including Erzegebirge-Krusne Hory area) and uranium deposits in Namibia are generated in collision orogenesis, associated with S-type granites. The generation of considerable volumes of anatectic S-type granites is one of the hallmarks of collisional orogenesis. These granitic intrusives are in many instances two-mica granites and usually associated with tin-tungsten and uranium deposits.

In 1986, Tu and Ding[19] pointed out that the Ganpo, Gongguan and other Hg-Sb deposits at the boundary between Shaanxi and Henan provinces constitute a part of the third global Hg-Sb ore belt—the Qinling-Central Asia Hg-Sb metallogenic belt, which was formed during the Yanshanian period. The convergence of the North China plate and the South China plate happened in Triassic time. Chen[1)] classified the long-distance effects of plate convergence as the subduction type, the terrain convergence type and the continental collision type and held that collision could lead to large-scale A-type subduction, granitic magmatism, metamorphism and relevant metallogeny.

In 1987, Hsu[20] described again the crustal structural patterns of collision-orogenic belts and pointed out that collision-orogeny was accompanied with the formation of the collision-type granites (corresponding to the S-type granites) in great numbers while subduction-orogeny was accompanied with the emplacement of the subduction-type granites.

In 1988, Amstutz considered that it was not proper to explain the formation mechanism of Mesozoic hydrothermal deposits in eastern China in terms of Sillitoe's model[21]. Hu *et al.*[22] proposed that the intensive Yanshanian A-type subduction took place in the area of eastern Qinling which resulted in the twin zonation of large numbers of granites and the formation of porphyry ore deposits.

In 1989, Deng[23] presented strong evidence suggesting that the formation of Cenozoic volcanic rocks in the Ali area of Tibet seem to be related with intra-continental subduction and then discussed the relationship between potassium basaltic volcanic rocks and intracontinental subduction[24].

In 1990, Chen[25] established the metallogenic model for collision-orogeny on the basis of the analysis of the rule of element mobilization and transport in the processes of collisional orogeny or of intracontinental subduction (A-type) and proposed that there would appear hydrothermal ore belts, granite batholith belts and porphyry belts in the upper parts of the intracontinental subduction zone. Petrogenesis and metallogenesis occur mainly at the stage from compression to extension (i.e. tectonically reversed stage) during collisional orogenesis. A great wealth of practical data developed from the investigation of gold deposits in western Henan provides evidence confirming that the model is scientific and valid, which can be used to explain the formation and distribution of gold deposits in Henan Province. In the same year, the journal *"Scientific and Technological Information on Gold Resources"* carried the paper pertaining to this metallogenic model. Hu et al.[26] put forward the hypothesis of lateral rock- and ore-forming sources, thinking that quite a number of ore deposits in eastern China are genetically connected with the subduction-collision of the Indo-Australian plate beneath and onto the Eurasian continent. Kerrich and Wyman proposed that gold deposits in Abitibi of Canada and Yilgarn of West Australia are related with the processes of oceanic crust closeness or continental accretion[27]. At the same time, about 200 models of metallogenesis are presented in the book *"Models of Ore Deposits"* (Chinese version) [13], but few of the models is concerned with collisional orogenesis.

In 1991, the metallogenic model for collisional orogenesis was used to interpret the differences in geological setting and metallogenic mechanism for different terrains on the southern margin of the

1) Chen, Y. J., The types and examples of long-distance effects of plate convergence, Abstracts of Graduate Students' Reports at Anniversary of the Founding of Nanjing University on 20 May (in Chinese), Geology Department of Nanjing University, 1986, 12—15.

North China Craton[28] and the rule of gold mineralization in western Junggar, Xinjiang[30]. The model has been fully evidenced[31] and widely accepted[32]1)—4). In the book "*Advances in Geology of Gold Deposits*", Yao5) well documented the metallogenic model for collisional orogenesis, holding that the model represents a new trend and predicts a forthcoming breakthrough in the genetic study of ore deposits. Koons et al.[33] also held that gold mineralization of great importance occurred during the post-collision orogenic uplift process.

In 1992, a large number of examples and a great wealth of geochemical data presented in the book "*Gold Mineralization in Western Henan*"[34] are used to describe the model of metallogenesis in response to collisional orogenesis and its application. This metallogenic model was introduced at the 29th International Geological Conference[35]. Luo et al.[36] interpreted the origin of gold deposits in Henan Province in terms of this metallogenic model. Zhai et al.[37] proposed that the middle-lower Yangtze district is located in a narrow zone sandwiched between the North China Block and the Yangtze Block and their intense Mesozoic collision controls the rock- and ore-forming processes adjacent to the linked zone. Ricard[38] proposed that the formation of the Porgera gold deposit in Papua New Guinia was related with alkaline magmatic activities in the arc-continental collision regime. To study the formation of giant quartz veins in collisional orogens, Kerrich and Feng inferred the nature and types of fluids in collisional regime[39].

In 1993, sponsored by the International Association of Ore Deposit Genesis, the Symposium on Metallogeny in Hercynian Orogenic Belt and Similar Settings was held in Czechoslovakia with the focus on magmatic activities in collision orogenic belts and related metallogenesis. Proceedings entitled "*Metallogenesis of Collisional Orogens*" was published [40]. At the 5th National Symposium on Mineral Deposits of China, Chen[41] put forward a new point of view that the greenstone belt-type gold deposits in China were also formed in the collision orogenic regime.

In 1994, Deng et al.[42,43] repeatedly advocated that there were formed muscovite granites or two-mica granites during collision orogeny or intracontinental subduction. Moreover, they explored in detail the characteristics of the related granites and the dynamic mechanism of their formation. In the same year, Chen6) finished his post-doctoral report at Peking University, entitled "Metallogenesis in collision orogenic regime". His post-doctoral report expounded in detail some problems concerning metallogenesis during collisional orogenesis and explored the relationship between the formation of gold deposits in Qinling, North China Craton, North Xinjiang and other locations and collisional orogenesis, holding that the Yanshanian ore deposits (including porphyry deposits) widespread in eastern China are closely related with Mesozoic collisional orogenesis and the evolution of granitoids in collision orogenic belts involves two series (normal and reversed), i.e. mantle type→ syntexis type→ transformation type→ alkali-rich transformation type→ alkali-rich syntexis type→ alkali-rich mantle type. At the 9th International Conference on the Genesis of Ore Deposits Chen6—8) presented two papers to place the focus on metallogenesis during collisional orogenesis.

In 1995, the Office in Charge of Xinjiang 305 Program presented to the authorities concerned a brief introduction to the main achievements obtained in the project entitled "To speed up the explora-

1) Chen, Y. J., The types and examples of long-distance effects of plate convergence, Abstracts of Graduate Students' Reports at Anniversary of the Founding of Nanjing University on 20 May (in Chinese), Geology Department of Nanjing University, 1986, 12—15.

2)Yao, G. W., Current Situation and Trend in Geological Study of Gold Deposits (in Chinese), Zhengzhou: Henan Institute of Geology, 1991, 137.

3) Guo, K. H., Ideas of exploration for mineral deposits in West Henan, Geology of West Henan (in Chinese), 1991, (1): 37.

4) Luo, M., Wang, H. Z., Nian, G. A., Outline of Gold Deposits of Henan Province (in Chinese), Zhengzhou: Henan Bureau of Geology and Mineral Resources, 1991, 423.

5) Yao, G. W., Current Situation and Trend in Geological Study of Gold Deposits (in Chinese), Zhengzhou: Henan Institute of Geology, 1991, 137

6) Chen, Y. J., Metallogenesis Druing Collisional Orogenesis: Research Results of Several Typical Areas in China (in Chinese), Beijing: Peking University, 1994, 100.

7) Chen, Y. J., Metallogenesis of collision orogenesis: evidence from some typical collision areas of China, Abstract of 9th Symposium of IAGOD, Beijing, 1994, 68—69.

8) Chen, Y. J., Metallogenic geodynamics, time, space and mineralizing model of gold deposits in greenstone belts, China, Abstract of the 9th Symposium of IAGOD, Beijing, 1994, 758.

tion of large-sized precious and nonferrous metal mineral resource bases in Xinjiang" under the State Key Scientific and Technological 85-902 Program for the Eighth Five-Year Plan. In this report it is considered that the most important metallogenic stage is the relax stage following continental collision. This hypothesis is regarded as one of the most important achievements for the State Key Program for the Eighth Five-Year Plan. Chen et al.[44] appealed to carry out research on the relations between fluidization and metallogenesis in intracontinental collision orogenic regime.

In 1996, the first oral presentation at the 9-1 Session of the 30th International Geological Congress was entitled "Metallogenesis during collisional orogenesis in special reference to the study of several typical areas, China". As exemplified by gold deposits in eastern Qinling, the tree-stage evolution model of ore-forming fluids in collision orogenic regime was proposed[45]. It was the first time that the hypothesis was proposed that the skarn-type gold deposits were formed largely during collisional orogenesis[46,47]. In the same year, under the State Key 305 Program for the Eighth Five-Year Plan and the projects supported by the National Natural Science Foundation of China were carried out on fluid activities in collisional orogenic regime in western Tianshan and their metallogenic significance. Shatov et al.[48] stated that the W-Sn-Mo deposits and their associated granitoids in Kazakhstan formed in collisional orogenic settings.

In 1997, at the 26th Young Scientists Forum sponsored by the Science and Technology Commission of China, it was suggested unanimously to put the project "research on metallogeny during collisional orogenesis" onto the list of frontier disciplines of geoscience and it was also appealed to carry out research on metallogeny in the Qinling collision orogenic belt. At the 7th Goldschmidt Conference, Chen presented the paper entitled "Three-stage evolution model of ore-forming fluids in collision orogenic regime"[49,50]. Hu et al.[51] discussed the contribution of intercontinental collision to the formation of gold deposits in the North China Platform.

In 1998, Wang et al.[52], on the basis of many studies, determined that the Mesozoic volcanic rocks in eastern China were formed in 195—75 Ma, mainly within the range of 140—95 Ma. As viewed in space, a "sandwich"pattern is recognized, i.e. calc-alkaline volcanic rock province in the north, shoshonite province in the middle and calc-alkaline volcanic rock province in the south. This provides strong evidence for the contributions of collisional orogeny to the formation of volcanic rocks and related ore deposits. The formation mechanism of volcanic rocks and related ore deposits could not be interpreted merely in terms of Pacific plate subduction. Instead, it is the result of combined action of both giant dynamic systems: (i) the subduction-collision of the paleo-Pacific plate under/onto the Eurasian plate, and (ii) the collision and subsequent extension and tension between the North China plate and the Yangtze plate. From detailed investigations, Lu et al. revealed that the granitoid rocks, gold deposits and relevant fluids in southern Wendeng, Shandong Province all are the result of continent-continent collision[53]. Zhou and Yue[54] attributed the gold-copper deposits in the middle-lower Yangtze area to the collisional compression-extension environment. The existence of syn-collision mineralizations in northern Xinjiang were widely evidenced from various aspects by a lot of geologists[55—60].

Chen et al.[61] have documented in detail the mineralizing geodynamic background of gold deposits in the granite-greenstone terrains of the North China Craton and argued that the gold deposits were formed at the transition stage from compression to extension during the Mesozoic collision between the North China and South China continents. Variations of metallogenic and petrogenic model for collisional orogenesis and their constraints was thoroughly analyzed[62]. The application and its usually encountered problems of the model for collisional metallogenesis was also guided and fully discussed[63].

The project "Fluidization and Metallogenic Effects in Collision Orogenic Regime" was arranged as one of the five second-ordered projects under the pre-selected National Climbing No.39 Program for the Ninth Five-Year Plan "Geological Fluids and Their Metallogenic Effects". Groves et al.[64] pointed out that the so-called mesothermal gold deposits associated with regionally metmorphosed terranes were formed during compressional to transpressional deformation processes at convergent plate margins in accretionary and collisional orogens.

In 1999, Dong[65] discussed the relationships between the metallogeneses and tectono-magmatic evolution of collisional orogens. Wang[66] reviewed the studies of fluidization and mineralization of convergent plate boundaries. Chen et al.[67] discussed the spatial zonal distributions of mineral deposits and granitoids in collisional orogens and their relationship with the fluidization during collisional orogenesis. They again emphasized three keys to understanding metallogenic model for collisional orogenesis, i.e. three-zone spatial distribution (epithermal-mesothermal deposit zone, granite and related ore deposit zone, porphyry and associated deposit zone, three-stage temporal evolution early compression stage, mid transition stage from compression to extension, late extension stage), mineral deposits and granitoids mainly formed in mid transition stage for the intensive depressurized melting or liquidation. They also recommended the value of 35℃/km as the geothermal gradient of the contemporary collisional orogens to study variations of zonational distribution of deposits.

3 Progress in the study of metallogenesis during collisional orogenesis

As viewed from the events listed above, it can be seen clearly that the study history since the emergence of plate tectonics can be roughly divided into two stages, the initial stage from 1971 to 1990 and the senior stage since 1990.

(i) Initial study (or discussion) stage (1971—1990). From the year 1971 Guild[5] denied any metallogenesis and magmatism during collisional orogenesis to the year 1990 Chen[25] systematically documented metallogenesis during collisional orogenesis and related magmatism and began to explore metallogenic dynamics, twenty years have passed. During this period the debate was focused on whether there were formed ore deposits in the process of collisional orogenesis, i.e. some scientific workers considered that there were formed ore deposits in response to collisional orogenesis as advocated by Mitchell[10,14], Kevalev[4] and Sawkins[11], and others held that ore deposits could by no means be formed in collision orogenic regime, as advocated by Bromley[15] and Guild[5,6]. At this stage, research work was only restricted to the scope of preliminary discussion, but did not really touch any aspect pertaining to the rule of metallogenesis during collisional orogenesis and the types of ore deposits. Therefore, this stage should be assigned to the initial study stage of metallogenesis during collisional orogenesis, or to the description stage.

In this stage, the results obtained from studies in structural geology and geophysics were overlooked, and the contributions of intensive horizontal tectonic movement to mineralization were ignored, which may be the reason that the research made less important progress in this stage.

(ii) The senior study stage with the focus on metallogenic dynamics (since 1990). Since the proposal and exemplification of the model of petrogenesis and metallogenesis during collisional orogenesis[29, 31, 34], gold deposits in the North China Craton[34, 41, 51, 53, 61], northern Xinjiang[29,55—60, 68] and Qinling Mountains[25, 31, 34-36, 69], copper-gold deposits in middle-lower Yangtze area[37, 54, 65], some skarn gold deposits and porphyry deposits in eastern China[37, 46, 47, 52, 54, 65], gold deposits in the Abitibi belt of Canada[27, 64], the Yilgarn Block of Western Australia[27, 64], the Ballarat area of Southern Australia[27, 64], the Monte Rosa Lodes area of Italy[27, 64] and the southern Alpine of New Zealand[33], the Porgera gold deposit in Papua New Guinea[38], some hydrothermal ore deposits in Western Europe[40], and some deposits associated with granitoids in Central Asia such as Kazakhstan[48] are all regarded as the result of collisional orogenesis or are genetically connected with collisional orogenesis. At present, scientists have made almost no doubt of the hypothesis of metallogenesis during collisional orogenesis and they have begun to conduct research on metallogenic dynamics, the distribution of ore deposits, metallogenic series, and geophysical and geochemical ore-search indicators. Thus it can be said that since 1990, research on metallogenesis during collisional orogenesis has entered such a senior stage that the focus of study is placed on metallogenic dynamics.

4 Main problems involved in the future study

The facts in hand indicate that in the early 1990s the international geological circles became to realize that metallogenesis during collisional orogenesis was an objective phenomenon. Chinese geologists proposed a definite model of metallogenesis in response to collisional orogenesis and expounded the mechanism of metallogenesis and the distribution rule of ore deposits[25, 29, 34, 35, 49, 50, 62, 63, 67]. Fluidization models advanced by Kerrich and Feng[39] and by Oliver[70] are similar, to some extent, to the model established by Chinese geologists[25, 45, 50].

All the progresses obtained by Chinese geologists are ascribed to the physical conditions richly endowed by nature in China. For instance, the two largest collision orogenic belts——the paleo-Tethysian Belt (also named the Mediterranean Belt) and the paleo-Asian Ocean Belt (also called the Ural-Mongolian Orogenic Belt)[71] pass through the Chinese continent, as are represented by the Tianshan-Mongolian-Xing'anling orogenic belt, the Kunlun-Qilian-Qinling-Dabie-Sulu orogenic belt and the Tibet-Sanjiang (tri-river) orogenic belt, which constitute the most typical, most abundant, most intensive and most complicated pattern of collisional orogenesis in China. In China's collision orogenic belts are widespread syncollisional granites and hydrothermal deposits such as Au, Ag, Cu, Pb, Zn, W, Mo, Hg and Sb deposits, hence providing a number of ideal candidates for study of metallogenesis in response to collisional orogenesis. For this, we appeal to bring into full play the natural conditions of China and make our best endeavors in the study of metallogenesis in response to collisional orogenesis.

On the basis of the current development of geoscience and progress in the study of metallogenesis in response to collisional orogenesis, we think the following problems will become the hot points of research and great breakthroughs will be brought about when they are successfully tackled.

1. The fine geometric structure of collision orogenic belt and the mechanism of compresso-orogenic and extensional uplifts; development of ductile shear zones in relation with tectonism and their controls over the development of ore deposits and rocks.

2. Magmatic activity and magmatic evolution in the process of collisional orogenesis and their relations with the evolution of Earth's dynamic background; the mechanism of magmatogene and its relation with fluidization processes.

3. Fluidization, evolution and dynamic mechanism; contributions of fluidization to magmatism, metallogenesis, metamorphism and tectonic deformation.

4. The generation, migration and evolution of ore-forming fluids and their controls over the localization of ore deposits; conditions for the mobilization, transportation and precipitation of ore-forming materials and their relations with spatial localization of orebodies; relations between the spatial localization of orebodies and the types of ore deposits; relations between ore deposit types and metallogenic series.

5. Mass/energy exchange at various levels within the lithosphere of a collisional orogenic belt; the upward transfer of mass and energy in the lower lithosphere and its controls over the shallow-level tectonic settings and their evolution as well as over magmatic activities, fluidization and metallogenesis.

6. Geophysical surveying and explanation of collision orogenic belts; regionally geochemical mapping and the discovery and explanation of geochemical anomalies; superimposition and transformation of fluids on geophysical and geochemical data (e.g. remagnetization).

7. Structural coupling of collision orogenic belts with basins; spatiotemporal conversion and mass/energy exchange.

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