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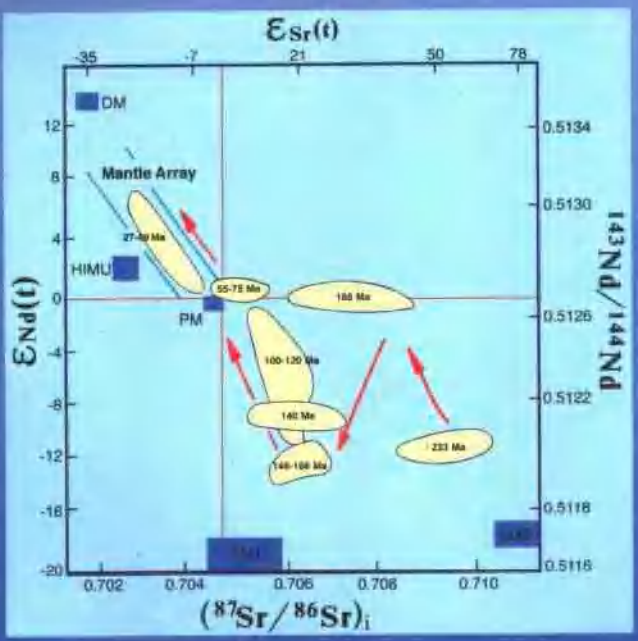
——年代学、地球化学和构造背景

陈义贤 陈文寄 等 著



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序

火山岩作为认识地球深部的窗口，其同位素地质年代学和地球化学等有关研究工作在近二十余年来取得了长足进展，并形成了岩石圈和大陆动力学研究的一个前沿领域，为人类认识地球深部提供了一条相对独立的新途径。

从探讨油气生成和富集规律的目的出发，在辽河石油勘探局陈义贤同志主持下，在辽西及邻区首次全面、系统地开展了中生代火山岩年代学、地球化学和构造背景的研究，本书是在系统总结上述研究成果的基础上编著面成的。

全书突出了多元与多维制约研究的科学思路及严谨的治学精神，在对大量基础数据的分析和处理的基础上，揭示了本区中生代火山岩的时-空分布特征、迁移规律、岩石圈深部壳幔动力学过程及其对区域构造演化控制的宏观规律等一系列具有重要理论意义的新认识。在火山岩年代学方面，采用了多种放射性衰变体系相互对比和制约，综合运用多种不同的等时线处理方法，成功地划分了本区火山岩的喷发旋回，证明了火山活动主旋回期在时-空分布上具有自西向东、由老到新，伴随着构造活动的东移而迁移的规律。而同位素填图、Sr-Nd-Pb 同位素等值线图及多维拓朴分析等同位素地球化学方面的研究，则不仅首次提出了研究区南、北岩区源区特征存在的显著差异，南区与古老华北克拉通基底及古老大陆岩石圈有关，北区则与相对年轻的古生代造山带背景有关的特征，面且证明了火山岩源区特征在时间上由早期富集地幔逐渐转变到晚期的略亏损-亏损地幔为主要组分的规律性变化过程。通过对中生代火山岩组成特征的共性及时空演化规律性的研究，本书明确提出了研究区中生代火山岩是在一个统一的大陆动力学环境下形成的，火山活动-盆地演化特征明显受区域构造运动迁移所控制，火山岩源区特征的时空变迁必然是壳幔深部过程的产物，这一过程同时也控制和影响了岩石圈浅部的地质过程。可以认为，本书是在岩石圈和大陆动力学这一前沿研究领域中十分成功的一个范例。

同时，本书所揭示的中新生代沉积盆地由西向东时代逐渐变新的发育演化历史，对石油勘探也有着重要的指导意义。由于盆地的主要生油层发育在盆地的深陷阶段，因此，随着盆地由西向东的演化过程，石油勘探的主要目的层也就随之由早变晚，这一结论性认识对位于本区的我国第三大油田——辽河油田的勘探开发提供了具有指导性意义的认识，提高了本区油气勘探的目的性，面面具有重要的应用价值，其整个研究的科学思路和技术路线也将会对相关油田的勘探开发提

供有意义的借鉴。

本书不仅对研究区中生代火山岩的年代学和地球化学等方面提供了不可多得的重要基础资料，而且整套科学思路和工作方法、技术路线也将会对这一研究领域的深入开展具有开拓性的指导意义。令人高兴的是，本书的研究是来自辽河油田对探讨油气生成和富集规律的需要，其研究成果又对油气勘探工作有实际的指导意义，因此，本书不仅有重要的科学价值，同时对石油地质工作也有重要的应用价值。我衷心地祝贺本书的问世，并且祝愿同位素地质年代学和地球化学工作能够在实际应用领域中发挥越来越重要的作用。

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Abstract

Volcanic rocks are considered as a window, which could provide the insights into the Earth's interior. Thus a considerable progress research of their isotopic geochronology and geochemistry was made during last twenty years, formed a frontier field for study of lithospheric and continental dynamics, and opened a new relatively independent way to understanding the Earth's interior.

For the purpose of studying the regularities of oil and gas generation and accumulation, a comprehensive and systematic research of geochronology, geochemistry, and tectonic setting of Cenozoic volcanic rocks has been undertaken in West Liaoning and its adjacent areas under the auspices of Chen Yixian, Chief geologist, Liaohe Petroleum Exploring Bureau. The book is formulated just on the basis of a systematic summarizing of the above-mentioned research results.

The region studied (West Liaoning and its adjacent areas) consists of western Liaoning (mainly the western area of Yilan-Yitong-Tanlu fault zone), southeastern part of Nei Mongol Autonomous Region, and southwestern part of Jilin Province. The study region covers a wide area, from east of Linxi-Weichang line to west of Yingkou-Anshan-Fushun line and south of Shanhaiguan Pass, with an area of about 30000km^2 in total. The region is complicated in geological structure, however, it is rich in mineral resources, such as the famous Liaohe Oil Field lies in the region. The Mesozoic-Cenozoic tectonic movements were frequent, volcanic activities were intensive, and the process of formation and evolution of basins is complex. These tectonic activities also provided material sources and tectonic space for formation of various mineral resources and oil-gas fields. Therefore, the research is of great scientific significance in understanding of the characteristics of temporal-spatial distribution and migration of Mesozoic volcanic rocks, features of crustal and upper mantle source regions, and tectonic settings, and hence in further understanding of geotectonic framework of the region, especially the Mesozoic-Cenozoic tectonic framework, the relationship between tectonics and basin formation, as well as the process of oil-gas formation and accumulation. Meanwhile, since the volcanic rocks appear to be a product of rapid eruption, cooling, and consolidation of deep magma on the surface, they are of evident significance in stratigraphical chronology. Therefore, construction and improvement of geochronology of volcanism and stratigraphic sequence are also another important purpose.

On the basis of predecessor's works, a complete and systematically summarizing of the investigation results of geochronology, geochemistry, and tectonic setting for Mesozoic volcanic rocks in West Liaoning and its adjacent areas is made in the book. The isotopic geochronological and geochemical approaches are employed to directly determine the age of

the volcanic rocks, and to study the characteristics of crustal and mantle source regions. In this study, the interdisciplinary approach and multi-dimensional constraint have been emphasized. As in geochronological study of volcanic rocks, multiple radiodecay systems (i. e. K-Ar and ^{40}Ar-^{39}Ar, Rb-Sr and U-Pb methods) were used in comparison and constraint of data to each other and various isochron processing methods were adopted to enhance the credibility of age data of the volcanic rocks. In isotopic geochemical study, an isotopic mapping, Sr-Nd-Pb isotope contour mapping, and multi-dimensional topological analysis method were used to clarify a continuous temporal-spatial evolution process of source region for the volcanic rocks in the region from Mesozoic to Cenozoic time. This essentially provides just an epitome of the deep reconstruction process after block fitting in eastern China completed in the Mesozoic. Under the controlling effec of a unified deep process in the crust and mantle, each stage and every region have shown its own specific characteristics, and distinct regularities in temporal-spatial distribution.

On the basis of understanding of characteristics of different isotopic dating methods (for the Mesozoic-Cenozoic volcanic rocks), we have selectively used K-Ar, ^{40}Ar-^{39}Ar, and Rb-Sr isochron techniques and U-Pb dating method for single minerals to determine the age of the Mesozoic volcanic rocks. Considering the less freshness of Mesozoic volcanic rocks than the Cenozoic, more complicated their components, and the lower apparent age in general, we have used many different isochron techniques of age data, the age data sets of rock samples which are different in apparent age but collected from same site with comagmatic and syngenetic rocks were generalized into one isochron age (meaning that some samples taken in the processing have their similar age). The fact indicates that there were 24 different volcanic eruption episodes in the region obtained by a comprehensive analysis of age data, which were gotten by using isochron and dating methods. It increases not only the total age value about 10 Ma in general, but also discriminates the continuonsly distributed, irregular age data into several volcanic eruption cycles different in time. Therefore, it follows that the research work provides a successful example in discriminating volcanic eruption cycles and in studying regional volcanic eruption history.

The results indicate that the Mesozoic volcanic rocks in West Liaoning and its adjacent areas can be distinguished into five eruption cycles and have their distinct temporal-spatial migration characteristics. From the eruption age data of the volcanic rocks obtained by using the above-mentioned methods in combination with petrological, sedimentalogical, and biostratigraphical characteristics, the Mesozoic volcanic rocks in the region can be divided into five volcanic eruption cycles: (1) Xinglonggou cycle, 180～190 Ma; (2) Lanqi cycle, 170～145 Ma; (3) Xinganling cycle, 145～140Ma; (4) Yixian cycle, 135～120Ma; and (5) Yingchengzi cycle, 120～110Ma. The major cycles of volcanic activity show a clear migration from west to east in time and space and a regularity of the eastward migration accompanied with the eastward tectonic activity. The regularity expresses more strikingly in the southern zone and may continuously extend to the basalt occurring in Lower Liaohe Cenozoic oil

basin. According to this evidence and from the relevant paleomagnetic and paleontological data, a stratigraphical column for the developmental stage of the Mesozoic volcanic rocks in West Liaoning and its adjacent areas was established.

Several two-dimensional isotopic mapping diagrams indicate that the characteristics of source regions in the southern and northern petrological zones of the studied region are significantly distinct and show an evident regular change in time and space. The southern petrological zone is characterized by the enriched Sr, Nd, and Pb isotope composition, i.e. the middle and western partsob sonthem petrological zone are mainly controlled by the mantle enriched in EMI component with local participation of EM Ⅱ component; but the northern zone and the eastern part of southern zone are controlled by undifferentiated to depleted mantle component. Meanwhile, a contamination of crustal material in a considerable amount exists in southern and northern source regions. The characteristics of spatial variation is evidently related with the lithospheric position at which the volcanic rocks are distributed, i. e. the southern petrological zone is related with old North China cratonic basement and old continental lithosphere, while the northern petrological zone is related with tectonic background of the relatively young Paleozoic orogenic belt.

In general, the characteristics of source regions for the volcanic rocks show also a regular change process in time: the earlier stage (180～230 Ma) is characterized by the existence of a subducted oceanic crust and participation of EM Ⅱ after the middle stage (110～130Ma), dominated by EM I type, a late stage represents mainly its slightly depleted to significantly depleted components. Since 110～130 Ma, the composition of source region for the volcanic rocks in southern zone has basically lacked of participation of EM Ⅱ type components. It indirectly indicate that the main block fitting process was completed in the region during this time, and the effect to subducted material and overlying sediments on the genesis of these volcanic rocks reduced down to a subordinate level.

The similarity and the regularity of temporal-spatial evolution of the composition of Mesozoic volcanic rocks in West Liaoning and its adjacent areas reflect the generation of the volcanic rocks in an unified continental dynamic environment. The characteristics of volcanic activity-basin evolution were evidently controlled by the migration of regional tectonics, the temporal-spatial evolution of which shows a clear tendency from west to east, from older to younger, and from enriched to depleted mantle in the source region. It further confirms that the temporal-spatial evolution of source region for the volcanic rocks represents a product of the deep crust-mantle process, which has also controlled and affected the geological process in the shallower lithosphere. Thus, we consider that the book provides a successful example of the research frontier of lithosphere and continental dynamics.

Since the Middle-Late Jurassic (about 160 Ma), geotectonic framework of the region has been strikingly changing, from latitudinal to northeastern orientation, i. e. from a Paleo-Asian domain to a Pacific domain. It reflects that the effect of westward subduction of the Paleo-Pacific Plate has involved the region and caused a partial melting of the enriched man-

tle source in deep lithosphere beneath the old blocks. With the development of the process up to Late Jurassic-Early Cretaceous, a regional extension led to development of extensive volcanic basin and volcanic arc and increasing contribution of depleted mantle components from the source region, which indicafes in gradual reduction of component enrichment degree. The process in the northern zone implies in a gradual transition int depleted mantle components. Up to Late Cretaceous (80Ma), basalt (volcanic rock in Ludong depression-basin), representive of the depleted mantle components, appeared. Since then, the region, especially its eastern part, turned gradually to be an extensional. The alternation of extension and compression led to formation of Cenozoic basins, dominantly the Lower Liaohe basin. This time is a period during which basaltic volcanics are dominant and the components in source region gradually turned to be mainly a depleted mantle, mixed to different degree with old lithospheric mantle. It reflects an assemblage of a series of tectonic features under the specific deep dynamic conditions, such as asthenospheric mantle upwelling, lithosphere thinning, crustal extension, and basin formation.

Obviously, the studies of geochronology, geochemistry, and tectonic setting of the Mesozoic-Cenozoic volcanic rocks in West Liaoning and its adjacent areas have revealed a developmental and evolutional history of the Mesozoic-Cenozoic sedimentary basins, which are gradually younger in age from west to east. This conclusion has a guiding significance for oil prospecting. It is known that the major oil-bearing formation has developed at the stage of basin depression. Thus, in the process of basin evolution from west to east, the major perspective oil beds have also become younger. Therefore, the main objective for prospecting of the oil beds is the Lower Jurassic series in the western basins of the region, the Lower Cretaceous series in the middle part, and Middle-Upper Cretaceous and Early Tertiary series in the eastern part, and hence one can raise the effectiveness of oil-gas prospecting in the region. Therefore, the studies have their practical importance and provide a meaningful reference to relevant oil-gas exploration.

In summary, the studies involved in the book not only resulted in a series of new important theoretical knowledges in the frontier field of the lithosphere from geochronology, geochemistry, and tectonic setting of the Mesozoic-Cenozoic continental volcanic rocks, suggested or enriched and developed the research methods and approaches, such as composite isochron processing of age data, multi-dimensional constraints, and regional isotopic mapping of volcanic eruption cycles, but also revealed a dynamic process in the lithospheric crust-mantle in West Liaoning and its adjacent areas and a macroscopic regularity of its controlling effect on regional tectonic evolution, and hence provide a guiding significance for exploration and development of the third largest oil field in China, the Liaohe Oil Field, and oil-gas resources in its surroundings. This is of an important practical value for oil geologists. The book gives abundant, important geochronological and geochemical data of the Mesozoic-Cenozoic volcanic rocks in the region and a set of scientific thinking ways and working methods which are of a guiding significance for deeper developing study in this field.

It is cheerful that the studies described in the book can meet the requirements to decipher the regularity of oil and gas generation and accumulation, so the results are of practical significance in oil-gas exploration. Therefore, the book has not only its scientific importance, but also potential application in oil geological research.

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