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The Dynamic Process Mesozoic-Cenozoic Igneous in Tibetan Plateau, China

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1. Introduction

Tibetan Plateau, China has intensive magmatic activity with widely magmatic rocks distribution, in the exposed area of about 300,000 km^2. Isotopic dating method has been the most important means in the determination of rock formation age, the inversion of history and mechanism of Tibetan Plateau and the establishment of patterns of magma there. Whereas the most outstanding natural laboratory on the Earth for studying continental collision orogensis (Allegrè et al.,1984; Molnar et al.,1993), investigations on Tibetan plateau have been conducting. The Chinese and foreign geologists had long-term research on geochronology of igneous rocks in Tibet since 1964 when the first K-Ar isotopic age data on Tibet has been published by Prof. Li, who worked in a scientific expedition of Tibet Academy Sciences. Study areas have spanned the various district of the plateau and the means of geochronology are constantly updated with the progress of isotopic dating techniques. However, owing to over 4500 m altitude and poor traffic system, a few areas have are studed, remaining 1,520,000 km^2 to do geological servey before 1999. After 2005, China Geological Survey has conducted the one hundred and one 1/250,000 scale region mapping on the western and the northern Tibet. Consequently, numerous radiometric age data of its magmatisms have been accumulated, including the most acive long half-life period radioisotope dating method, such as the K-Ar, fast neutron activation of ^{40}Ar-^{39}Ar, Rb-Sr, zircon and monazite U-Pb and SHRIMP. It is both important scientific and practical significance to make full use of these valuable data collested from nature condition scurviness areas, clean up and dig out some useful information among them.

It has been shown that the climax and valley of magmatic activity just corresponds to that of tectonic activity and vice versa. Furthermore, the tectonic - magmatic process is often accompanied by relevant metamorphism, mineralization and uplift cooling of geological body or belt. Therefore, the statistical isotopic age data of igneous rocks is the concentrated expression of the geological process, which reflects the regional characteristics of major geological events recorde better than the application of a single age of geological body in some way (Bi et al.,, 1999). The increased isotope age data about its magmatism enable us to identifie the formation and distribution of the main magmatism in Tibetan Plateau and fine a new approach to trace the geology process of Tibetan Plateau.

To this end, the chapter collects the Mesozoic and Cenozoic isotopic age of all kinds of igneous rocks in the Tibetan Plateau from the literature and the latest region geological

survey reports, including 1875 radiometric age data, filtrats them by geological facts and geochronological characteristics, collated and summarized statistically them in regional and by lithofacies. Synthesis the distribution and the frequency of their radiometric age data enable much useful information to be obtained about time and space frames of Tibetan Plateau magmatism, enriching and improving the regional geodynamic process of Tibetan plateau. Therefore, it, conjuncting with some results we got leads us to identify the characteristics of the region distribution of igneous rock of Cenozoic- Mesozoic, and a migration order of Cenozioc volcanic rocks and a sequence of mgmatic-tectonic events in Mesozoic –Cenozoic of Gangese in statistical perspective.

2. Clustering and screening of the previous radioactive ages

Acquisition and application of a large number of Isotope geochronology data provide an important foundation for the division of Tibetan Plateau magmatic stages and comparisons, playing a positive role for broaden the study of Tibetan Plateau from the local to the region associated with global change and even. However, the data obtained from different testing times and researchers, and in different laboratories, by various dating methods are most of the scattered in various Chinese and foreign literature, to serve the limited purpose of the study and areas, and sometimes there are a few contradictions in the data itself. In order to access reliably the Mesozoic and Cenozoic radioactive ages of Tibetan Plateau, we conduct such work as following.

To begin with collection of data from now to previous, we trace the original isotope data as far as possible to determine the characteristics, location, original number of rocks samples and the method used. We eliminate duplication of reporting data, and then review and sort them by these following criteria.

Firstly, we screen the data by geological methods. For example, Luma bridge intrusion at the western part of Gangdise, the existing isotopic age are: K-Ar age of 159 Ma and 72 Ma and U-Pb age of 67 Ma for granodiorite, while 60 Ma K-Ar ages for biotite granite. We don't credit the age of 159 Ma since it intruded into the Lower Cretaceous rocks of limestone and sandstone. We remove 307.5 Ma of zircon U - Pb of tonalite rocks 76-110 from eastern Shiquanhe mass and 289.6 Ma of zircon U-Pb age of Jiangpa granodiorite complex body when statistics since these dating and the surrounding geological age discrepancies.

Secondly, the locations of sampling show that there is a big imbalance in the Tibetan Plateau geochronological study. In the overall point of view, there are more geological dating data along the highway, others are less; and there are more data in middle and eastern Tibetan Plateau, while in western and northern Plateau less, except for some focal research ares, which have significantly more data, such as in the north Hoh Xil, the Ulugh Muztagh, Jingyu lake, the western Ritu pluton and so on. To some extent, it limits the representativeness of the data and the reasonableness of their weight in the statistical calculation. In order to obtain relatively objective results, for the same rock mass, we take any one or two results, if it has the same lithology with multiple measurements and the similar ages. For the large mass, such as the Quxu pluton and so on, five data will be taken. However, a bulky database is still likely to be retained for some large mass since intrusive, especially batholith at Tibetan Plateau general has numerous lithology and are multi-stage intrusion (Regional Geology of Tibet Autonomous Region, 1993).

Thirdly, we generally prefer more recent data that measured to older one in the same geological body regarding the considerable progress in testing technology of isotopic age.

On the same geological bodies with different isotopic age data obtained the screening methods are: U-Pb method of credibility, followed by ^{40}Ar-^{39}Ar method, Sm-Nd method and, finally, Rb-Sr method and K -Ar method. For the K-Ar analys, the dilution method is more accuracy than the volume; and, the results of mineral separates are more reasonable than whole-rock in the same test methods determine. On the other hand, some abnormal data in preliminary study are not optional if the same author does not mention in his later literature.
Fourthly, all data are reserved if there is no reasonableness cause to remove them, such as we reserve the two data of Nyingchi granodiorite rock, which are of 17.7 Ma by K-Ar age and of 154 Ma by U-Pb method. Some of the data are much early-stage work, involving many types of rock, scattered data points (such as the Long County rock), can not take care, so that we keep majority.

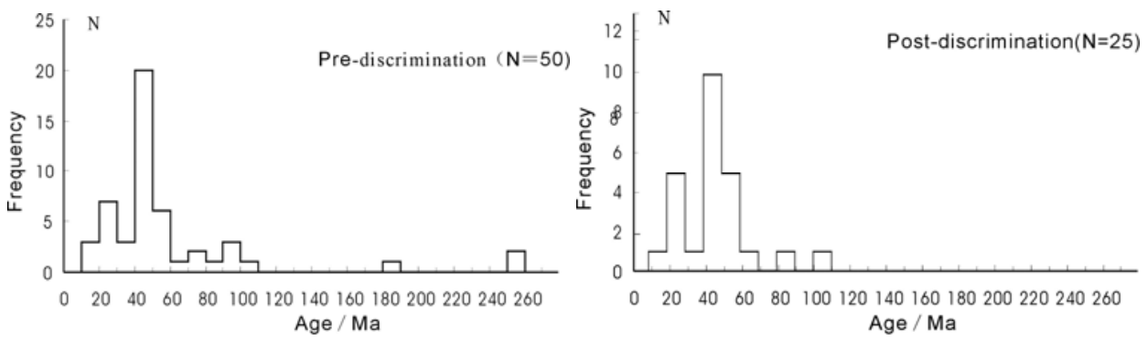


Fig. 1. A comparison of the data of isotopic ages of Quxu granites between pre-and post-discrimination

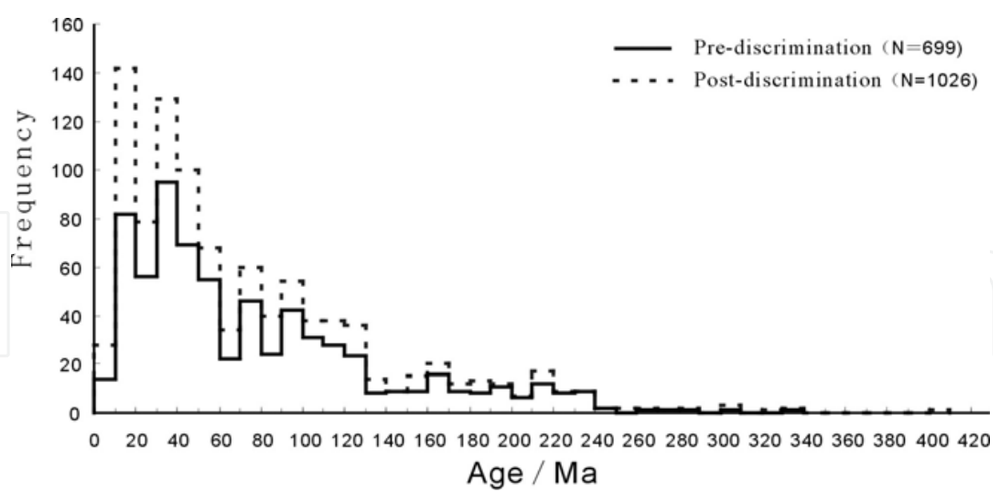


Fig. 2. A comparison of the existing data of isotopic ages of intrusive rocks in the Tibetan Plateau between pre-and post-discrimination

Fifthly, we screening dataset as same volcanic rocks as intrusive rocks. However, since their severe natural environment at Tibetan Plateau, most volcanic cycle and intermittent of the volcanic eruption here are generally unclear. Therefore, the exact location of samples and horizon are difficult to determine at patch distribution volcanic rocks area, resulting in hard

to determine more fully the reasons for taking care of data. In general, we retain any of the similar results at the same region; and reserved all of them if they are in different stage of volcanism, such as: results in Zhonglugu sites at the Southeast Coqing, rhyolites and basaltic volcanic rocks of the determination results were 39.97 Ma and 56.25 Ma, the two are reserved (Xie, et al, 2002).

Consequently, more intrusive rocks data have been removed, but the overall distribution of the data have not formed a big change (Figure 1, 2); when most data of the volcanic rocks and mafic, ultramafic rocks are reserved owing to the absent of adequate causes, leaving no major change in the number of samples (Figure 3).

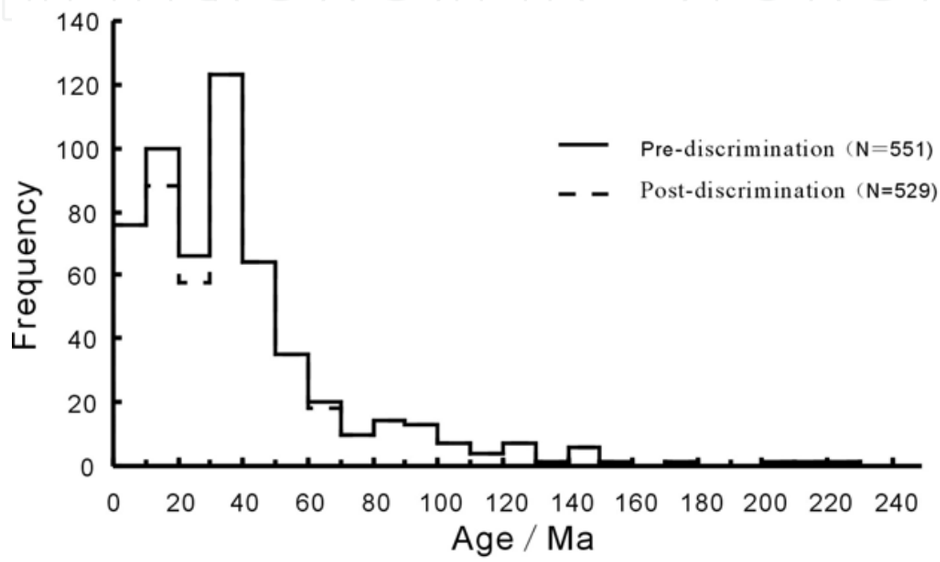


Fig. 3. A comparison of the existing data of isotopic ages of volcanic rocks in the Tibetan Plateau between pre-and post-discrimination

3. Analyses on statistics results

3.1 Overview

Adopted the above criteria, we collected 1916 isotopic age data, inclding the K-Ar method, fast neutron activation ^{40}Ar-^{39}Ar method, Rb-Sr method, zircon and monazite U-Pb method , Zircon ion microprobe mass spectrometry, among which K-Ar method of accounting for 65%, ^{40}Ar-^{39}Ar method of accounting for 17%, U-Pb method of accounting for 11%, Rb-Sr method of accounting for 7%, plus a small amount of Sm-Nd, Neutron activation, fission track law and the data does not indicate the method used in literature (Figure 4a). Among them, the the K-Ar and 40Ar-39Ar dating method are most used (93% for volcanic rocks and 74% for intrusive rocks respectively, Figure 4b, c). However, the results using U-Pb zircon dating method in intrusive rocks significantly increased compared with the results using in volcanic rocks (Figure 4c), which is compatible with the dating methods in different application field. Furthermoer, some of the early determination of the isotopic age data quality is reliable, and the recently completed test results can be compared the age (Figure 5). So that we think previous method of dating is the right choice, which can be used for statistical analysis.

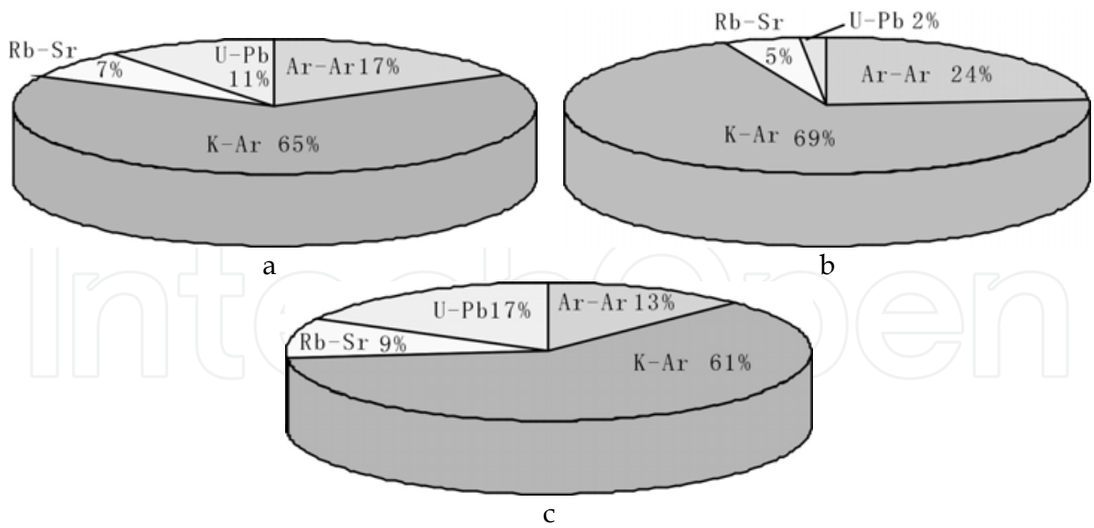


Fig. 4. A sketch map showing various methods of isotopic dating used for igneous rocks in the Tibetan Plateau. a. General drawing; b. volcanic rocks; c. intrusive rock

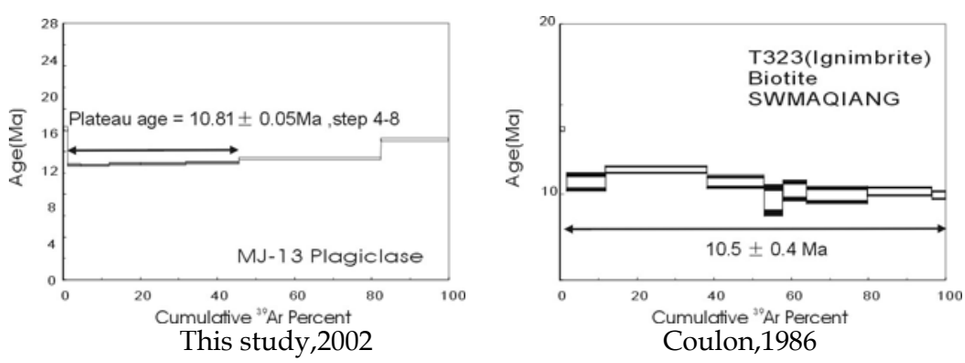


Fig. 5. Results of isotopic dating of the Neogene volcanic rocks in Majiang area, Tibet

3.2 The frequency histogram of intrusion and volcanic rocks

The frequency histogram of the isotopic age after filtering shows that magmatism in Tibet Plateau occures all stage duing Cenozoic and Mesozoic; and it is uneven in different geological periods and various rock types. Overall, however, their value of the intermediate-acidic intrusion and intermediate-acidic volcanic rocks decrease with age, infering the trend of magmatism abviousely intensified from Mesozoic to Cenozoic (Figure 6); Specifically, the frequency value of the isotopic age of the intermediate-acidic intrusive and extrusive volcanic rocks can be divided into two phases, that is 250 - 140 Ma and 140 - 10 Ma; and the former is serrated, without any outstanding peaks and troughs; the latter has a frequency distribution upward oscillation curve towards present and much higher values of total average frequency and maximum. Compare to volcanic rocks, intrusive rocks has longer active period, from 260 - 10 Ma, and can be divided into three stages: 260 - 140 Ma, 140 - 50 Ma, 50 - 0 Ma, with the progressiving frequency value, segment by segment. At 240 Ma, 140 Ma, 60 Ma, and 20 Ma, the frequency of isotopic age of intrusive rock were sudden jump in, with the maximum frequency of the peak ages of intrusive rocks in 50-30 Ma and then, after 10 Ma, the intrusion greatly reduced, turning to silence.

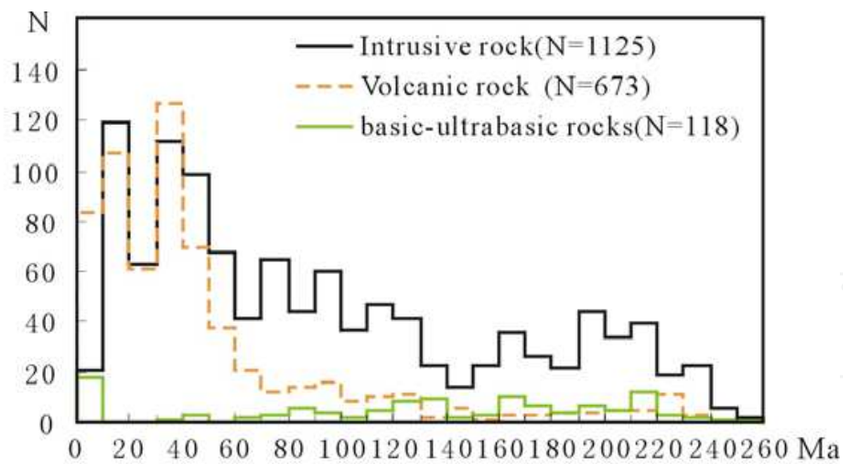


Fig. 6. Histogram of isotopic ages of igneous rocks in the Tibetan Plateau

Regarding volcanic activity, it began later than intrusion one, with a small amount of intermittent appeared since 230 Ma. Ever since 130 Ma, the curve of frequency distribution of isotopic ages of volcanic rocks is slowly rising, and acceleratedly increasing at 70 Ma, forming a summit at 40 - 30 Ma, which the value of frequency of isotopic age is higher than that of intrusive rocks. After that, the value of frequency of isotopic age of volcanic rocks sudden drops into a valley in the 30-20 Ma, and increase again after from 20 Ma to 10Ma, and then slightly decreased and continued to the present. The distribution pattern in statistics diagram that the volcanic activity began later than the intrusive rocks and has so far remained well above the value of the frequency distribution of intrusive rocks may show volcanic lag in response to tectonic events. The frequency of isotopic age of volcanic and intrusive rocks occurred cogradient peak in 50-40 Ma and 20-10 Ma, indicating two strong magmatic activities at the time in the Tibetan Plateau. Mearnwhile there is a significant trough between 30 Ma to 20 Ma in the frequency values of isotopic age of both intrusive rocks and volcanic, reflecting the tendency to ebb and flow synchronously of the strength of both volcanic and intrusive activities Tibetan after 70 Ma-60 Ma at the Tibetan Plateau.

3.3 The frequency histogram of basic-ultrabasic rocks

The change of the frequency distribution of isotopic age of basic-ultrabasic rock is not significant in Figure 6, owing to the total number of samples considerably less than the intermediate-acidic intrusive and volcanic rocks on the total number of samples. We map them separately (Figure 7), and can learn that frequency of the isotopic age of basic - ultrabasic rock of Tibetan plateau distributs generally in two groups, that is 260 Ma - 40Ma and 10 Ma - 0 Ma. In the diagrame, basalt aged from 10 Ma –0 Ma are all restricted to Tengchong, eastern Tibetan and the ages between 50 Ma and 40 Ma of them confined in south of Yarlung Zangpo and North of Longmuco-Shuanggou-Lancangjiang suture while other ages of basic-ultrabasic rock distributes in diversity regions of Tibetan plateau. In 220 Ma, 180 Ma, 140 Ma and 90 Ma, respectively, the values of the frequency distribution of isotopic age in the second sector of basic-ultrabasic rock activities appear comparatively high, demonstrating that the periods of basic-ultrabasic upsurge. On the whole, they wear off with time and reach to zero, infering that the collage of terranes developed and has ceased since 60Ma.

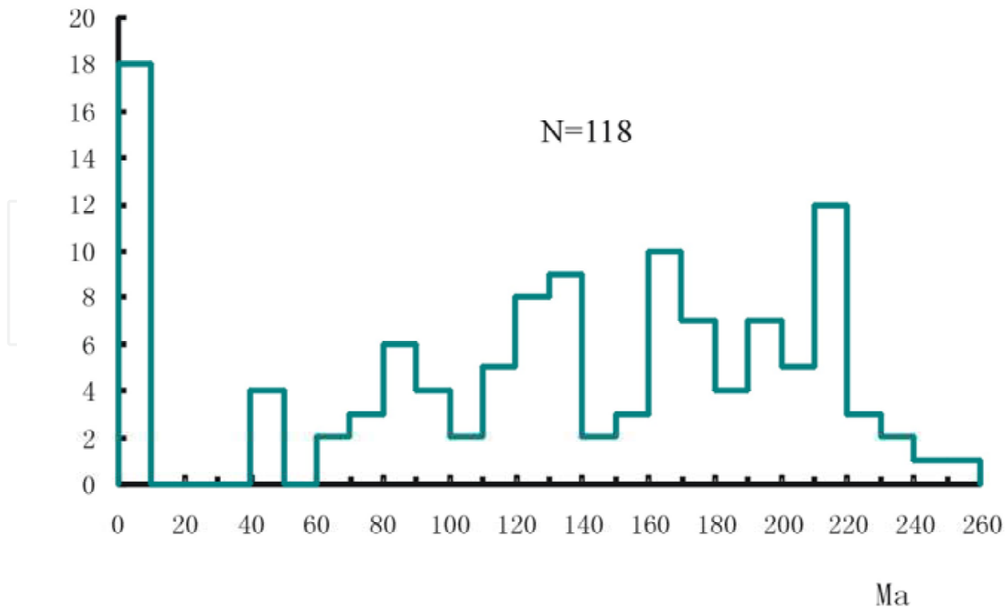


Fig. 7. Histogram of isotopic ages of basic-ultrabasic rocks in the Tibetan Plateau

4. Analyses on statistics results

4.1 Regional geological

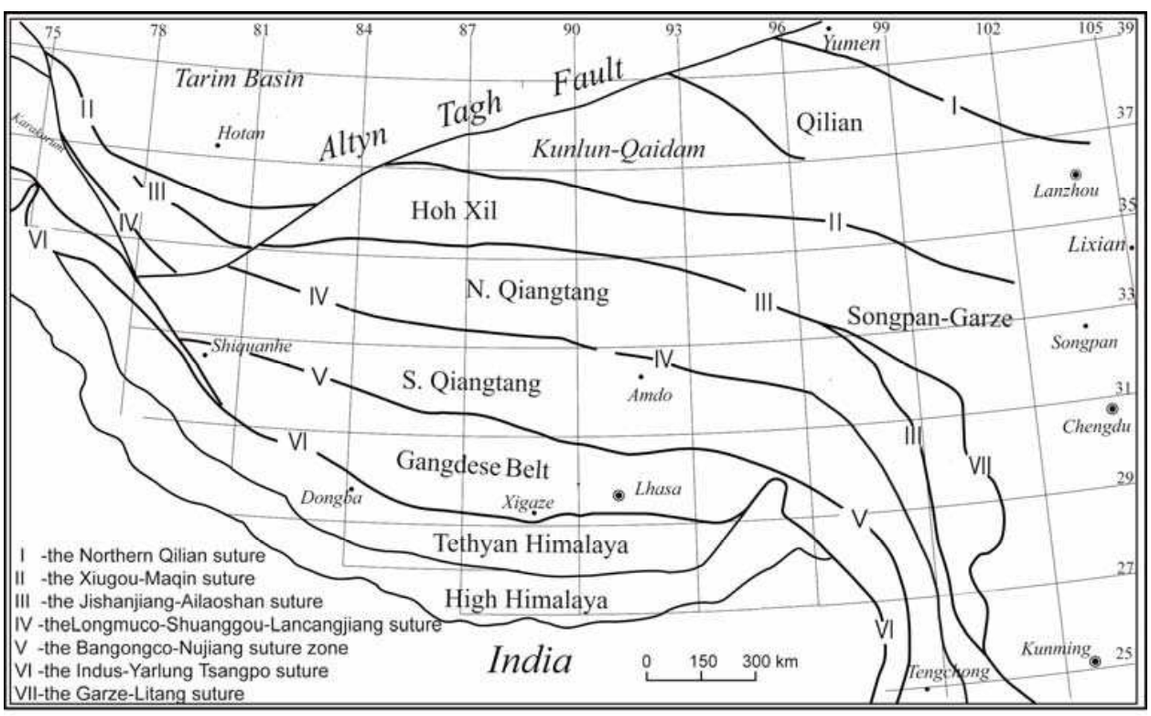


Fig. 8. Outline map to show the main crustal blocks, suture zones and faults in the area of the Tibetan Plateau simpled from the 1:250,000 scale geologic map (Pan et al., 2004)

Despite the appearance of the plateau as a single geological entity now, the Tibetan plateau represents a collage of terranes, each reflecting its own distinct geological history (Wang and Mo, 1995). There is a close relationship between the formation of igneous rocks and the tectonic events caused by plate movement, such as the multi-period ocean crust subduction, continent – island arc and continent – continent collision and the intra – continental convergence (Figure 8). Therafore, We review and analyze our collected isotope dating data by intermediate-acidic intrusive rocks, intermediate-acidic volcanic rocks and basic - ultrabasic rocks from north to south of Tibetan Plateau, that is the west Kunlun, Northern Tibetan, Gangdise and Himalayan belt (including the Transhimalayan and highe Himalayan), and eastern Tibetan Plateau in order to find a possible link between the formation time of igneous rocks in different regions and these tectonic feature and ophiolite zone.

4.2 Intrusive rocks

The frequency distribution in the isotopic values of Mesozoic-Cenozoic intrusive rocks in the Tibetan Plateau is shown in Figure 9. It demonstrates that the intrusive activities of entirely plateau have two period with an apparent lull between 150 -140 Ma. The frequency values of 260 – 150 Ma are lower than that of 140 – 10 Ma. Among of them, the intrusive activitise of eastern Platean and west Kunlun was more intensive than other areas during Jurassic-Triassic period while the most activity area changed to Gangdese during Cretaceous and Cenozoic. The highest values of frequency of isotopic ages appear in Triassic instrusive rocks of eastern Platean and in Cenozoic instrusive rocks of Gangdese, reflecting the diversity central related geologic associations. Regard as Cenozoic intrusive rocks in the eastern Tibetan Plateau, isotopic age frequency is higher than Mesozoic ones and has a isolated peak of 40 Ma-30 Ma. Soon afterwards, the intrusion of magma of eastern Tibetan Plateau tumble rapidly down and almost complete ceases after 10 Ma, infering a shor-lived and large-scale intrusive activity.

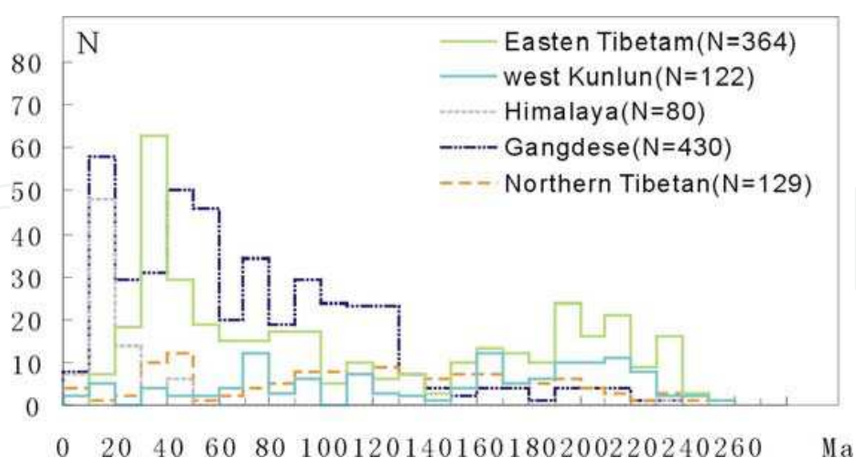


Fig. 9. Histogram of isotopic ages of intermediate-acidic intrusive rocks in the Tibetan Plateau

During the 240-150 Ma, in Gangdise belt, the frequency of isotopic age values of intrusive rocks are distributed and low in value, without too much significant change except for slighly rising tendency; Since then, the frequency of intrusion ages of Gangdese upsurges

and evolves toward a "climactic" caldera-forming atage until 10 Ma. Then, it drops as low as the value as 130 Ma ago; During this section, the frequency of isotopic age of intrusive rocks at Gangdese apperas four peak periods of 20 - 10 Ma, 60 - 40 Ma, 80 - 70 Ma, 1 3 0 - 90 Ma, with gradully growing numbers and summist at interval 60 - 40 Ma and 20 –10 Ma, corresponding to the subduction of India plate and the collision of India-Asia (about 65 Ma).

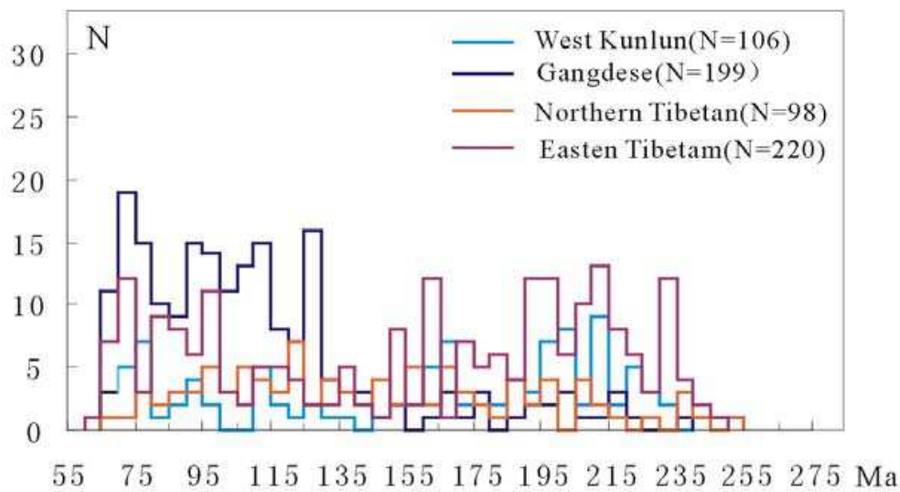


Fig. 10. Histogram of the frequency of over 65 Ma intermediate-acidic intrusive rocks in the Tibetan Plateau

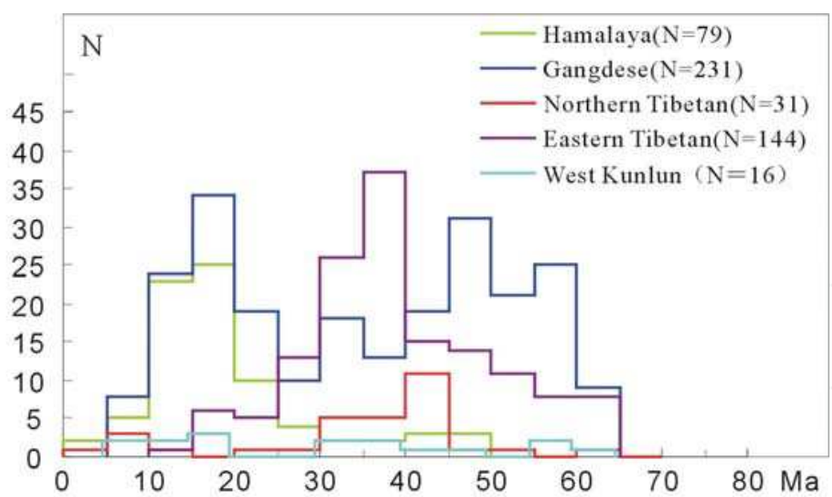


Fig. 11. Histogram of the frequency of less 65 Ma intermediate-acidic intrusive rocks in the Tibetan Plateau

Mesozoic-Cenozoic intrusive rocks wildly spread in the notthern Tibetan and west Kunlun with totally lower frequency of isotopic age, inferring smaller intensity. However, contract to the notthern Tibetan, the frequency of isotopic age in the west Kunlun attenuates from Mesozoic to Cenozoic. We conjecture that an influence of the India-Asia collision weaken

from south to north. Apart from a data of Kangmar gneissic dome, the isotopic ages of Himalayan intrusive rocks appear only after 50 Ma, concertrated between 20 Ma and 10 Ma, which imply a post-collsion tectonic activity.

We rescale the frequency of isotope dating of intrusive rocks and get two histograms in order to facilitate a comparison in diverse pool. It shows that the active area of intrusive activities turning from the west Kunlun and eastern Tibetan Plateau to Gangdese since 135 Ma. During Crateous, the numbers of eastern Tibetan remains higher while the one of west Kunlun becomes smaller (Figure 10). The frequency histogram of isotope dating of Cenozoic intrusive rocks reveals that there are three distinguished intrusive activities during, there are 40 - 30 Ma for eastern Tibetan, 20 -10 Ma for Gangdese and Himalaya(Figure 11). Therefore, we infer that Cenozoic intrusive activities of Tibetan Plateau migrated from Gangdese to northern and eastern Tibetan, and then returned to Gangdese and to Himalaya. The transition period appears between 30 – 25 Ma, revealling another turning time of the statues of Tibetan lithosphere.

4.3 Volcanic rocks

The hisgram of frequency of isotopic age of Mesozoic-Cenozoic volcanic rocks (Figure 12) seems clearly distribut of small number 150 Ma ago, indicating an inferior volcanism at Plateau then. However, volcanic activity increased since 130 Ma in Gangdese, and started a steadily upward stage, with a large peak at 60-30 Ma iinterval; After 60 Ma, the frequency of isotopic age of volcanic rocks in Northern Tibetan elevated and went up to a higher numbers, with the curve being asymmetric Normal distribution and the peak at 20-10 Ma.Additional, The frequency distribution of isotopic ages of volcanic rocks in the eastern Tibetan Plateau and in west Kunlun also forrm a big independent summit in 40 –30 Ma and 10 Ma to presant respectively. In general, Cenozoic volcanic activity has much more intensty than Mesozoic one. Consequently, we depict divide the data in two kinds of scales in order to review them separately.

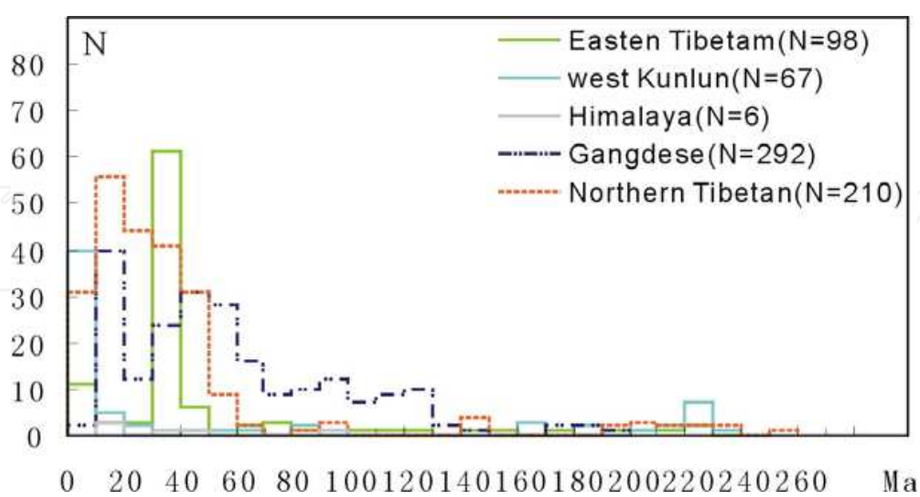


Fig. 12. Histogram of isotopic ages of intermediate-acidic eruptive rocks from various regions in the Tibetan Plateau

Volcanic activies occurs in differ part of Tibetan except for Gangdese and Himalaya during Triassic, with higer numbers of isotope age in west Kunlun and northern Tibetan.

Meanwhile, the frequency of isotopic ages of volcanic rocks of west Kunlun between 230 – 220 Ma forms the highest peak of Mensozoic volcanism in the Plateau. Besides Himalaya, Jurassic volcanic rocks scatter intermittently in Tibetan Plateau in low numbers of isotope age with summit of 150 – 140 Ma in northern Tibetan. Since Cratecous, the frequency of isotopic ages of volcanic rocks of Gangdese has much high numbers than others, implying the consequence of subduction of Indan plate. Meanwhile, the frequency of isotopic ages records the widespread presence of volcanic activites in East Tibetau, and separated in west Kunlun and Northen Tibetan; both are in low low numbers (Figure 13).

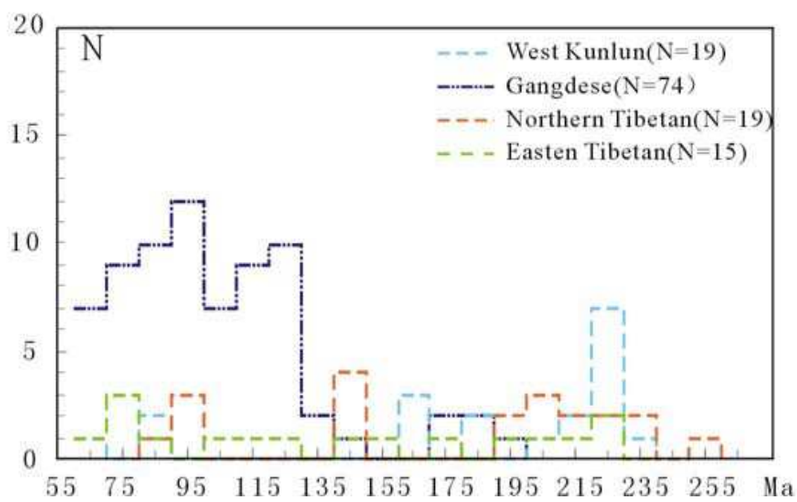


Fig. 13. Histogram of the frequency of over 65 Ma intermediate-acidic extrusive rocks in the Tibetan Plateau

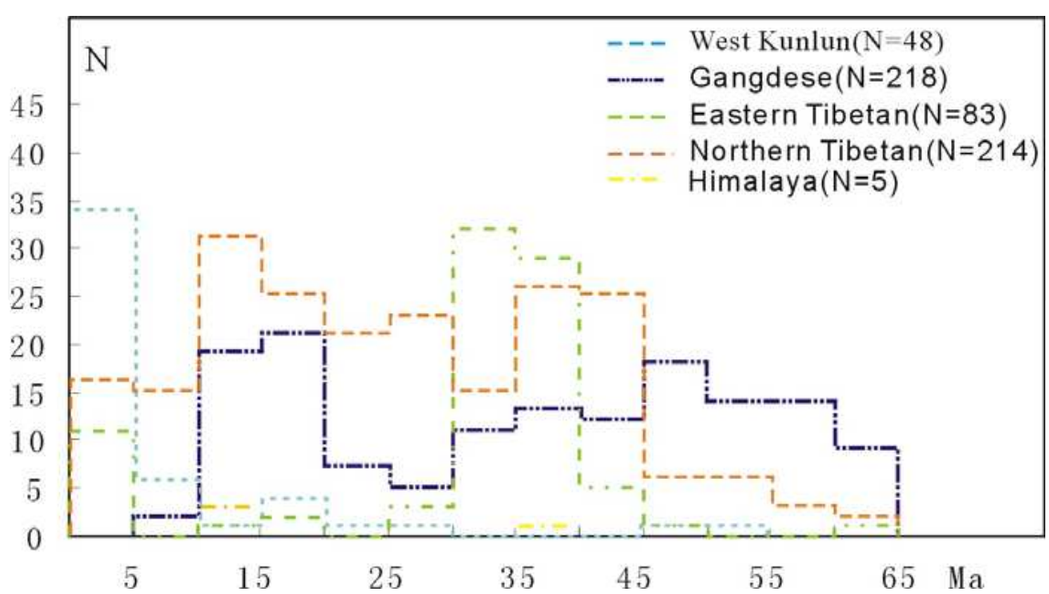


Fig. 14. Histogram of the frequency of less 65 Ma intermediate-acidic extrusive rocks in the Tibetan Plateau

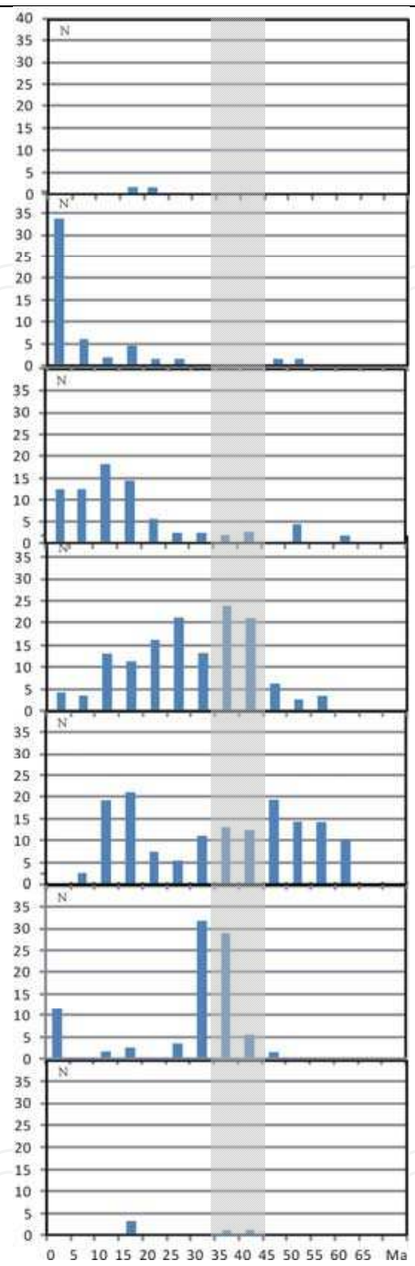
Tibeatn Plateau has fairly violent volcanism in Cenozoic period, with diversity centers in the process of time. Since 65 Ma, volcanic activity in Gangdise proceeded with higher intensity until 30 Ma. The frequency of isotopic ages of volcanic rocks in Northern gradual enhances and attains a higher numbers. At the moment of 45 Ma, frequency far outnumbers the one of Gangdese, indecting that a transfer of the center of volcanic activity. Volcanism of eastern Tibetan oncentrated between 40 Ma and 30 Ma, while was very feeble in other times with only intermittent and a small number of frequency, demonstrating volcanicbeing short-lived and high intensity characteristics there. Analogous pattern appears in the frequency of isotope dating in west Kunlun. Its large-scale, short-lived and high-intensity volcanic activity emerged in 5 - 0 Ma with intermittent distribution at any other time of Cenozoic. The histogram of the frequency of isotope ages reveals that the upsurge of volcanism of eastern Tibetan correspondece to the trough of Gangdese and Northern Tibetan, while the upsurge of volcanism of West Kunlun steps at the period of the trough of another regions. It is seems there is a complement intensity.Turning point in the two stages of volcanic activities is between 35 - 30 Ma and 5 – 0 Ma (Figure 14).

4.4 Migration sequence of the Cenozoic volcanism in the Tibetan Plateau

We suppose that Cenozoic volcanic activities of Tibetan Plateau migrated from different regions according to the frequency distribution of isotopic ages. Therefore, we divided northern Tibetan into Qiangtang and Hoh Xil and add the data of Lixian, Gansu province to show the overall volcanical perspective of Plateau. Isotopic ages of volcanic rocks in the Himalayan belt were collected to six, and five of the six are young than 50 Ma, mostly are 20-10 Ma, accordancing with the pattern of intrusive rocks. The isotopic ages of four samples from Lixan, Gansu province are between 20-10 Ma. The histogram of the statistical data of Cenozoic isotopic age data from Tibetan plateau shows that volcanic activity among the Tibetan plateau has progressively intensified since 70Ma and reached the climax in the interval 40-35Ma, after which it continued with reduced intensity from 35Ma and reached the lower level during 25-20Ma. Since then, the volcanism reactivitied and came to the sub-peak during 10-15Ma. From then, the intensity of volcanism declined and maintained at a mild level. It seems that there are two peak stages on Cenozoic volcanism of Tibetan plateau which may infer the transformation of dynamics of Tibeatan plateau.

The diagram shows a migrating order in Cenozoic volcanic activity of Tibetan Plateau is Gangdese → Qiangtang→Eastern Tibet →Himalaya, Hoh Xil and Lixian, Gansu province and Gangdese → West Kunlun (Figure 15). Therefore, the Cenozoic volcanic activity in Tibetan plateau is of the characteristics from the center (that is Gangdise) relocating to the edge of the plateau; after 10 Ma, it has completely transferred from the center of the Tibetan Plateau; and the migration of the volcanic activity occurred in 30-20 Ma and the reduction of volcanism in Gangdese may suggest the existence of some stress, resulting the areas with intensed volcanism changing in the plateau.

In early paleogene Cenozoic volcanic activity in Gangdese of Tibetan Plateau continused and increased, forming suumit of 50 -45 Ma. Then, the center of volcanism transferred to Qiangtang. 35 Ma, it changed to east Tibetan with two big frequency of isotope dating. Lately, volcanical activity returned to Qiangtang and migrated toward north at Hoh Xil and Lixan, Gansu province 10 Ma later. Meanwhile, volcanical activity migrated toward south at Gangdese and Himalaya. Volcanism remained in 5 – 0 Ma in the margin of Tibetan, there are the west Kunlun, Hoh Xil and eastern Tibetan, while volcanic activity in other parts of Tibetan Plateau significant reducted or turned to quiet.



Lixian,Gansu province	4
Weat Kunlun	5
Hoh xil	4
Qiangtang	2 4
Gangdese	1 4
Eastern Tibetan	3
Himalaya	4

Fig. 15. Migration sequence of the Cenozoic volcanism in the Tibetan Plateau

4.5 Ophiolite and basic – ultrabasic rocks

Ophiolite belts are complexity and research limitation (Qiu et al., 2005); among them, Bangong-Nujiang and Yarlung Zangpo with large-scale are the most important borderlines for the tectonic units divided in Tibetan (Figure 8). Qiangtang and Gangdese terras are comparted from by the former. The collision suture between the Indian plate and Asia continent is well shown by the latter. There is always a small-scale ophiolite belt exposed on the southern side of each belt respectively. Most of the data points of isotope dating of

ultramafic rock in the Tibetan Plateau distribute along the Yarlungzangbu ophiolite and Bangong- Nujiang ophiolite belt. Yet a few data of have been accumulated, forming a limited database with unconspicuous statistical laws. To facilitate the analysis, statistical data is divided into the southern and northern Gangdise largely on Coqen - Xainza fault, corresponding respectively to the formation and activities of Yarlungzangbu and Bangong-Nujiang suture (Figure16).

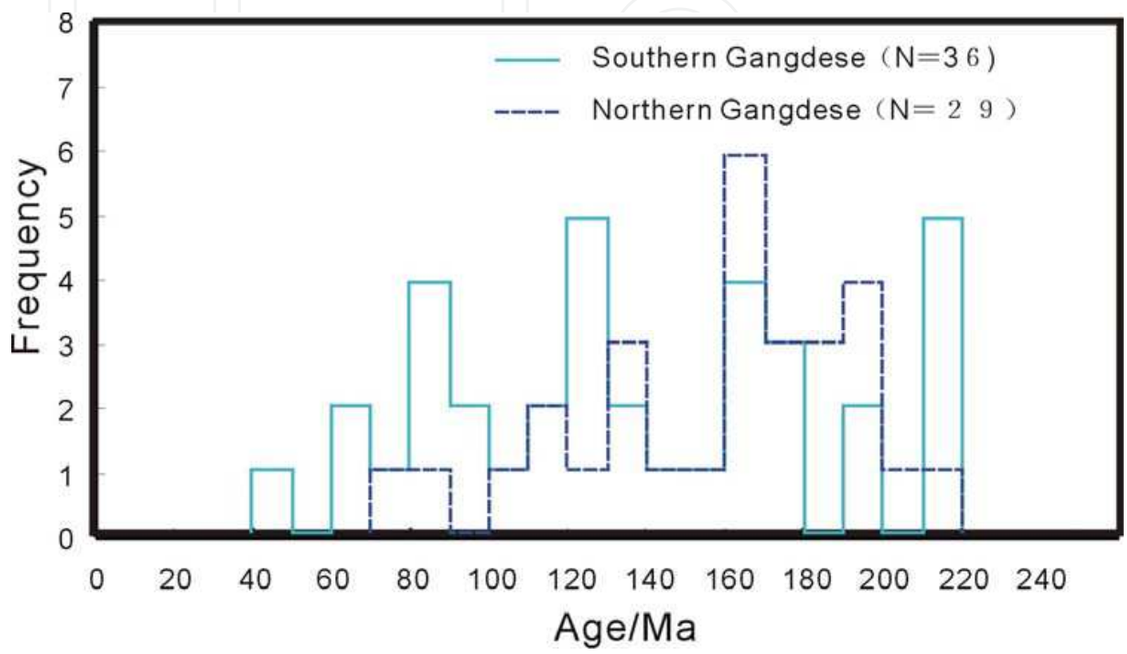


Fig. 16. Histogram of isotopic ages of basic-ultrabasic rocks from various regions in the Tibetan Plateau

The figure shows that the frequency of isotopic age of the southern Gangdese peak in 220 - 210 Ma, 130 - 120 Ma and 90 - 80 Ma, with gradually descend number, inferring various intensity of the basic-ultrabasic activities in Mesozoic and Cesozic. It is very interisting the the isotopic age of older than 200 Ma confined in eastern Yarlung Zangpo ophiolite belt so that we take 130 - 120 Ma as the peak time of it since it is more than 1500 km long. Constract to the northern Gangdese, the data of isotopic age of basic-ultrabasic rocks distribut continuously and maintain in higher frequency between the ages of 180-120 Ma, indicating that this period is the active for the basic - ultramafic magma of the Yarlung Zangpo ophiolite belt.

The highest frequency value of isotopic age in northern Gangdese is in 170-160 Ma, maybe representing a stronger period of mantle activity. Howeve, the frequency value of isotopic age is also high between 200 Ma and 160 Ma, infering that the activities of mafic – ultramafic commence earlier than south. There is a few mafic – ultramafic rocks in southen Gangdise after 70 Ma, which may relate to its location of southern margin of India-Asia colision. Since 40 Ma, basic and ultrabasic magmatic activity stopped completely. We synthesize the subducting of oceanic crust commenced about 180Ma in Bangong-Nujiang suture towards south and about 130Ma in Yarlung Zangpo suture towards North by the frequency and distribution of the magmatism of North Gangdese and South Gangdese.

5. Process of the Tethy in Tibetan Plateau

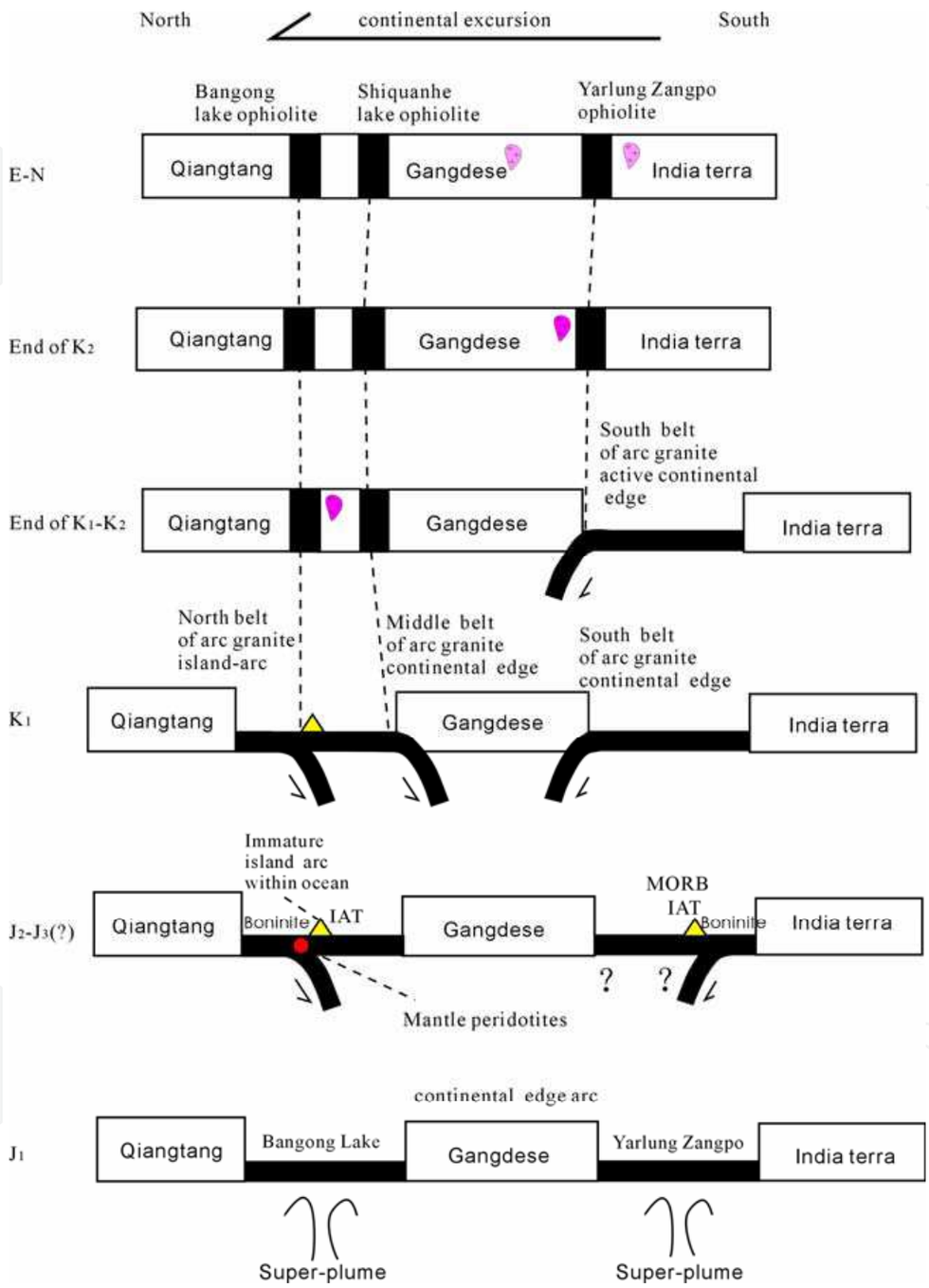


Fig. 17. Diagram showing the dynamic process of the Evolution of the Tethy in Tibetanan Plateau

Tibetanan Tethyan Oceans were developed in Mesozoic period, which represented by Bangong-Nujiang and Yarlung Zangpo: (1) gabbro age of 191—195Ma in Bangong-Nujiang suture, and violent gabbro magmatism about 180Ma in Yarlung Zangpo, and Jurassic

Radiolarian fossils found in the abysmal cherts indicate both oceans might be opened at the same times in early Jurassic. (2) boninite and boninite series recognized in the volcanic rocks of 140—170Ma in Bangong-Nujiang suture and 110—170Ma in Yarlung Zangpo suture, indicate the initial subduction episode happening, and the O-type adakite recognized in intrusive rocks of ≥95—139Ma in Bangong-Nujiang suture and ≥65—110Ma in Yarlung Zangpo suture indicate the subduction continuing. (3) Bangong-Nujiang oceanic basin closed by the end K_1, and Yarlung Zangpo oceanic basin closed in K_2/E (≈65Ma). (4) after the collision of India-Asia plates at about 65Ma, large-scale magmatic activities of 65—40Ma was caused on the south Gangdeze. (5) With the continuous subduction of India plate toward North, the occurrence of C-type akakite of 45—35Ma in Qiangtang and 25—8Ma indicate the orogenic lithosphere de-rooting episode happening in Qiangtang first, then in Gangdese.

We depict a dynamic process of the Evolution of the Tethy in Tibetanan Plateau based on the the statistical and analytical data (Figure 17).

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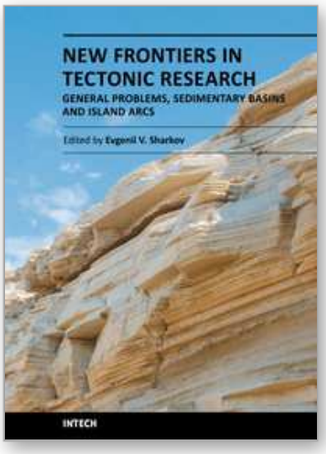

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