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综 述

GEOLOGICAL EVENTS AND MAMMALIAN DISTRIBUTION IN CHINA

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Abstract I utilized the results of research on the distribution patterns of mammalian species in China, incorporating these information as biological evidences in the study of paleo-environmental change. I used a method of quantitative mapping for the analysis. The examples discussed in this article illustrate how geological events and resulting environmental patterns and other changes have affected animal distributions.

Key words Distribution pattern, Geological events, Zonal landscape system, Barrier, Transition, Zoogeography

1 Introduction

For biogeographic studies, seeking patterns is the most basic task, followed by seeking to explain what processes produced those patterns. The objective of this study is to shed light on a simple relationship; animal distributions are the result of adaptation to processes of geological and paleo-environmental change. The common characteristic of modern biogeographic distributions is that they are the evolutionary product of adaptation to an ever changing environment.

1.1 Geological events and their geographical consequences in China

Since the beginning of the Tertiary Period, and the disappearance of the Tethys Sea resulting from joining of the Eurasian plate and the Indian plate, there have been tremendous changes in the geological structure and geographical environments of continental China. The thrusting of the Indian plate underneath the Eurasian plate, and the impacts of the Himalayan tectonic movements since the Miocene epoch have been dominant forces in shaping the latest stage of Chinese physical environment (Liu *et al*., 1984). The uplift of the lofty Tibetan (Qinghai-Xizang) Plateau has been the major cause of the formation of the modern monsoon system in East Asia (Tang, 1995). Consequently, following three great natural divisions of continental China have been established (Plate I).

1) *Eastern Monsoon China* It is generally dominated by monsoon humid climate and forest vegetation. A series of west to east trending mountain ranges—the Yinshan Mts., the Qinling Mts., and the Nanling Mts.—serve as barriers between the great climatic zones of temperate (Northeast China), warm temperate (North China), subtropical (Central and Northern South China) and tropical (Southern South China). The most distinct barrier is the Qinling Mts.-Huai River line, which has formed an important physical geographical division between north and south in eastern China since the Pleistocene (Zhou, 1984). In conformity with world-wide climatic fluctuations, shifting of climatic zones was manifested latitudinally in this realm. With minor exceptions, the great tendency in this shifting was for the tropical, humid rainforest zone to regress southwards since the Early Pleistocene from the Changjiang river area to the southernmost border in the Late Pleistocene, and then move slightly northwards in the present time (Liu *et al*., 1984). The cold temperate climatic zone, part of the periglacial taiga of the Siberia, has expanded southward to Northeast China in the Early

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Pleistocene, and then retreated back to the northernmost section of that area since the Middle Pleistocene. Obviously, this realm has not been covered by continental ice sheet and served as a refugium —"Pantu Ground" (Kahlke, 1961).

The Loess Plateau in the middle reaches of the Yellow River indicates an expansion of dry-cold climate, with the loess dust source being the Northwestern Arid China area, since the Early Pleistocene (Li, 1998). Interposed between northeastern China and southeastern China areas the Loess Plateau area is climatically semiarid, while the loess deposit plain of the north China plain is semi-humid in the present time.

2) *Northwestern Arid China* The so-called Dry pole of Asia, named by the German geographer Troll, is located in southern Xinjiang (Li, 1998). Areal differentiation within this realm is related mainly to decreasing moisture conditions from east to west as shown in the vegetation sequence of semi-arid/steppe, arid/steppe-desert and extremely arid/desert. Since the Late Cretaceous and the early Tertiary, a general trend of desiccation in northwest China has occurred, accelerated by the rain-shadow created by the uplift of Tibetan plateau since the Early Pleistocene (Shi *et al*., 1995).

3) *Tibetan Frigid Plateau* This, the highest plateau in the world with alpine climate and vegetation, is characterized mainly by cold steppe and cold desert in the inner part, while in the southeastern margin of the plateau, the Himalayan-Hengduan mountain system, is distinguished by vertical natural zones from tropical or subtropical forests in deep river gorges to alpine tundra. The plateau was almost non-existent during the Pliocene. Since the middle Quaternary, and up to the present, it had reached from an average elevation of 3 000 m to more than 4 000 m above sea level. The continued uplift of the plateau has intensified the alpine climate itself, and increased the forces of aridity in the inner part of the plateau. The vestiges of Pleistocene glaciations are restricted to some valley glaciers, piedmont glaciers and, in part, to some small ice sheets, but there has never been a great ice sheet (Shi, 1991). In the course of uplift and climatic fluctuation, the forest has in general retreated from the interior of the plateau to the southeastern lower margin, while the original landscape of the southeastern margin has undergone vertical shifting (Zhang *et al*., 1981). Climatically, the southeastern flank of the Himalayan and Hengduan is attributed to the monsoon realm. However, topographically, the Himalayas are inseparable from the Tibetan Plateau.

1.2 Distribution patterns of land vertebrates in China

Based on investigation and study of entire species ranges, the most obvious patterns in the distribution of existing land vertebrates in China, apart from pan-tropic and pan-boreal patterns, is a tendency of geographical diversification (Zhang, 1999). There are nine main patterns occurring, showing a great extent of congruence with geographical regionalization of China at different scales, and which can be divided into two major categories: (1) four great zonal patterns: Boreal, Central Asian, Oriental, and Old world Tropical; and (2) five regional patterns: Highland, Himalayan-Hengduan, Southern China, Northeast China and Continental Island. Each pattern is based on occurrence of characteristic or endemic species, but some species range further outside of the main spheres of the patterns, depending on barrier effects of physical environment or dispersal abilities of species in the continent. Thus, a transition zone must be built up between two adjacent patterns. Furthermore, based on faunal dominance as a whole, they belong to either Palaearctic and Indomalayan (Oriental) realms, the concept of which has been recognized by biogeographers since the time of Wallace (Darlington, 1957). The relationship of the nine patterns can be shown in Fig. 1. Although there remain insufficient data for a few rare species which are treated as exceptions, it provides basic facts as generalization for one of the starting points in further study. A more detailed pattern classification with subdivisions has been given in a monograph, "Zoogeography of China" (Zhang, 1999).

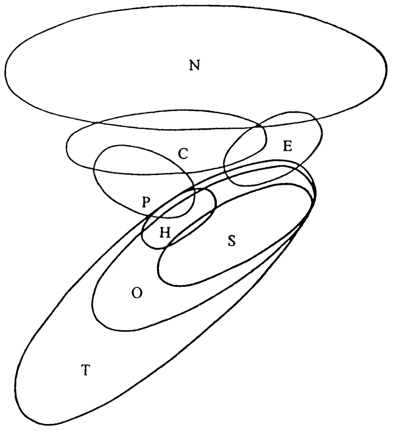

Fig. 1　The distribution patterns and their relationship of land vertebrates of China

Palaeartic Realm.　N: Boreal　E: Northeast　C: Central Asian　P: Highland　Indomalayan Realm.　H: Hengduan-Himalayan　S: Southern China　O: Oriental　T: Old World Tropic, island pattern omitted

2　Methodology

2.1　Geological events

The geological events described above have already been brought to light by geological and paleogeographical researches and have been accepted as part of geoscience theory. This situation allows us to have enough faith in the results of basic research on geological and paleo-geographical events to discuss distribution of plants and animals, and to avoid the danger of having biogeographers and paleogeographers recirculate the same information in new hypotheses. The above statement is in accord with Andel's (1979) ideas on the relationship between plate tectonic theory and biogeography, supported by Briggs's (1987: V) statement that, "If these enthusiastic remarks were indeed true, the task of biogeographic research would be greatly simplified!" Additionally, dated fossil records of locations could been reviewed to indicate the general tendencies of historical migrations. This article utilizes the results of geological research in China, incorporating this information as geological evidence in the study of mammal distribution.

2.2　Zone-landscape system

Since 1949, a series of physical regionalization works on both national and local scales has been conducted. So far, the most comprehensive study was completed in 1958 and revised recently by the Working Committee of Physical Regionalization of China, Chinese Academy of Sciences (National Atlas Compilatory Committee 1999). According to this Committee, the three great natural divisions with distinct geological histories respectively, as described above, has been defined. Subsequently, 12 natural zones and 90 natural regions have been identified. Natural zones have relatively uniform temperature and moisture conditions as well as similar zonal soil and vegetation. A natural region has not only uniform zonal features (climatic, biological, and soil), but also fairly uniform azonal characteristics (geological and topographical). It is equal to "landscape" defined by Russian geographers (Kysekin*, 1960). A natural unit of region or landscape reflects more fully the total physico-geographic environment, in which varied animal habitats occurred repeatedly. Obviously, it may be to a great extent a reflection of natural environmental characteristics rather than a political boundary such as provincial divisions. Using the zonal-landscape system for zoogeographical study has been suggested first by Russian zoologists (Kysekin*) and its methodology has been introduced with a concrete approach for application in China (Chang *et al*., 1964; Zhang, 1995). The distribution data have been inputted into the natural region or landscape system for analysis.

3　Results

The nine main patterns (Fig. 1) indicate a significant degree of spatial overlapping of species distribution over the vast territory, and showing highly non-random patterns. The three spatial phenomena that shape dispersal patterns, (1) effective *barriers*; (2) partial barriers that lead to the formation of *transition zones*, and (3) *corridors*, which have a filtering effect, are exemplified (Plate I) to illustrate how geological events and resulting

* Kysekin, A. P.　1960　Zoogeography of Soviet Union. Study Review Vol. 109. Moscow Pedagogical Institute (in Russian): 3~182.

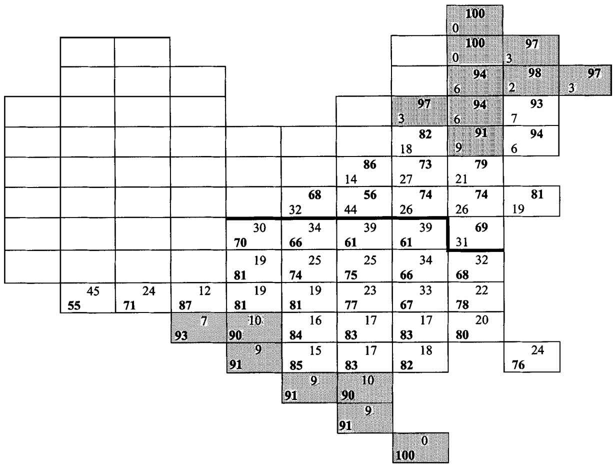

Fig. 2 Transition ratio of Palaeartic and Indomalayan mammal faunas in Eastern China

Number in right upper corner: Percentage of Palaearctic mammal fauna against the total of the both in the landscape. Number in left lower corner: Percentage of Indomalayan mammal fauna against the total of the both in the landscape

Marked by mesh: the area of landscapes most dominated by the faunas (Palaearctic-to north; Indomalayan-to south)

environmental divisions and other changes affect animal distributions. Moreover, the fossil data highlight the impact of paleo-geographical processes on the existing distribution.

3.1 Geographical congruence of mammal distribution patterns

The nine types of the patterns of geographical congruence can be list with character species as follows.

1) Boreal Cold temperate climate zone of taiga evolved since post-maximum glacial age, shifting with mainly southwards migration since the Late Pleistocene. Characteristic species: Eurasian water shrew (*Neomys fodiens*), wolverine (*Gulo gulo*), moose (*Alces alces*), Siberian flying squirrel (*Pteromys volans*), Eurasian red squirrel (*Sciurus vulgaris*), Ikonnikov's mouse-eared bat (*Myopus ikonnikovi*), northern red-backed vole (*Clethrionomys rutilus*), arctic hare (*Lepus timidus*), etc.

2) Northeast Temperate climate zone of forestland or forest-steppe developed from periglacial land in the north and loess land in the south since the Late Pleistocene. Characteristic species: giant shrew (*Sorex mirabilis*), lesser weasel (*Mustela amurensis*), long-tailed souslik (*Spermophilus undulatus*), striped hamster (*Cricetulus barabensis*), Maximowiczi's vole (*Microtus maximowiczii*), Manchurian hare (*Lepus manschuricus*), etc.

3) Central Asian Arid climate zone developed since the Late Tertiary, and in a general tendency of desiccation since the Pleistocene. Characteristic species: long-eared hedgehog (*Hemiechinus auritus*), Chinese desert cat (*Felis bieti*), Mongolian gazelle (*Procapra gutturosa*), ground squirrels (*Spermophilus spp.*), dwarf hamsters (*Cricetulus spp.*), many species of jerboas, Dipodidae and gerbils, Gerbillinae, etc.

4) Highland Tibetan Plateau and its adjacent highland, alpine and periglacial climate developed since the M. Pleistocene. Characteristic species: snow leopard (*Panthera uncia*), white-lipped deer (*Cervus albirostris*), yak (*Bos grunniens*), Tibetan antelope (*Pantholops hodgsoni*), Himalayan marmot (*Marmorta himalayana*), pine voles (*Pitymys spp.*), pikas (*Ochotona spp.*), woolly hare (*Lepus oiostolus*), etc.

5) South China Subtropic-tropical forestland, refuge of animals adapting to warm climate during southwards shifting of climatic zones from the north since the Mid-Pleistocene. Characteristic species: grey shrew (*Crocidura attenuata*), lesser horsesboe bat (*Rhinolophus blythi*), southwestern mouse-eared bat (*Myotis altarium*), great everning bat (*Ia io*), Tibetan stump-tailed macaque (*Macaca thibetana*), Chinese ferret-badger (*Melogale moschata*), muntjae (*Muntiacus reevesi*), hairy-footed squirrel (*Belomys pearsoni*), etc.

6) Himalayan-Hengduan Subtropical mountain environment, natural zones shifting vertically since the Pleistocene, but retaining environmental diversity of tropics and subtropics in low elevation. Character species: Szechuan water-shrew (*Chimarrogale styani*), Yunnan snub-nosed monkey (*Rhinopithecus beiti*), lesser panda (*Ailurus fulgens*), takin (*Budorcas taxicolor*), flying squirrels (*Petaurista spp.*) orange-bellied Himalayan squirrel (*Dremomys loktiah*), Szechuan jumping mouse (*Eozapus

setchuanus), pikas (*Ochotona spp.*) etc.

7) Oriental Tropical climate zone of the southeast Asia, has remained climatic stable in core area since the Tertiary, fluctuation in northernmost part with generally southwards migration during the Pleistocene. Characteristic species: Horsfield's shrew (*Crocidura horsfieldi*), white-tail mole (*Parascaptor leucurus*), Many species of flying squirrels, Pteropodidae and horeshoe bats, Rhinolophidae, all species of trident bats, Hipposideridae, Dormer's bat (*Scotozous dormeri*), Taiwan tubed-nosed bat (*Kerivoula picta*), most species of Primates, hog-badger (*Arctonyx collaris*), yellow-throated marten (*Martes flavigula*), all species of viverrid, Viverridae, Asiatic golden cat (*Felis temmincki*), Indian muntjac (*Muntiacus muntjak*), mainland serow (*Capricornis sumatraensis*), flying squirrel (*Petaurista* spp.), oriental tree squirrels (*Callosciurus spp.*), bamboo rats (*Rhizomys spp.*) old-world rats (*Rattus spp.*), etc.

8) Old-world tropic Tropic-subtropical climate of the low latitudinal area of the Old-world, remained climatic stable since the Tertiary. Characteristic species: greater horseshoe bat (*Rhinolophus ferrumequinum*), European free-tailed bat (*Tadarida teniotis*), Schreiber's long-fingered bat (*Miniopterus schreibersi*), leopard (*Panthera pardus*), etc.

9) Island Hainan and Taiwan, connected with continent more than twice during the Pleistocene due to sea level changes. Characteristic species: Hainan moonrat (*Neohylomys hainanensis*), Hainan flying squirrel (*Petaurista hainana*), etc. (Hainan); Taiwan long-tailed shrew (*Soriculus sodalis*), mono-horned houseshoe bat (*Rhinolophus monoceros*), Taiwan macaque (*Macaca cyclopis*), Taiwan flying squirrel (*Petaurista pectoralis*), etc. (Taiwan).

3.2 Remarkable barriers

3.2.1 Tibetan Plateau Alpine environment beyond tree-line is a forbidden land for almost all species adapted to lowland temperate or tropic climate.

3.2.2 Great Himalayan Mountain System All species associated with of the three patterns (South China, Oriental and Old World Tropic) are restricted to its southern flank, reaching their upper limits at different elevations; so far known from Chinese territory are such species as Assam macque (*Macaca assamensis*) - 2 500 m (Zheng *et al.*, 1981), langur (*Presbytis entellus*) - 2 800 m, yellow-throat marten (*Martes flavigula*) - 3 000 m, Perny's long-nosed squirrel (*Dremomys pernyi*) - 3 100 m. etc. (Ying *et al.*, 1993). The uppermost limit of Oriental species is coincident with the tree-line of the subalpine forest (4 000～4 500 m). On the other hand, some of the highland elements reach their lowest limits in alpine scrubs, such as, blue sheep (*Pseudois nayaur*), wooly hare (*Lepus oiostolus*), and Himalayan marmot (*Marmota himalayana*), etc. A few species, such as alpine musk deer (*Mosch sifanicus*), Tibetan hamster (*Cricetulus kamensis*), etc., reach farther down to the lower limit of subalpine forest (3 200 m) (Feng *et al.*, 1986). Thus, a narrow vertical transition zone along the south flank is created.

3.2.3 Qinling Mts.-Huai River line, coinciding with the northernmost limit of subtropic deciduous broad leaved forest Many species of the Indomalayan Realm reach their northernmost range limits on the southern flank below an elevation of about 3 200 m, such as great striped shrew (*Sorex cylindricauda*), short-tail moupin shrew (*Blarinella quadraticauda*), gray shrew (*Crocidura attenuata*), Szechuan burrowing shrew (*Anourosorex squamipes*), intermediate horseshoe bat (*Rhinolophus affinis*), snub-nosed monkey (*Rhinopithecus roxellanae*), lesser panda (*Ailurus*

Wu, J. Y., M. M. Shao, Y. L. Zheng and S. Y. Song 1978 Mammal Faunal Study of Qinling Mts.. Unpublished Paper (in Chinese). [吴家炎, 邵孟明, 郑永烈, 宋世英 1978 秦岭兽类区系, 未刊.]

Zheng, Z. X., Z. J. Feng, R. Z. (Y. Z.) Zhang and S. Q. Hu 1981 On the land-vertebrate fauna of Qinghai-Xizang plateau with considerations concerning its history of transformation. Memoirs of Beijing Natural History Museum. No. 9. Beijing. (in Chinese). 郑作新, 冯祚建, 张荣祖, 胡淑琴 1981 青藏高原陆栖脊椎动区系及其演变的探讨. 北京自然博物馆研究报告 (9)

fulgens), Chinese ferret badger (*Melogale moschata*), small Indian civet (*Viverricula indica*), clouded leopard (*Neofelis nebulosa*), Chinese muntjac (*Muntiacus reevesi*), red and white fly squirrel (*Petaurista alborufus*), Perny's long-nosed squirrel (*Dremomys pernyi*), Chinese pygmy dormouse (*Typhlomys cinereus*), Chevrier's field mouse (*Apodemus chevrieri*), Himalayan rat (*Rattus nitidus*), Edward's rat (*R. edwardsi*), etc. (Wu *et al.*, 1978; Zhang *et al.*, 1997).

3.2.4 Eastern limit of arid-inland/northwest limit of monsoon area, along the margins of the Tibetan Plateau in the south and the loess plateau and Inner Mongolian plateau in the north, is a more or less distinct division between arid adapted elements of the Palaearctic and humid adapted elements of the Indomalayan realm (Zhang *et al.*, 1997). Arid adapted elements: beech marten (*Martes foina*), Pallas's cat (*Felis manul*), zeren (*Procapra gutturosa*), Daurian pika (*Ochotona daurica*), clawed jird (*Meriones unguiculatus*), etc.

Humid adapted elements: Himalayan water-shrew (*Chimarrogale himalayiaca*), great horseshoe bat (*Rhinolophus ferrumequinum*), Japanese pipistrelle (*Pipistrellus abranus*), rhesus (*Macaca mulatta*), leopard cat (*Felis bengalensis*), etc. (Zhang *et al.*, 1997).

3.3 Corridor or gap

3.3.1 The Hengduan mountain system provides ecologically diverse habitats in three dimensions and exhibits a topographically south-north trend, serving as a favorable dispersal area forspecies of the adjacent patterns (Zhang *et al.*, 1997).

South China: Chinese shrew (*Neotetracus sinensis*), Szechuan burrowing shrew (*Anourosorex squamipes*), yellow-bellied weasel (*Mustela kathiah*), forest musk deer (*Moschus berezovskii*), Perny's long-nosed squirrel (*Dremomys pernyi*), Chinese field mouse (*Apodemus draco*), etc.

Oriental: house shrew (*Suncus murinus*), white-tailed mole (*Parascaptor leucurus*), Himalayan leaf-nosed bat (*Hipposideros armiger*), rhesus (*Macaca mulatta*), Assam macaque (*M. assamensis*), Tibetan stump-tailed macaque (*M. thibetana*), yellow-throated marten (*Martes flavigula*), bog-badger (*Arctonyx collaris*), small Indian civet (*Viverricula indica*), masked palm civet (*Paguma larvata*), clouded leopard (*Neofelis nebulosa*), sambar (*Cervus unicolor*), mainland serow (*Capricornis sumatraensis*), Pallas's squirrel (*Callosciurus erythraeus*), Chinese bamboo rat (*Rhizomys sinensis*), etc.

Boreal: Ussuri large white-toothed shrew (*Crocidura lasiura*), beech marten (*Martes foina*), mountain weasel (*Mustela altaica*), Lynx (*Felis lynx*), red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), Siberian fly squirrel (*Pteromys volans*), Siberian chipmunk (*Eutamias sibiricus*), root rat (*Microtus oeconomus*), etc.

Highland: Tibetan fox (*Vulpes ferrilata*), Tibetan bear (*Ursus pruinosus*), snow leopard (*Panthera uncia*), alpime musk deer (*Moschus sifanicus*), Tibetan gazelle (*Procapra picticaudata*), blue sheep (*Pseudois nayaur*), woolly hare (*Lepus oiostolus*), Himalayan marnot (*Marmota himalayana*), etc.

Central Asia: Chinese deser cat (*Felis bieti*), Pallas's cat (*Felis manul*).

Many families reach their highest species densities in the Hengduan range, including shrew (Soricidae), mustelid (Mustelidae), viverrid (Viverridae), cats (Felidae), deer (Cervidae), bovid (Bovidae), sciurid (Sciuridae) and pikas (Ochotonidae) (Zhang, 1999).

3.3.2 Loess Plateau serves as a dispersal corridor for eastwards expansion of a few species of Central arid pattern to the north China plain, where they encounter a semi-humid climate, while some strictly humid adapted species disappeared there, forming a gap, and disjunct distributions (Zhang *et al.*, 1997).

Eastward dispersal: Daurian ground squirrel (*Spermophilus dauricus*), mid-day gerbil (*Meriones meridianus*), common Chinese zokor (*Myospalax fontanieri*), lesser long-tailed hamster (*Cricetulus longicaudatus*).

Gap in distribution: Eurasian common shrew (*Sorex isodon*), Laxmann's shrew (*S. caecutiens*), lesser shrew (*S. minutus*), De Winton's shrew (*Soriculus hypsibius*), Japanese mole (*Mogera wogura*), European free-tailed bat (*Tadarida teniotis*), Fukien mouse-eared bat (*Myotis frater*), water bat (*M. daubentoni*), David's mouse-eared bat (*M. davidi*), Savi's pipistrelle (*Pipistrellus savii*), Schreibers's long-fingered bat (*Miniopterus schreibersi*), otter (*Lutra lutra*), Eurasian red squirrel (*Sciurus vulgaris*), harvest mouse (*Micromys minutus*), etc.

3.4 Broad Transition

In Eastern Monsoon China, there is a large-scale transition between two major faunal realms, the Palaearctic and the Indomalayan, reflected by progressive subtraction of faunal elements in opposite directions. There are 99 species of Palaearctic and 303 species of Indomalayan involved in the study. The extent of the transition is indicated by percentages of each fauna against the total of the both in each landscape unit throughout the region (Fig. 2, compare to Plate I).

Palaearctic: The highest proportion (100 %) is concentrated in the Xinganling Mts., the northernmost region of the Northeast China, the cold temperate zone. The proportions is higher than 90 % in the rest of the Northeast China, the temperate zone, and remains at 74 %～56 % to the north of the Qinling Mts. and northern area of the Huai river. Farther to the south in the subtropic zone, including Taiwan, the proportion decreases to 49 %～20 %, and less than 10 % in the southernmost region of the continent and on Hainan Island.

Indomalayan: Except for the islands of the South China Sea, where there are only few species of old-world rats (*Rattus*) introduced by human transportation, the highest degree of 90 %～93 % is occurring along the southern margin of the continent, the tropical climatic zone. In the mountain-hill areas of the sutropic zone, it remains 85 %～61 % with graduate subtraction from the south to the Qinling Mts. Northward over the Qinling Mts. and reaching to the southeastern part of Northeast China, there is a rapid subtraction from 44 % to 2 %. No Indomalayan species occur in the cold temperate (taiga) zone.

Therefore, the broad transition may be marked approximately between the southern limit of temperate zone in the north (about 42°N) and northern limit of the subtropic zone (about 28°N～24°N) in the south of eastern China (Plate I).

3.5 Fossil records in eastern part of China

The study of Quaternary mammals of China has been mainly concentrated in the eastern part of China. Based on the data available (Huang, 1986, 1979; Kahlke, 1961; Zheng *et al.*, 1991; Zhang, 1984; Xu, 1992), a few genera and species have been selected to give a very general picture of migration tendencies coincided with climatic zone shifting during the Quaternary.

3.5.1 Oriental or Old World Tropic elements: hyaenas (*Hyaena*, *Crocuta*), tapirs (*Tapirus*), hog-deer (*Axis*) etc. ranged widely in eastern China and retreated southward out of continental China totally or almost so since the Late Pleistocene or the Holocene.

Mole-shrews (*Anourosorex*), muntjac (*Muntiacus*), bamboo rats (*Rhizomys*), crested porcupines (*Hystrix*), civets (*Viverra*), etc. which extended northward to southern part of Northeast China, have retreated southward to the south of the Qinling-Huai River line, following the southward shift of the subtropical and tropic zones since the Middle or the Late Pleistocene (Ma *et al.*, 1992).

Sambar (*Cervus unicolor*), muntjac (*Muntiacus muntjak*), etc. reached the southern flank of the Qinling Mts. and lower reaches of the Huai River, and gibbons (*Hylobates*) reached the area of middle reaches of the Changjiang River, in the Pleistocene, but have retreated to existing middle subtropical or southern subtropical zones of South China since the Holocene (Huang, 1991a, b).

Musked palm civet (*Paguma larvata*), macaques (*Macaca*), etc. had reached North China, in the northern limit of the subtropic zone during the Early-or Middle Pleistocene (Teilhard, 1940; Zhang, 1981). The northern limits have remained with almost no change compared with those of the present northern limit of the warm-temperate zone, despite of the recent extirpation of rhesus (*Macaca mulatta*) several decades ago near Beijing, caused by human activities (Zhang *et al*., 1989).

3.5.2 Boreal (Holarctic) elements: Eurasian water shrews (*Neomys*), moose (*Alces*), wolverines (*Gulo*), beavers (*Caster*), water voles (*Arvicola*), etc. extended southward to differing degrees during the Pleistocene, the southernmost limit among them reaching to the existing subtropical zone, but have retreated since the Late Pleistocene, back to the existing cold temperate (taiga) zone of northernmost Northeast China (Xu *et al*., 1987; Zhou, 1963)

Stoat (*Mustela erminea*), arctic hare (*Lepus timidus*), characteristic species with circumboreal in distributions of the cold temperate zone, ranged southward to Northeast China as well. So far as known, their Pleistocene fossils occur only in Europe, Siberia, Japan and North America (Kurtén, 1968, 1980; Yoshinari, 1982).

3.5.3 Humid adapted species: red-toothed shrews (*Sorex*), Chinese water deer (*Hydropotes inermis*), otter (*Lutra lutra*) are presently absent in North China and adjacent areas, where semi-arid or semihumid areas exist. Their fossil have been recorded there during the Later Tertiary and (or) the Quaternary.

4 Discussion

Since the concept given by Wallace (1876), the Himalayan mountain system has been recognized as an important topographic and climatic barrier in zoogeography. There is a narrow transition zone mainly along its southern flank, pointed out by Hoffmann (2001). A few examples there for the transition zone have been given above. Through time, with the uplifting of the Tibetan plateau and the ever-increasing barrier effects of the Himalayan section and the plateau as well, Central Asian aridity gradually increased, and a distribution pattern developed where, since the Early Pleistocene, mammals were increasingly adapted to aridity.

In conjunction with the formation of the Tibetan plateau, the Hengduan mountain system arose, a range oriented perpendicular to the Himalayas. This topographic characteristic made the range a north-south corridor for dispersal, or a gap in the Himalayas—Qinling barrier. The richness of the mammal fauna could be further explained from an ecological and paleogeographic point of view. The altitudinal zonation of natural vegetation in this mountain system, with its diversity of ecosystems, provided a wide variety of habitats for plants and animals, and allowed for the possibility of considerable overlap in the distributions of mammals representative of different patterns of regional climate. The verticality of the Hengduan mountain system is great, and the mountains are in intermediate latitudes, so global climate changes starting in the Pleistocene have had only a limited impact on the range of montane landscapes in the region, with a shift in vertical vegetation zones of only some hundreds of meters. Thus, prevailing factors preserved pre-exiting, heterogeneous ecological conditions within strictest possible limits. This biologically diverse and historically stable environment was highly favorable for maintaining species richness.

Environmental change in eastern monsoon China was much different from that of Hengduan. There has been an horizontal shift with large scale fluctuation, resulting in the formation of a transitional zone between the Indomalayan and the Palearctic realms. Darlington (1957: 472) has postulated that only in eastern Asia, between the Oriental and Palearctic faunas, is there full-scale transition without intermediate subtraction between major faunas. The broad transition described above generally agrees with his point of view. The transitions of the two major faunas occurred almost over the whole eastern China, except for the cold temperate zone to the north of 50°N latitude, where there are no Indomalayan species. Comparing the strength of their respective transitions, the Palearctic one is stronger than that of the Indomalayan. The general tendency of mammals to migrate southward migrations over this vast area of eastern China during the Quaternary could be an indicator that the present faunal transition zone might be the heritage of this historical impact.

The location of the boundary between the two major faunal realms has thus been a contentious issue in the area of eastern China. Hoffmann (2001) reviewed the previous opinions of the southern Palaearctic in China and adjacent countries. He has suggested a transition zone of the two major faunas coinciding with the area of middle and lower reaches of the Changjiang River, between 28°N and 33°N and marked the northern line of the transitional zone as the southern boundary of the Palaearctic. I have considered that the division along Qinling Mts. and Huai River line could more suitably serve as this boundary. It is the delimitation between the relative dominance to the north and rapid replacement to the south of the Palaearctic faunal transition (Fig. 2). It also exhibits a coincidence with the most important geographic line of eastern China, the Qinling-Huai River line (34°N, west～33°N, east) characterized by northernmost limit of sutropical forest and isotherm of main temperature 0 ℃ of January (Plate Ⅰ).

The conclusions of this work are as follows.

1) The current distributions of mammals of continental China can be divided into nine patterns. Their range of different distribution types can be delineated in general terms, through the use of different physical geographic criteria that indicate congruence. These distribution types are the result of long-term adaptation to changing geographic environments.

2) Since the disappearance of the Tethys Sea, the most important geological event has been the uplifting of the Qinghai-Xizang Plateau. The natural realms and climatic-vegetation zones that this event gave rise to had different effects on different species; depending on what types of environments and regions they adapted to. Animals adapted to different natural environments or natural regions were affected to different degrees by the formation of geographic corridors and barriers. Since the Qinghai-Xizang Plateau itself developed into a high-altitude frigid climate, it was off-limits for many species and a haven for those adapted to cold, high-elevation zones.

3) Although the geographic zones that have developed since the Middle Pleistocene have undergone many north-south shifts, the basic configuration of the north-south differentiation has not changed. The barrier-effects of the Himalaya-Qinling-Huai River line have varied between species, but in the coastal region of eastern China, this has been a weak barrier. The north-south transitional affects have been much more pronounced in species that depend on humid environments, and a broad transitional zone has resulted. However, the Qinling-Huai River line may serve as the division of the Palaearctic and the Indomalayan realms in the eastern China.

4) The transition between the humid southeast and the arid northwest has become an effective barrier between the Central Asian fauna and the Southeast coast fauna in terms of ecological adaptation to humidity.

5) The corridor effects of the Hengduan Mountains are most distinctly expressed in the exchange of species between the northern-southern and lowland-highland regions. The area of loess plateau and loess plain in the North China has been most effective as a corridor for the eastward migration of arid zone species. At the same time, it has also been a barrier or partial barrier to species strictly adapted to the humid zones.

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中 文 摘 要

中国地质事件与哺乳动物的分布

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自第三纪初开始, 古地中海 (Tethys) 消亡, 欧亚板块与印度板块合并至今, 中国大陆的地质构造运动与古地理环境变迁大势, 已为许多有充实基础的地质学研究所揭示, 且普遍被地学界所接受。这一情况使我们可以在信赖地质 - 古地理事件研究成果的基础上, 讨论生物的分布, 而避免在生物地理与古环境之间产生循环论证的危险。

本文列举的事实, 说明了我国因地质事件而产生的自然环境分化与变迁对动物分布的影响。概括而言, 它表现为三种与动物扩散 (dispersal) 能力相联系的效应: 有效的阻障 (barrier) 效应; 部分的阻障效应, 与此相联系的是过渡 (transition) 现象; 走廊 (corridor) 或过滤 (filter) 效应。喜玛拉雅 - 秦岭 - 淮河一线是一条重要的地形 - 气候分界线, 始于上新世, 延伸至今。其阻障效应反映在动物区系上古北与东洋的明显分化和相应的分布型的形成。在整个第四纪内, 随时间的推移, 青藏高原的抬升, 喜马拉雅段不断强化其阻障效应, 中亚地区的干旱逐渐加强, 一个适应干旱条件的动物区系随之形成。而在秦岭段所在的东部季风区发生过数次自然地带的南北推移, 结果形成了此两大区系的过渡。正如 Darlington (1957: 472) 所说广泛而充分的过渡 (full transition), 以致对古北与东洋两大区系在此季风区的划分意见产生较大的分歧。但是, 沿秦岭 - 淮河一线仍有一两大区系的明显消减带, 表明其对不同类群的动物仍有不同程度的即部分的阻障作用, 可以作为古北与东洋两界在本地区的分野。黄土高原与华北平原半干旱 - 半湿润环境的形成是对基本上属于湿润环境的季风区的干扰。它一方面是喜湿动物的阻障, 导致南北方向扩散 (dispersal) 的中止或间断 (disjunction), 另一方面成为干旱成分向东扩散的通道。伴随着青藏高原而形成的横断山系, 其走向与喜马拉雅相反。地形上的这一特点, 使其形成了南北动物扩散上的过道或阻障上的缺口。此山系的垂直自然地带, 为动物在生态上提供了多种栖息环境。横断山系垂直幅度大, 且位于中低纬度, 在自更新世以来世界性的气候变迁中, 山地景观带只引起小幅度的、以百米计的垂直移动, 不象北方或开阔景观中大幅度的水平推移, 因而最大限度地保存了原始的而且是世质的生存环境。这种多样性的和在历史变迁中相对稳定的环境, 对物种的保存和分绌都是十分有利的。陆栖脊椎动物中许多类群的物种密度, 在本山系均达到最高的事实, 可以此假设提供佐证。总的说来, 中国哺乳动物动物的现代分布的 9 个主要类型, 其分布范围大体上分别于不同尺度的自然地理环境相一致, 是长期以来适应地质 - 古

地理变迁的结果。

关键词 分布格局 地质事件 区域景观系统 屏障 过渡 动物地理

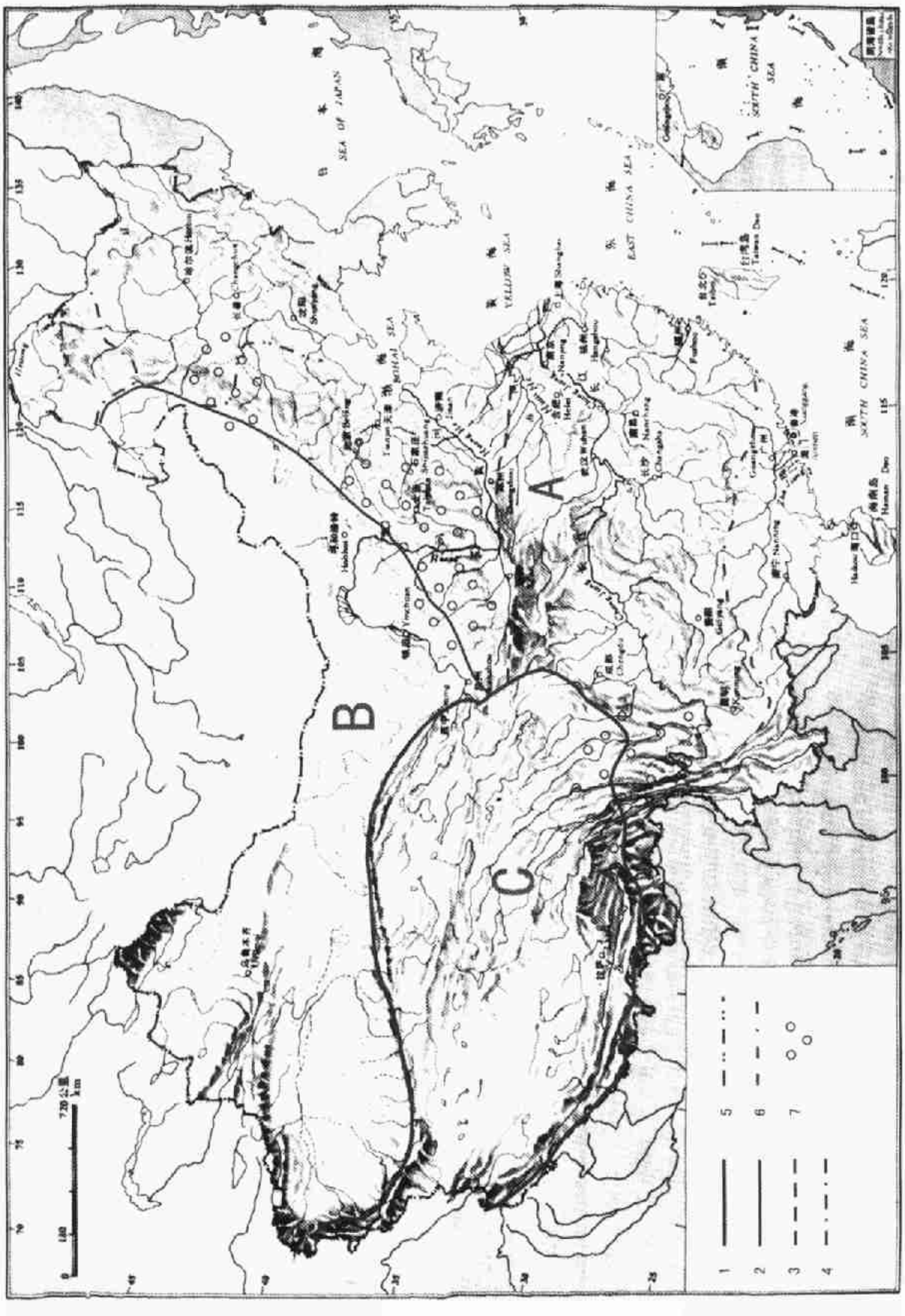
图版说明 (Explanation of Plate)

图 版 Ⅰ(Plate Ⅰ)

A: Eastern Monsoon China B: Northwestern Arid China C: Tibetan Frigid Plateau

1: Qinghai-Xizang Plateau 2: Eastern limit of Arid area/ northwestern limit of Humid area 3: Division of Palaeartic and Indomalayan mammal faunas (Min Mts-Qinling Mts-Huai River line coinciding the isotherm of mean temperature 0 ℃ of January) 4: Southern limit of cold temperate zone (northernmost limit of Oriental elements) 5: Southern limit of the most dominant area of the Palaeartic mammal fauna (coinciding the southern limit of the temperate zone in eastern China) 6: Northern limit of the most dominant area of the Idomalayan mammal fauna (coinciding the northern limit of the tropic and montane tropic-subtropic in southwestern China) 7: Corridor area

Base map quoted from Zhang, Y. Z., S. K. Jin, S. H. Li, Z. Y. Ye, F. G. Wang and M. L. Zhang 1997 Distribution of Mammalian Species in China. Beijing: China Forestry Publishing House.



图版说明见文后 (Explanation at the end of the text)