tered into the Late Triassic, which indicate the region to have been affected by tensile force formerly and by compressive force later. The late Indosinian orogeny caused the covers with their basement to be folded up and faulted, accompanied by intrusion of many granite batholiths, and made this region turn into the constituent of the intracontinental Indosinides in the central part of Heilongjiang Province. The fold belt and granite zones extend in NE to NNE directions. During the early Yanshanian sybcycle, there occurred strongly faulting and related magmatism. For example, the Shenshan granodiorite zone (in Nei Mongol) and the west-marginal fault of the Guanghua Mesozoic rift were developed in the Longjiang zone; accompanying the dextral faults in NW-direction, a series of NE trending faults such as Keluo and Xigangzi were formed in the Muhe zone, along which the Xiaolingshan and other ultrabasic bodies were emplaced; in the Bindong zone, there appeared faults with one set developed best in NE direction, such as the Xitushan-Gaolingzi (in the southwestern sector of the Zhangguangcai Mt.) intermediate-basic (alkali) volcanics-granosiorite intrusions zone and the Yilan-Shulan fault and accompanying intermediate-basic (alkali) volcanics-small granodiorite body zone. During the early stage of mid-Yanshanian subcycle (J_2), molasse-like deposits and acidic tuffaceous clastics accumulated in the small downfaulted basins (distributed very locally) and on the western margin of the Guanghua Mesozoic fault-depression was formed Middle Jurassic coal-bearing clastic formation. In the middle stage (J_3), the intermediate-basic to acidic intermediate volcanic materials were thrown out along the faults of NNE and NE directions, while in the late stage (early-middle Early Cretaceous), several volcanic zones were formed, e. g. the volcanic zones in Guanghua Mesozoic rift (III_2^2), Songnen central depression (III_3^3) and Maoershan depression (III_2^{2-1}). The Songnen Mesozoic rift belt (III_3) has two distinct development stages within the period of Late Yanshanian: faulting stage and large-scale depressing stage. It began to be shriveled for the most part in the early Himalayan and reserved itself as small depressions only in the western part. The Songnen rift disappeared ultimately in the mid-Himalayan subcycle. Just when the Songnen Mesozoic rift was downwarping extensively, the Wuyun-Jieya Cenozoic rift zone (III_5) began depressing and taking sedimemts of the early-middle Late Cretaceous age. Another faulted depression in small scale was developed along the banks of Heilongjiang River and recieved deposits including sandy conglomerates with abundant dinosaur fossils of late Late Cretaceous.

To the Tertiary, in the Bindong and Muhe upwarp zones formed local fault-depressions and took place the intermittent ejection of molten magma of basalt along fractures. The volcanoes acted in Quaternary in the Wudalianchi area and there was formed the famous landscape of Wudalianchi volcanic cluster. The earthquakes associated with them are still active up to now.

5.3.4 Yichun-Yanshou Geosynclinal Fold System (Ⅳ)

The Yichun-Yanshou geosyncline was regenerated on the palaeo-Yichun plateau and the east part of Xiao Hinggan-Songnen block. The basement of the Palaeo-Yichun Plateau

comprises the lower Proterozoic Dongfengshan Group of high-greenschist to low amphibolite facies metamorphic rocks, commonly containing tourmaline. The protoliths and metamorphic features of this group are different from those of the Hinggan and Xingkai Lake block. The high-grade metamorphic rocks in the auriferous iron-silicon metamorphic formation of the Dongfengshan Group may be either residual chips (?) of older crystalline basement or the basal layer of the group. The middle-upper Proterozoic are lacunary in the basement. The Lower Cambrian, being the earliest cover, contains the biological elements both from Siberia Sea and from South China Sea, therefore the Yichun plateau is regarded as a micro-crustal block at that time between these two continents. This micro-block and the Xiao Hinggan-Songnen block together as the ground on which has lain the regenerated geosyncline have been conbined, by inference, by the Zhangguangcailing orogeny. The Tieli-Shangzhi fault is the ancient-suture zone between these blocks. During Early Ordovician, the block-faulting to have come on since the end of early Caledonian subcycle turned into rift-faulting which differentiated the conbined continent into several tectonic units with their own proper features; the Maolin-Mulan rift as a geosyncline in the west, the Fengmao-Yabuli rift as a geosyncline (prior depressing and next faulting) in the east and the Wuxing-Guansongzhen central rise. In addition, there are the Xiangyang concave in the centre of the central rise, and some convexes in both geosynclines. The sedimentary sequence comprises in ascending order: (1) quartzose conglomerates-quartzose sandstones-carbonaceous shales, indicating that the craton was in down-warping steadily; (2) extensive acidic volcanics and argillaceous-siliceous shales, inferring that there was a condition of faulting and depressing of the continental crust; (3) calcareous clastics and limestones indicative of subsiding evenly at that time; (4) intermediate-basic lavas, together with the basalts containing skeletal crystals in the Erheying-Heilonggong area (site of ancient suture zone), representing the products of another strong subsidence associated with local extension of the fracture. The sequence was folded, uplifted and intruded by granite. No flysch deposits were accumulated there. The closure of geosycline may be caused by opposite orogeny of the two blocks on its side. The eastern part of the fold system was welded to the northern part of Jiamusi rise by the giant I-S type monzonite-granite bodies. During the early Variscan subcycle, there happened transgression for a time, which laid down the Devonian marine facies sediments (equivalent to Emsian-Eifelian Stage) here and there in the connect areas of the rise and depression within the geosyncline region. Local mollasses of Givetian Stage have been discovered. The Upper Carboniferous-Lower Triassic sequence, comprising terrestrial-marine-terrestrial facies sedimentary-volcanic series, is scattered and this reflects that these deposits were accumulated in rift basin environment on the epicontinental mobile belt adjacent to the Nei Mongol-Jilin sea. The continuous sedimentary contact relationship of terrestrial facies mollasse on the underlying marine facies mollasse shows that no folding took place before the accumulation of the latter. The early Indosinian orogeny made the whole region uplift consistently and, so that, no Middle

Triassic was deposited. The scattered Upper Triassic acidic volcanics, along with their basement, were folded up and occurred as "boat" floating on the granite batholith zone. These geologic bodies together served as the main part of late Indosinian intracontinental orogeny belt. During the early Yanshanian subcycle, the Yichun-Yanshou fold system was cut by the NE direction fault into two parts: the Yichun and Yanshou. The western and northern parts of the Yichun belt were superimposed with calc-alkaline volcanic basins or downfaulted coal-forming basins of mid-Yanshanian subcycle. During the late Yanshanian, the area along the bank of Heilongjiang River was involved into the Wuyun-Jieya Cenozoic rifted zone, while the Yilan-Shulan fault bacame a Cenozoic rifted zone only during the Himalayan Cycle.

Xingkai Lake-Bureya Mountain Block Region

In the course of Mashan cycle formed a continental nucleus in this region and during the Xingdong cycle, around it formed the continental crust. The Xingkai Lake-Bureya Mountain block was finally solidified through the crust-dismembering and the following combination in the course of the Jinning cycle and the accreting once again of the continental crust in the Zhangguangcailing cycle. The block began differentiating itself since the beginning of Variscan cycle and its eastern part became a regenerated geosyncline during the late Indosinian time and was inverted as a part into the circum-Pacific continental marginal mobile belt in the early Yanshanian subcycle.

5.3.5 Laoyeling Block (Ⅵ)

It is the main body of the Xingkai Lake-Bureya Mountain block region and extends both northwards and southwards into the territory of the Russia. The block was separated by the NE trending Yilan-Shulan and Dunhua-Mishan faults into three parts: the northern, middle and southern. The middle part is best preserved. The Mashan rise (V_2^3) being the paleo-nucleus comprises the upper Archean Mashan Group. The Hutou rise (V_2^8) is the southern part dislocated by the Dunhua-Mishan sinistral fault. Resuming their original seats, the Mashan rise and Hutou rise should have been two oval domes arranging in E—W direction and, as the two rounded ends, consituting a dumbbelt, which shows an E—W trending structural system of Mashan cycle. The lower Proterozoic is of epicontinental geosynclinal formation. There is great thickness of sediments with extensive BIF and minor volcanics near the paleo-nucleus; and with far from the paleo-nucleus, the thickness of sediments decreases, with very few BIF but apparently increasing volcanics, graphite-quartz schists and graphite schist. This indicates that as distance from the nucleus went on, the terrigenous clastics decreased in quantity and the crustal mobilazation has been enhanced. After the Xingdong orogeny, brachy anticlinal-synclinal folds in N—S direction occurred near the paleo-nucleus and flattening domes away from it. The heterochthonous granodiorites (mainly of I-type) occurring near the nuclear area welded the dismembered paleo-nucleus to the nearly N—S trending fold belt of lower Proterozoic rocks. The ap-

pearance of cordierite in the rocks of Mashan Group which is characteristic of low pressure metamorphism and the oldest superimposing metamorphic age of 1840 Ma from granulite indicate that the Mashan Group has been in a metamorphic environment characterized for Xingdong Group. It is deduced from this that the paleo-nucleus has been destroyed by the tectonic orogeny deriving folds in N—S trending and then welded by late penetrating granites, so it was an autochthonous paleo-nucleus. The uplifting of crust (or the adjusting of mantle-crust relationships) made the lower and middle parts of mid-Proterozoic lacuna and caused its breaking in the late stage of mid-Proterozoic (about 1200—1000 Ma ago, tentatively to be assigned to the Early Jinning subcycle) to produce three geosynclines of early stage rift type: the Taipinggou (in Loubei county), Yilan and Mudanjiang. At the end of mid-Proterozoic the geosynclines were closed through A-type subduction at shallow level, and the Lower Subgroup of Heilongjiang Group was deposited in the rift axis areas, while the Upper Subgroup, in the semi-graben basins by the side of the rift. The Guangfutun syntectonic granodiorite body was emplaced into the core of anticline consisting of the rocks of the Lower Subgroup and the hypautochthonous muscovite-epidote granite bodies welded the NE—SW direction fold belts to the paleo-continental crust at the end of the tectonic cycle. During the late Jinning subcycle, along the crossing faults associated with the rift geosynclines were formed local basins, in which the Majiajie Group was deposited and then subjected to high-greenschist—low-amphibolite facies metamorphism under heat flow from the depth. Under the influence of Jinning orogeny (about 800—850 Ma ago), this group was folded up with well-developed phyllitic structure of the rocks and intrusion of hypautochthonous muscovite-tourmaline granite bodies. During the Zhangguangcailing cycle, the western part of the Jiamusi rise (roughly to the west of the Mudanjiang fault nowadays) turned into an eugeosyncline, which laid down deposits of Zhangguangcailing and Huangsong Groups folded up by the Zhangguangcailing orogeny and, as a marginal rise zone of the Laoyeling block welded by granodiorite (of I-S type) together with the paleo-crust. In the course of Caledonian cycle, Laoyeling block, having been a land of Gandwana type for the most part, was in rising without Cambrian to Silurian deposits except the Lower Cambrian covers found only in northeastern Luobei and in local places of Xingkai Lake area. The intrusion of granite bodies of anatectic magma in Shuangyashan-Baoqing and western Mishan, related to deep faulting and occurred along with the strongly folding of the deposits of Yichun-Yanshou geosyncline, apparently resulted from the eastern tectonic domain coming into collision with the western domain at some places.

During the Variscan cycle, the Laoyeling block underwent tectonic evolution different in the west and in the east which allowed the latter area to produce the Baoqing transitional belt (V_3), where were laid down successively deposits of Lower Devonian seamarsh facies and Middle Devonian marine-paralic facies, Upper Devonian terrestrial acidic volcanics and Lower Carboniferous deposits of littoral to terrestrial facies. These formations having a nature of cover indicate that even the transitional belt has not changed its character as a

part of platform at that time. From the late Mid-Carboniferous to the early Late Permian, the Laoyeling block area was land in the west and sea in the east. The Tethysian sea spread northwards in two branches to cover the Laoheishan rift (V_1^3) and the Wandashan area respectively. In the land area was formed the Upper Carboniferous coal-bearing clastic formation and erupted Lower Permian alkali basalts, and in the sea region were laid down shallow-marine clastic-carbonate rocks. The paralic facies deposits were formed in the area between regions with above two kinds of deposits respectively. However, the Upper Permian continuously-distributed terrestrial accumulations (including Vladivostock, Russia, where was the site of sea in Early Permian) suggests that no geosyncline was there developed yet. During the late Indosinian subcycle, the Wandashan area remobilized to become a geosyncline, and in the Baoqing transitional belt paralic and terrestrial sedimentary-volcanic formations occurred only. The Wandashan geosyncline was closed by the late Indosinian orogeny which at the same time had great influence on the Laoyeling block (detailed in the later section). Meanwhile, intense press of the Laoyeling block upon the Hinggan-Nei Mongol tectonic Domain resulted in refaulting of the Jiayin-Jiamusi and Yilan-Mudanjiang palaeosuture zones and palaeosuture zone along the eastern margin of the Taipingling rise. Then the block as a passive continent suffered A-type subduction, which made the Zhangguangcailing-Taipingling areas involved in the intracontinental orogeny belt, where the crust thickened and late-Indosinian granite batholiths intruded.

5.3.6 Wandashan-West Sikhote Geosyncline Fold belt (Ⅵ)

Located in the easternmost part of Heilongjiang Province, the belt extends northwards into Russia. Its south part is cut down by the Dunhua-Mishan fault. The portion in the territory of Heilongjiang Province is called the Wandashan eugeosynclinal fold belt (Ⅵ).

The Wandashan geosyncline was regenerated in the late Indosinian subcycle. The exotic blocks of pregeosynclinal formations from the melange in this fold belt consist of rocks with ages as early as the late Middle Carboniferous—Early Permian, which mostly are Tethyan fusulinid-bearing limestone. However, the gravitational data indicate that the fold belt have a crystalline basement very similar to that of Jiamusi rise.

As we know, the Ladinian-Norian stage strata are chiefly made up of radiolarian siliceous and argillaceous rocks, with intercalated limestones in the upper part, which reflect a downfaulted deep trough environment for their formation. This sequence is overlain conformably by wildflysch deposits. Turbidites and radiolarian argillaceous flysch rocks contain rock-fregments of fusulinid-bearing limestones, silicilites, ultramafic-mafic complex and basic-ultrabasic lava, constituting the melange bodies, which as independent unit can be mapped. The melange blocks are best developed along the margins of geosynclinal fold belt with associated ultramafic-mafic accumulational complex zones, reflecting there have been a deep ocean trench along the margins of geosyncline. The rock fragments in greywakes mostly are of acidic pyroclastics and partially of basic-ultrabasic rocks (with

spinifex textures). It is clear that the site of deposition of turbidite was very close to the volcanic eruption region. The ultramafic rocks in the accumulates are ferruginous ultrabasics, with which the spilites have a gradational contact and having a calc-alkaline nature, being of differentiated products of basaltic magma. The ultramafic lavas (komatiites) erupted lastly and magnesium ultrabasic rocks distributed along the western margin of the fold belt are provided with even more features of upper mantle rocks. The well-developed cumulus crystal texture in these rocks and their magmatic origin signify that there took place spreading in the Wandashan geosyncline area and the rupture of crust has gone downward from the upper layer. So this suggests that the ultramafic-mafic rocks in this area occurred later than radiolarian siliceous rock series. Further upward on the sedimentary colum, there is flysch composed of turbidite sandstones (conglomerates) and siltpelites. During orogenic process, granites intruded along the margins of the geosyncline, while anatectic granodiorites were emplaced into the flysch formation. The whole Wandashan fold belt constitutes the Raohe anticlinorium. Thrusts in both fringes of the anticlinorium in the opposite direction and oblique faults in NE and NW directions are developed.

Generally, the Wandashan fold belt is an N—S trending arc slightly projecting to west, showing the westward-overthrusting (or obducting) the Baoqing transitional belt. This has been also supported by electric and magnetic compsite sections. From that time on, the fold belt acted again in unison with the Laoyeling block in tectonic evolution.

Sinistral motion of the Dunhua-Mishan fault marking the turn of the late Indosinian into early Yanshanian subcycle has cut both the Laoyeling block and Wandashan geosynclinal fold belt and made them displaced. The displaced parts of some marked tectonic units, deep faults and other geologic bodies such as Zhangguangcailing rise, Mudanjiang faults, Lower Subgroup of Heilongjiang Group in Mudanjiang area, Mashan rise and Wandashan geosynclinal fold belt all have been distributed in sinistral motion to a distance no less than 240km and served as geologic elements respectively such as Taipingling rise, east-marginal fault (in the territory of Russia filled by Tertiary deposits) of the Taipingling rise, Baodong rise, Hutou rise and West Sikhote geosynclinal fold belt (in the territory of Russia). At the same time, a series of NEE trending oblique faults occurred on both sides of Dunhua-Mishan fault with best development on the northwestern side and parallel faults formed very distinctly on its southeastern side. The Yilan-Shulan fault, without strike-slip but dextral motion in the late, has also formed simultaneously.

During the early Yanshanian subcycle, the Dunhua-Mishan fault was inverted from compressive shearing to tensile shearing with dextral nature. This resulted in the extrusion of alkaline basalts and intrusion of granodiorites on its southeastern side, however, on the northeastern side were formed faulted basins, mainly linear in shape, receiving the Longzhaogou Lower Subgroup deposits. The basal conglomerates of the Lower and Middle Subgroup of Longzhaogou Group contain abundant fragments of radiolarian pelites and siliceous rocks, being of mollasse deposits. During the mid-Yanshanian subcycle, areal

downfaulted depressions were developed on the Jiamusi rise, in consequence a series of coal-forming basins were formed. It is shown from the pattern of distribution of the lands and seas that the NNE direction tectonic system was developed and bacame gradually distinct and ripe at that time. The fold belt as a whole was upwarped in the late Yanshanian subcycle, and associated by development of some downwarp on it, such as the Hailang concave (V_1^{1-1}) and some small basins superimposed by the Sanjiang Cenozoic rifted zone (V_4), which is a result of Hamalayan cycle. In addition to that rifted zone there were also formed the Hulin Cenozoic faulted depression (V_2^5) and linear rifts of Dunhua-Mishan and Yilan-Shulan and was developed the overflow of basalt magma in Himalayan cycle.

5.4 Neotectonics (Omitted)

6. REGIONAL GEOLOGICAL HISTORY

Geotectonically, the Heilongjiang Province extends across parts of the Paleo-Asian tectonic domain and the circum-Pacific tectonic domain. Taking the line joining Jiayin, Jiamusi, Yilan and Jingbo Lake as a boundary, the region to the west of it is named Hinggan-Nei Mongol fold belt (Hinggan division in short) and the region to the east is called Xingkai Lake-Bureya Mountain block (Xingkai Lake division in short). These two regions have had completely different geologic history before the late Indosinian orogeny. The Hinggan division situated in Palaeo-Asian tectonic domain was the southeastern-marginal mobile belt of the Siberian-Monglian continent, some parts of which were reactivated during early Paleozoic into geosyclines folded and uplifted successively in the coures of mid-Caledonian and mid-Variscan, and finally merged into the circum-Pacific continental margin mobile belt by the late Indosinian orogeny. Xingkai Lake division, possibly a portion of the circum-Pacific continental margin tectonic domain, was disintegrated during late Paleozoic and part of it was reactiveted into geosyncline during early Mesozoic and then changed into Pacific-type continental margin. In brief, the following events were experienced in Heilongjiang Province, i. e., the formation of continental crust, convergent motion and collision of existed continental blocks and the spliting and incorporation of sialic crust within these blocks. Four stages of geohistory can be divided according to the geohistorical sequence as late Archean, Proterozoic, late stage of Proterozoic-early stage of Early Jurassic and late Early Jurassic-Quaternary.

6.1 Late Archean

Within the territory of Heilongjiang Province, only in Xingkai Lake division the history of evolution of the late Archean continental nucleus can be traced from the Mashan

Group. As the oldest products of nuclear crust in this province the protolith of Mashan Group was formed under an oxygen-deficient active continent-arc environment in volcanic island sea with intense ultrabasic-basic-intermediate volcanic activites. Basaltic magma began to differentiate at the late stage to produce intermediate-acidic volcanics. Rocks of the group have experienced medium pressure-high temperature regional dynamothermal metamorphism, forming prograde metamorphic complexes of lower amphibolite facies-high amphibolite facies-granulite facies with the high amphibolite facies as the major one. Migmatites and migmatic granites containing minerals rich in aluminium were caused by subsequent in situ remelting of these metamorphic products in the late stage of metamorphic process. The metamorphic rocks underwent mainly vertical plastic deformation and, therefore, east-west elongated oval domes were formed. The injection of basic dykes, accompanying the fracturing of the rigid crust made the old continental nucleus consolidated.

6.2 Proterozoic (2500-670 Ma)

It includes the primary stage of formation of crustal blocks during the Proterozoic paleo-megacycle and the final stage of formation of these blocks during Proterozoic neo-megacyle.

6.2.1 Xingkai Lake Division

The embryonic basement of Xingkai Lake block was formed after Mashan orogeny. There appeared continental margin environment around the old nucleus and deposited Xingdong Group during early Proterozoic. It is composed of deposits of a megacycle of sedimentation in geosyncline, constituted by clayshale formation, clastic-carbonate formation and flysch formation. Volcanic intercalations, leaning to intermediate-basic in composition, increase away from the continental nucleus in quantity. This shows that there was not any change in crustal activity there at that time. The nucleus has served as a sources of clastic materials as indicated by the appearance of metamorphosed sedimentary magnetite quartzite in the Dapandao Formation developed near that nucleus. Sedimentary sequences suffered low-pressure dynamothermal regional metamorphism, forming a metamorphic rock association mainly of lower amphibolite facies and then followed by migmatization to produce the migmatitic granite bodies with domed shape. Allochthonous granodiorite and monzonitic granite bodies were also formed in this stage. This marks the beginning of magmatic intrusions caused by continental crust thickening. The appearance of brachy folds (anticline and syncline) near the continental nucleus and flattened domes far away from it indicates that the deformation happened at that time was still plastic in predominance. With the rising of deformation in a more brittle state after folding, there appeared the intrusion of allochthonous granodiorite bodies (I-S type), which made the geosyclinal fold belt welded upon the old continental nucleus to form the major part of Xingkai Lake block. Xingdong orogeny marks the end of Proterozoic paleo-megacycle.

After Xingdong orogeny, Xingkai Lake block was uplifted as a whole, and in the interior of the block were formed aulacogens about 1200 Ma years ago, near the axis of which in the valley were deposited deep water facies pelite (containing manganese concretion in its lower part), silicolites, basalt and dacite with serpentinite fragments. The halfgrabens on the side of the valley received alkaline basalt and trachyte of Zhoujiatun Formation and greywacke-magneso-limestone of Xiangyangcun Formation. The bimodal volcanic association of alkaline basalt, tholeiite and dacite near the axis of the aulacogen and the bimodal volcanic association of alkaline basalt and trachyte in the halfgraben basins marked the first appearance of rifting within the continental crust in the geological history. When the rift acted from spreading into converging state, the shallow A-type subduction has led to the superposition of the strata on both margins of the rift and the formation of high-pressure greenschist facies series metamorphic rocks and middle-pressure lower amphibolite facies series metamorphic rocks constituting the paired-like metamorphic belts. The latter belt is accompanied by hypautochthonous epidote-muscovite granite bodies. It is deduced from the U-Pb age of 922 Ma of the Lower Subgroup of Heilongjiang Group that the age of the first episode, Heilongjiang orogeny, of the Jinning Cycle is about 1000 Ma ago.

The deposits in aulacogen were folded and uplifted by Heilongjiang orogeny and at the same time the marginal crossfaults were spreaded with occurring of two small but deep faulted basins as Majiajie basin and Gangbenshan basin, in which the Majiajie Group was deposited. The sedimentary rocks were metamorphosed by heat flow from deep crust to form an andalusite-garnet-staurolite prograde metamorphic zone and phyllitic structure was created by subsequent folding. Intrusion of tourmaline granite stock took place at the end of this tectonic event. The upper age-limit for the second episode of Jinning cycle is 850-800 Ma.

The early history of the block as represented by uplifting, rifting and welding was ended by Jinning orogeny. In the late stage of late Proterozoic, to the west of the existing continental block, there was developed a pericratonic mobile belt where was laid down the Zhangguangcailing Group (and Huangsong Group) comprising clayshale formation, submarine intermediate-basic and intermediate-acidic volcanics and argillo-arenaceous flysch formation with emplaced ultramafic-mafic rocks. The sedimentary-volcanic series experienced a regional metamorphism to make a greenschist-lower amphibolite facies rocks series come into being. The geosynclinal deposits were folded and uplifted by Zhangguangcailing orogeny (about 670 Ma) to have served as a marginal upwarping zone of the Xingkai Lake block, with development of syntectonic granodiorite (I-type) bodies of syntectic origin. This upwarping zone was welded to the old block by granodiorite and monzonitic granite bodies of anatectic origin, such as intrusive bodies in Chushan and Zihe areas, distributed in the eastern part of the fold belt. Up to that time the Xingkai Lake block was at last consolidated and Proterozoic neo-megacycle ended itself.

6.2.2 Hinggan Division

It is situated to the south of Aldan shield and has been a marginal mobile belt of old continental nucleus during the Proterozoic. In the early Proterozoic, the northern part of Heilongjiang Province was a part of a geosyncline in which were deposited Xinghua Formation and the lower part (consisting of basic and intermediate-acidic volcanics, carbonate rocks and iron-bearing siliceous formation) of Xing'anqiao Formation in its subsiding stage and the upper part of Xing'anqiao Formation (comprising argillo-arenaceous flysch formation) in the uplifting stage. The geosynclinal deposits were folded and uplifted by intense crustal orogeny at the end of early Proterozoic and there was formed the basement of Hinggan block. The southeastern margin of the block which was in a stable state during the mid-Proterozoic sank again to a geosyncline in the early stage of late Proterozoic. The Luomahu faulted depression on the continental margin was an eugeosyncline with deposits of the lower part of Luomahu Group comprising calc-alkaline volcanic rock series of rhyolite intercalated with basalt and dacite erupted during its subsiding stage and of the upper part of Luomahu Group composed of the argillo-arenaceous flysch intercalated with intermediate-acidic volcanics laid down during the inversion stage. The back-arc miogeosyncline (epicontinental shallow sea) received only flysch intercalated with acidic tuffs; and in the forearc basin (deep shallow-sea or bathyal sea) was deposited the Fengshuigouhe Group of pelite interlayered with minor sandstones and lenticular limestones. The second episode of Jinning orogeny caused the geosynclines to be folded and the continent had its accretion (thickening) southeastwards. At the latest Proterozoic the marginal faulted depression occurred in place farther southeast, in the Xiao Hinggan Mountains area, and the forearc, in the southwest part of Zhangguangcai Mountain area, where was laid down Yimianpo Group. This geosyncline was folded and uplifted by the crustal orogeny happened about 670 Ma ago. At that time, in the Ergun region which consolidated long ago, however, there appeared faulted depression in NEE direction, in which formed the Lingdian Group. It comprises rocks, in ascending order, of metamorphosed fine-grained feldspar-bearing quartz sandstone-siltstone intercalated with intermediate-acidic lava and crystallized clastic limestone → intermediate (acidic) lava and tuff → slate → metabasic lava with ultramafic-mafic complexes. This makes it clear that the faulted depression acted with spreading motion, and therefore was characteristic of a rift. The geosyncline was closed by Zhangguangcailing orogeny. From that time on, the Hinggan block as a whole was finally consolidated up. Between the Hinggan and Xingkai Lake blocks there was the "Palaeo-Yichun block", whose crystalline basement is composed of lower Proterozoic metamorphosed boron-bearing series-Dongfengshan Group. It existed as a stable block during the mid-to late Proterozoic.

6.3 Latest Proterozoic-Earliest Jurassic

A new stage of tectonic evolution, i.e. Phanerozoic, appeared within the territory of

Heilongjiang Province 670 Ma years ago. There was a major tendancy of development in this stage displaying itself in evolution of life from the thriving of marine invertebrates to gradual flourishing of land flora, and in sedimentation from mainly marine deposits to chiefly terrestrial accumulative formation as well as in the rupturing and re-incorporation of continental crust.

6.3.1 Xingkai Lake Division

After the formation of the Zhangguangcailing marginal upwarping zone, some regions within the Xingkai Lake block uplifted were depressed in the Early Cambrian and received deposits of Jinyinku Formation as the earliest cover. There are no any sedimentary recored of Middle Cambrian to middle Early Devonian to be preserved. When the sedimentary formation in Yichun-Yanshou geosyncline was folded, uplifted and incorporated with the Xingkai Lake block by the middle Caledonian orogeny, the existing faults within the limits of the block were reactivated, resulting in the intrusion of syntectic granite. In the course from late Early Devonian to Early Carboniferous, the block began to differentiate itself into western and eastern portions with somewhat different tectonic evolution. There occurred an intracontinental depression along Mishan-Baoqing-Suibin, in which formed platform type formations consisting of littoral swamp facies-marine facies-paralic facies deposits. Marine zoolites of Middle Devonian and Lower Carboniferous rocks are mainly of North American elements with certain common elements of South China, Australia and Vietnam, which indicate this area to belong to Australia-Pacific paleozoologic province.

This division was in the circum-Pacific subsided continental margin area from Middle Carboniferous to Early Triassic. Sea waters from the ancient Pacific spreaded in two directions branched by a peninsula, i.e. the part of Xingkai Lake block in Russia; one extended along the West Sikhote-Wandashan and went farther north and the other flooded westward the Yanbian district, Jilin Province. Therefore, the region to the west of the line of Tongjiang-Dongfanghong was in land and the area to the east of the line was covered with sea water, while the Jidong and Laoheishan areas were frequently under the sea level. The most part of Heilongjiang Province was exposed to be denudated during Middle Carboniferous. In the Late Carboniferous there appeared fault-block depressions with coal-bearing acidic volcaniclastic formation. During Early Permian, there happened rupturing of crust with eruption of high alkaline andesitic basalt of Erlongshan Formation; no deposits were laid down in the time from late Early Permian to early Late Permian in the land areas, but there were accumulated thick sediments in marine basins; from latest Permian the whole division was uplifted to be land, with accompanying fractures, along which took place the eruption of andesitic basalt flow, lasted to the early Early Triassic.

The interval from late Early Triassic to early Middle Triassic was a period of general uplifting of the division, during which the transition zone from sea to land was stretched and thinned to lead to the Wandashan area depressed and faulted into a deep trough. From late Middle Triassic to middle Late Triassic in the trough were firstly deposited very thick

abyssal radiolarian siliceous-pelitic sediments and subsequently the alternation of acidic-volcanogenic-material-rich sediments and abyssal pelite. The tension opening in sea trough led to the rise of basaltic magma, from which were derived accumulations of ultramafic-mafic complex and pillow lavas with a composition mainly of spilite. As the spreading of the trough became more intense, the upwelling of mantle brought about some ultramafic effusions and mafic-ultrabasic intrusions. In the course from late Late Triassic to early Early Jurassic when the forces acted on opposite sides of the deep trough changed from tensile to compressive, there was formed the melange (wildflysch) of Dalingqiao Formation and subsequently flysch was deposited during the orogenic stage. The Wandashan reactivated geosyncline was folded and uplifted during late Indosinian orogeny at about 200 Ma years ago, with intrusion of anatectic granodiorite (S-type) and monzogranite along marginal faults of the geosyncline. At this stage in the depression basins by the side of Wandashan deep trough accumulated Upper Triassic coastal-shallow sea facies deposits containing Australian-Pacific element *Monotis* (*Entomonotis*) *ochotica* and overlying veriegated terrestrial coarse-grained clastic rocks, and appeared the eruption of acidic volcanics along the faults. While in Taiping Moutain region developed Upper Triassic acidic volcanic eruptions containing *Cycadocarpidium-Taeniopteris* assemblage, a flora characteristic of warm region.

6.3.2 Hinggan Division

It includes Yichun block and Hinggan block, which have different tectonic history displaying in size and the character of their basement.

6.3.2.1 Yichun Block It was consolidated at the end of the early Proterozoic and was in uplifting condition during middle-late Proterozoic. As a whole, during early Cambrian, this region submerged to receive the deposits of Xilin Group containing *Proerbia* sp., which is a Siberian-Arctic element. Its coexisting with *Kootenia* sp. indicates that waters in this region were possibly linked at that time with waters from Australian-Pacific ocean and the very thick carbonate deposits suggest that the climate was warm amd damp at that time. All the block was uplifted during Mid-to-Late Cambrian. During the time from Early to Middle Ordovician, the sea water from the north covered the whole region and the contiguous faulted depression at the southeastern margin of Hinggan block, resulting in formation of a Caledonian sea-trough. There remained a lot of "platform fragment" in the trough, which constituted a median rise zone. To the east of it, the geosyncline experienced a primary stage of downwarping and a subsequent stage of faulting-downwarping, and the area to the west of the rise zone and the central depression were charactrized by remobilization of faulting-downwarping only. The landmasses on both sides of the trough were compressed towards each other during the mid-Caledonian orogeny at late Middle Orodovician. This led to the geosyncline to be close in "compressive-yield" style. The intense compression resulted in remelting of deep crust and upwelling to form a Xiaoxilin type contaminated monzonitic granite zone (S-type), and then in intrusion of syntectic

granodiorite (I-type). The overthrusting of the geosynclinal fold belt toward the Xingkai Lake block caused intrusion of the gigantic Dafeng monzonitic granite body (I-S type) along their boundary, which led to the crust-blocks to the east of Xinkailing fault to be welded into a unified one. The brachiopod fauna from Xiaojingou Formation is similar to that from Ordovician rocks formed in Da Hinggan trough. It indicates that these two areas have been a part of the Okhotsk-Mongolia sea-trough.

This division was in uplifting without any sedimentation from Late Ordovician to middle Early Devonian. During late Early Devonian-early Middle Devonian, the sea waters made a transgress from north and then a regress from south to north and deposited in this interval coastal-shallow sea facies clastic and carbonate materials in some local small faulted basins. At late Middle Devonian in some intermountain depressions in Yanshou area was accumulated molasse bearing Siberian flora element *Barsassia sibirica*. There was no any sedimentation from Late Devonian to Middle Carboniferous. The division was involved in the marginal mobile belt bordering on the Nei Mongol-Jilin sea during Late Carboniferous.

6. 3. 2. 2 Hinggan Block This block has accreted twice in the southeast during Late Proterozoic but did not solidify firmly by Zhangguangcailing orogeny. Therefore, the uplifting at the last stage of Proterozoic resulted in dismembering of the inhomogeneous crust-mass into fault-blocks meaning a future differentiation in development of them. The divergence and convergence of these blocks gave a typical example for such a tectonic orogeny.

The Hinggan block was divided in Early Cambrian into two parts by Xinkailing fault (from Aihui to Yirshi), with uplifting of the southern part and subsiding of the northern part. The latter, equivalent in area to the greater part of Da Hinggan Mountains, was flooded by waters from the Siberian sea. That is the beginning of formation of the cover rocks. The Lower Cambrian Xinglong Group overlies unconformably the late Proterozoic granite bodies (Sm-Nd age of 638 Ma). The northern part of Hinggan block was in denudation during Middle-Late Cambrian. Due to the uneven uplifting and denudation and the variation of thermal regimes of the lithosphere, there appeared aulacogen-regenerated geosynclines: the Xinglonggou miogeosyncline lying between the Xinghua-Tayuan fault and Pangkaimen-Shierzhan fault and the Handaqi eugeosyncline situated on its southeast and bordered on the south by the Xinkailing fault.

The Xinglonggou geosyncline regenerated in the early Early Ordovician had evident changes of its depression center with time. It received in its western part Ordovician deposits but no Silurian records have been found there. Lower Devonian sediments were laid down in the eastern part of the geosyncline and migrated again the center of subsidence to the west during Middle Devonian. These sedimentary formations were folded in the course of Late Devonian with the sea water migrating to Tahe transition zone on the west and the geosyncline closed at last at the end of Visean age of Early Carboniferous.

The Handaqi geosynclinal fold belt is the major part of Da Hinggan Mountains geosynclinal fold system. In the northwestern part of the geosyneline there was the Luomahu central rise, to the north of which was located the Kuanhe faulted depression and to the south the Handaqi faulted depression. The geosyncline was generated in the middle Early Ordovician and lasted to the early Late Devonian. The sedimentation continued throughout comprising three subcycles with three submarine volcanic eruptives of intermediate-basic composition. It is the late stage of geosyncline development from the latest Devonian to the Visean Age of Early Carboniferous, during which accumulated molasse in the intermountain basins and the sea migrated southward to the Honghutuhe area to the south of Xinkailing fault. Syntectonic granites of early Variscan subcycle resulted in close of the marginal portions of the geosyncline, and the first phase of granite intrusion of mid-Variscian subcycle led to the final close of the geosyncline as a whole.

The appearance of genobenthos in large amounts in Middle and Late Devonian marked an important turning point both in evolution of life and in change of sedimentation conditions from predominate marine facies to the land facies in the first place. No Middle Carboniferous sediments are observed. From Late Carboniferous to Early Triassic, the Ergun block kept uplifted and the Da Hinggan Mountains fold belt was mainly in uplifting with locally downwarping, but the Xiao Hinggan-Songnen block which has been in uplifting for a long time was sinking in this period and, with the Yichun-Yanshou mid-Caledonian fold belt together, became a marginal mobile belt contiguous to the Nei Mongol-Jilin sea. On the mobile belt accumulated a very thick sequence of continental-marine-continental facies, with a common presence of volcanic materials. The Lower Triassic inland lake facies was restricted within the limits of Xiao Hinggan-Songnen block and Da Hinggan Mountains fold belt. The existance of varicolored clastic rocks lying on the lacustrine deposits indicate that there was crustal uplifting and dry and hot climate there and then.

The evolution of the Paleozoic regenerated geosynclines were ended by the mid-Variscan, then the crust in territory of Heilongjiang Province presented itself as a unified one. The land plants did not show obvious differentiation in evolution from Late Carboniferous to Early Triassic and they all belong to the Angara-Cathaysia mixed flora, and yet the marine animals developed in different evolution on the two sides of Jiamusi rise zone-Zhangguangcailing-Taipingling rise zone (there was channel to the south of Jingbo Lake in Jilin Province during Late Permian). The marine faunae living in the southeast of Xingkai Lake area were constituted by warm water animals, while those developed in the southeast of Hinggan Mountains area were mixed faunae consisting of both cold water and warm water individuals.

No sediments of Middle Triassic have been seen. The middle-late stage of Late Triassic acidic volcanics are very extensive in distribution, with development of late Indosinian granite bodies, especially in Yichun-Yanshou area and in the conjunction of Zhangguangcailing marginal rise with Jiamusi rise, where was formed a huge zone of granite

batholiths.

The late Indosinian orogeny caused the Wandashan geosyncline to close rapidly and large scale of intracontinental mountain-building process in Zhangguangcailing and in the area to the west of it. After the ending of Indosinian orogeny at the early Early Jurassic (about 200 Ma B. P.), there appeared a sinistrial couple probably due to the northeastward motion of the Pacific-Kula plate. This resulted in a long distance of horizontal displacement (at least 240km) along the Dunhua-Mishan fault. Such a large scale displacement undoubtedly marked a transformation of Paleozoic tectonic style into Mesozoic-Cenozoic one occurring between the early stage and late stage of Jurassic.

6.4 Late Early Jurassic-Quaternary

The whole area of Heilongjiang Province was in the circum-Pacific continental margin mobile belt. Four stages of development may be recognized: appearance of early coal-forming basins, calc-alkaline volcanic eruption and development of late coal-forming basins, formation of large scale petroliferous fault-basins and effusion of basaltic flow and development of linear faulted depressions on the plain and along the intermountain space.

The coal basins of the first stage formed under the influence and control of the preexisting tectonic framework, with lineament in NEE or E—W direction. In the second stage (Late Jurassic), however, there appeared continental volcanic eruption in Da Hinggan Mountains area and the structural lines obviously turned to NNE because of the interaction of the Pacific plate and the East Asian continent and the upwarping of the mantle. From then on, started a course of successive appearance of depression zones in direction from Da Hinggan steep gravity gradient zone towards the sea: the middle Yanshanian faulted depression zone, late Yanshanian faulted depression zone (Songnen Basin) and Himalayan faulted depression zone (e. g. Yilan-Shulan, Sanjiang and Dunhua-Mishan faulted depression zones), while the inland coal-forming basins were in forming and developing in the western part of the province, and the sea water extended over the east part where formed Jurassic paralic coal-bearing formation and Lower Cretaceous paralic-limnic coal-bearing formation.

The paleo-Hinggan Mountains uplifted rapidly after mid-Yanshanian orogeny and to the east of the paleo-mountains developed a large scale faulted depression basin—Songliao basin (its part in this province is called Songnen basin), in which accumulated mainly deposits of land facies with minor marine facies.

As the continental margin of eastern China was being stretched and ruptured from the beginning of Himalayan cycle, Heilongjiang Province as a whole was in subsiding. Faulting and block-faulting were particularly extensive in area to the east of Songnen basin, where the Sanjiang, Yilan-Shulan, Dunhua-Mishan and Hulin areas have transformed into Cenozoic faulted depressions. The sedimentation center of Wuyun-Jieya basin to the north

of Songnen basin was in the territory of Russia.

It was warm and damp during Palaeogene period and as a result coal and oil shale are widespread in distribution in Palaeogene deposits in Heilongjiang. But it tended to be dry during Neogene and rocks formed at that time are all with an increase in purplish red color. The alternation of cold and warm climate in Quaternary has caused periglacial environment within the territory of Heilongjiang.

The general tendency of the intermittent eruption of Cenozoic basaltic magma from about 45 Ma B. P. to 1721 is that the alkalinity of magma increased temporally from the old to the young and spatially from the east to the west. The magma activity decreased in scope with time and only occasional weak seismic activities occur now in Wudalianchi lake area, this reflects a general trend of stability of the crust in Heilongjiang Province.

CONCLUSION

This monograph gives a systematical summary on stratigraphy, volcanic rocks and volcanism, intrusive rocks and intrusion, metamorphic rocks and metamorphism, geotectonics and geological history of Heilongjiang Province, on the basis of which a brand-new geologic map at a scale of 1 : 1 000 000 was produced.

The significant achievements gained in the compilation of this book and in the supplementary field and in house studies are as follows: (1) the affirmation of existence of Archean rocks in the province based on an isotopic age of 2539 Ma obtained for the Mashan Group nearby Jixi city; (2) the first find of micropaleobotanic remains of late Proterozoic in Zhangguangcai Mountain area, which made possible to have set up Zhangguangcailing Group and Yimianpo Group; (3) the first discovery of Middle Ordovician brachiopods in rocks nearby the seat of Shangzhi county, which led to establish a stratigraphic succession for Ordovician rocks in Yichun-Yanshou division; (4) the finding of Early Jurassic marine fauna in the Wanda Mountain region, which filled in the gap in Lower Jurassic stratigraphy in Heilongjiang; (5) the first dating of reliable Caledonian ages for granites in Yichun-Yanshou division, where a Caledonian granite belt was picked out; (6) the obtaining of a number of reliable Indosinian ages for granites in Yichun-Yanshou division and the first recognization of Indosinian granite belt there; (7) the dating of reliable late Proterozoic age for granites exposed in Zhangguangcai Mountain area and the distinguishing of granite bodies of Zhangguangcailing age, and (8) the determination of large numbers of isotopic ages for Ordovician, Triassic and Cenozoic volcanic rocks.

Some new ideas on the geology of Heilongjiang have been put forward in. (1) Geotectonically, the province comprises two parts: the Hinggan Mountains-Nei Mongol geosynclinal folded region and the Xingkai Lake-Bureya Mountain massif, which are subordinate to Palaeo-Asiatic tectonic domain and circum-(palaeo) Pacific tectonic domain respective-

ly. They strikingly controlled the distribution of sedimentary, magmatic and metamorphic rocks and tectonic evolution before late Indosinian orogeny, and had influence also on the geotectonic evolution after it. (2) It is refused that the eastern part of Heilongjiang Province is a part of "the Jilin-Heilongjiang late Variscan geosynclinal fold system" and the Da Hinggan Mountains fold system is the product of a primary geosyncline. These points of view have been held by the geologists with traditional ideas. In contrary, this book considers that geosynclines developed since Palaeozoic in the province for the most part are of the intracontinental and those occurring in Hinggan Moutains region were regenerated in Palaeozoic and folded one after another as a result of middle Caledonian and early and middle Variscan orogenies; and, however, those appearing in the Xingkai Lake region were regenerated at early Mesozoic and folded owing to the late Indosinian orogeny. (3) It is affirmed that the late Indosinian granites widespread in distribution in Zhangguangcai Mountain, Yichun-Yanshou and areas to the west of them are products of "post-platform type" (or intracontinental) orogeny. (4) A new point of view was advanced for Dunhua-Mishan fault which has slipped sinistrally up to 240 km at a time between the early and the late of Early Jurassic epoch. (5) There are proposed four stages of development in geological evolution in the province: stage of formation of the nucleus, stage of formation of the crust mass, stage of dismembering and matching of the continental crust and the stage characteristic of being circum-Pacific type continental margin mobile zone. The tectonics of the province can be summarized as follows. The nuclear area of the Xingkai Lake block formed at about 2500 Ma years ago and the continental crust blocks of Xingkai Lake, Palaeo-Yichun and Hinggan formed at about 1850 Ma years ago. The faulting-downwarping zones (early stage of the rift) appeared in the Xingkai Lake block at about 1200 Ma B. P. and then they were shrinked successively into intracontinental fold belts at 1000 Ma and 800 Ma years ago. The Zhangguangcailing marginal rise appeared at 670 Ma years ago, which marked the final consolidation of the Xingkai Lake block. The Hinggan block which was in rising at middle Proterozoic has grown southeastwards reaching to the Xiao Hinggan Mountains at the early time of late Proterozoic and to the southwestern part of the Zhangguangcai Mountain at the late stage of Late Proterozoic, during the latter time the accretion (thickening) was accompanied by destruction.

After its formation, the continental crust mass was rising at the end of Proterozoic and there appeared the Xinkailing deep fault, which made it uplifting in the south and subsiding in the north at Early Cambrian. The Yichun block sank into a table-land, and the Xingkai Lake block subsided locally only. Middle-Late Cambrian block-faulting caused the Hinggan block to have broken up into the Ergun massif and Xiao Hinggan-Songnen massif and appearance of Da Hinggan regenerated geosyncline between them. The Yichun-Yanshou region was regenerated into a geosyncline system and the Xingkai Lake block was uplifted. At the end of Middle Ordovician, the Yichun-Yanshou geosyncline system closed itself and joined its opposite land masses. In the late Early Devonian, the Xingkai Lake

block, differentiated into two parts, the eastern and the western, with features unlike. The Da Hinggan gerenerated geosyncline was closed in Early Carboniferous (Visean Age). At that time the crusts in the province united together. At the late of Middle Carboniferous, the Xiao Hinggan-Songnen massif and Yichun-Yanshou fold system were subsided to become a continent-marginal block-depression bordering the Nei Mongol-Jilin sea, where transgression occurred once in the Permian Period. The Xingkai Lake block further differentiated and as a result its southern and eastern parts turned into a section of the circum-(palaeo)Pacific continental marginal block-depression belt. Wandashan region was regenerated into geosyncline at Middle Triassic. From the end of Late Triassic to the early time of Early Jurassic, in Zhangguangcai Mountain-Xiao Hinggan Mountains area took place the "post-platform" (intracontinental) orogeny accompanied by occurrence of a huge granite belt and the Wandashan regenerated geosyncline closed itself. Up to this time, the whole province became only an integrated land. Followed that, sinistral Dunhua-Mishan fault had a slide up to 240 km in distance, which marked a transformation of the Palaeozoic tectonic style into the Mesozoic-Cenozoic one.

The time interval from late Early Jurassic to Middle Jurassic is the early stage of formation of coal-forming basins, during which inland coal-bearing basins were formed in the upper reaches of Heilongjiang River and paralic coal basins in Longzhaogou area. It is the stage of formation of calc-alkaline volcanic rock belt and later coal-forming basin from Late Jurassic to middle Early Cretaceous. During this period, the tectonic line changed its trend into NNE, and the calc-alkaline magmatic rock belt occurred and inland coal-forming basins developed in the Da and Xiao Hinggan Mountains areas, and coal basins with paralic and, upwards, paralic-limnic coal-bearing series were fromed in Xingkai Lake region. The stage of formation of large petroliferous basin refers to the time interval from late Early Cretaceous to middle Late Cretaceous, during which formed the Songnen inland petroliferous basin. At the time after late Late Cretaceous, fault depression belts occurred and Cenozoic basalts erupted in the areas to the east of the Da'an-Dehu line. Finally, present geomorphic features were formed. It is a stage characteristic of eruption of basaltic magma and development of plain and valley fault depression.

The major problems remaining to be solved are as follows: (1) Archean rocks have not been recognized in the Hinggan division; (2) The metamorphic rocks in middle Proterozoic series and in the lower part of Upper Proterozoic series want to date reliable ages; and (3) It is a pending discussion whether there exist early and middle Variscan granites in the eastern part of the province.

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