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Jurassic rocks, bivalves, and depositional environments of the source area of the Yangtze River, Qinghai Province, western China

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Jurassic rocks are abundantly developed in the source area of the Yangtze River, South Qinghai, with the greatest thickness of 6311 m, including five stratigraphic units: Qoimaco Formation, Buqu Formation, Xiali Formation, Suowa Formation, and Xueshan Formation. Based on sufficient fossils of bivalves, ammonites, and brachiopods, the major part of these formations is ascribed to the Middle Jurassic Bathonian to Callovian. No diagnostic fossils have been found from the Lower Qoimaco Formation or Upper Xueshan Formation, which could possibly contain in part Bajocian and Oxfordian taxa respectively.

Source area of Yangtze River, Jurassic, rocks, bivalves, depositional environments

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In southern Qinghai, Jurassic rocks are abundantly developed in the source area of the Yangtze River and the nearby area, with clear layers, simple structures, and abundant fossils, among which the marine bivalves are most prolific. Hence, it is one of the most important areas in China, even globally, to study the Jurassic bivalves. In the last two decades, many researchers have conducted paleontological and stratigraphical investigations and achieved great progress. However, with an average elevation higher than 5000 m, this area is characterized by thin air and harsh natural environment and is sparsely populated and extremely inconvenient for travel. Therefore, it is restrained for the field work to extend into the central area of those snow-capped mountains such as Geladaindong Mt., resulting in a great number of unsolved problems with respect to the stratigraphic division and correlation, depositional environments as well as biological groups within this area, such as whether the Qoimaco Formation bivalve fauna belongs to Bajocian [1], geochronological problems of Xueshan Formation and Suowa Formation, i.e., whether the former contains Cretaceous sediments and whether the latter belongs to the Late Jurassic, whether those several bivalve assemblages established can be applied in this area [2], and what are the control factors of the extremely thick Middle-Late Jurassic sediments. We have carried out 1∶250000 mapping and a geological survey in the Chibzhang Co area (ranging from 90°–91°30′E, 33°–34°N). In addition to re-measuring the section of the Qoimaco Formation in Tanggulashan Village, Golmud City, Qinghai (No. A), we measured nine sections (Figure 1), including: sections of the Qoimaco Formation in Bagerima, Tanggulashan Village (No. B); the Xiali Forma-

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tion in Bolongzhangba, Tanggulashan Village (No. D); the Buqu Formation in Bolongri, Tanggulashan Village (No. E); the Suowa Formation-Xueshan Formation, at Darima, Tanggulashan Village (No. F); the Buqu Formation at Tongnama, Tanggulashan Village (No. C); the Buqu Formation-Xueshan Formation (No. I) in Zebazasuoma, Amdo County, Tibet; and the Buqu Formation in Cuojuri, Amdo County (No. G) and the Qoimaco Formation in Bagerilongba, Baingoin County, Tibet (No. H). Moreover, through the field work within the study area of 15500 km^2, detailed observations and sampling were carried on the rocks from each formation based on lithology, lithofacies, and sedimentary characters, and on the systematically sampled fossils of various classes. Through our studies, some new information and evidence are offered to solve those problems mentioned above, and to subdivide and correlate the Jurassic strata within this area, as well as to provide new materials and evidence to better understand the geological history and the evolution of depositional environments within this area.

1 Lithostratigraphy

Tectonically, the source area of the Yangtze River is located in the southern part of the Qiangtang Basin, between the Jinshajiang-Lazhulong suture zone and the Bangong-Nujiang suture zone, where the central uplift belt which extends almost E-W transversely lying in the south. Jurassic strata are abundantly developed in the studied area, whose sedimentary characteristics, variations of petrology and lithology, and the richness of bivalves are controlled largely by the tectonic settings mentioned above.

As to the stratigraphic regionalization, the studied area belongs to the North Qiangtang Stratigraphic Region. The majority falls into the category of the Yanshipin stratigraphic sub-region, except for the western and southwestern part of the Chibzhang Co, which belongs to the Purigangri-Buruogangri stratigraphic sub-region and the Tumian-Nadigangri sub-region respectively. Generally, the Jurassic strata of the North Qiangtang area are composed of three suites of clastic rocks and two suites of limestone, i.e., the so-called "Three sandstone layers with two limestone layers in between". From the top down, these are the Qoimaco Formation, the Buqu Formation, the Xiali Formation, the Suowa Formation and the Xueshan Formation [3], and the greatest thickness in the studied area is more than 6311 m. The lithology assemblages and sedimentary facies characteristics of each formation are obvious.

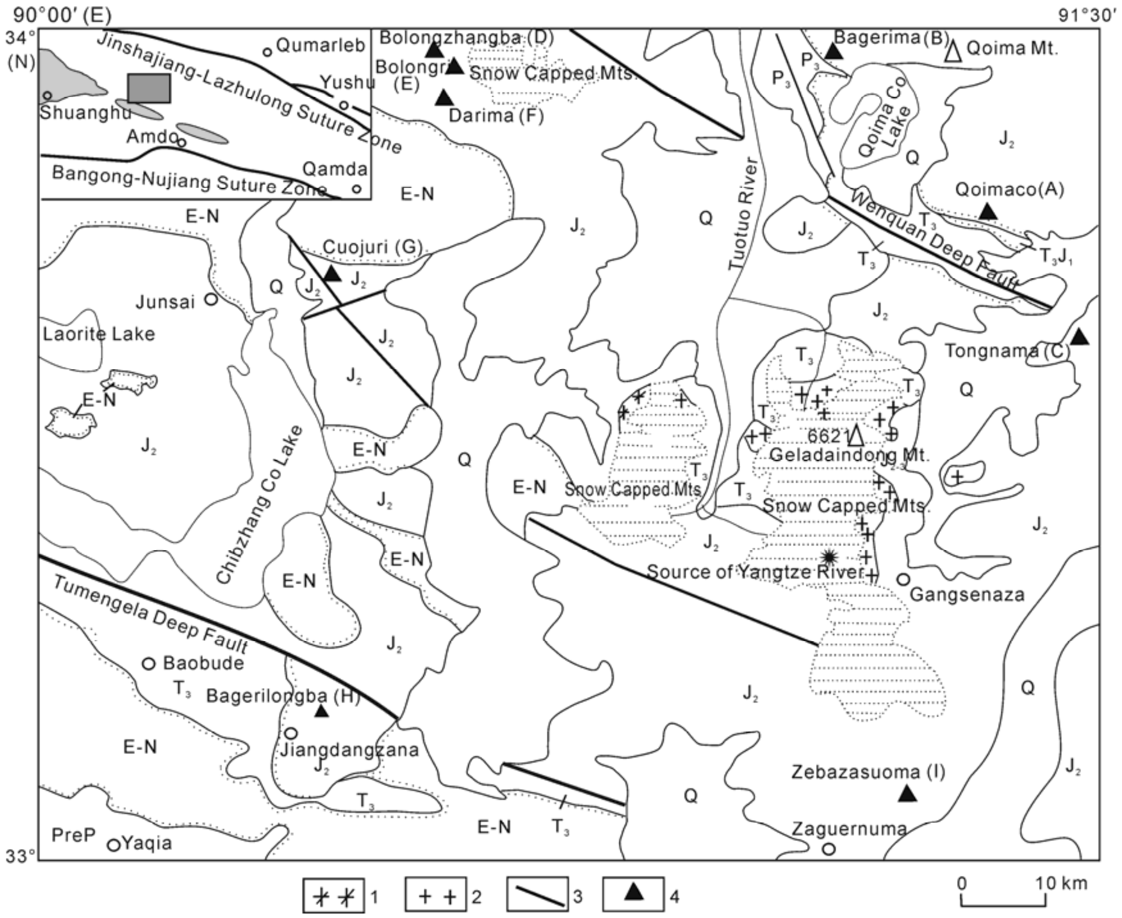

Figure 1 Geological map of the source area of the Yangtze River, with the locations of Jurassic sections marked with A–I. 1. Yanshanian granite; 2. Himalayan granite; 3 fault; 4. location of the sections.

(1) The Qoimaco Formation (J_2q) represents the earliest Middle Jurassic sediments in this area. It is named after the studied area of the Qoima Co. The lower limit is characterized by the dark red thick layers of polymict conglomerates, appearing to be in angular unconformity with the underlying Upper Triassic Jiapila Formation, the Bagong Formation or the E'ertuolongba Formation (Figure 2(a)), rather than by the parallel unconformity as previous researchers suggested [4]. Locally, it overlaps the Late Triassic or older strata. The upper limit is characterized by the disappearance of clastic rocks and the appearance of a great amount of limestone as well as by the Buqu Formation. This formation is composed mainly of dark red, scarlet, grey, dark grey detritus-quartz-sandstone, quartz-sandstone, siltstone; the bottom is formed by polymict breccias, with rare oospararenite and fine-grained calcarenite in the lower part and carbonate fine conglomerate. In the Geladaindong Mt. area, the bottom is developed as fluvial facies composed of basement conglomerate, pebbly sandstone, which is in obvious angular unconformity with the lower part volcanic unit of the Upper Triassic E'ertuolunba Formation; to the north, the bottom part of this formation is formed by pluvial grey or purple thick layers or massive calcareous cemented middle-fined grained polymict breccias, in unconformity with the detritus in the upper part of the E'ertuolongba Formation; whereas on the south of Geladaindong Mt., in the Qoimaco Formation that is exposed in Jiangdangzhana, Bagerilongba, etc., the fluvial facies in the bottom, grey quartziferous conglomerate, is in unconformity with the second unit of the Tumengela Formation. The thickness of the bottom conglomerate decreases from the southern part, which is close to the central uplift belt to the north, where the composition of conglomerate varies with the change of lithology on which it is overlying. In the southern part such as Baobude and its vicinity, it is formed by quartziferous conglomerate with the thickness of ca. 400 m, whilst in the central part near the quartz crystal deposits, it is formed by intermediate-basic volcanic rocks of ca. 100 m thick. To the north of Qoimaco-Bagerima, the composition is siliceous rocks, quartzite, rhyolite of 22.7 and 73.2 m thick, respectively. Tabular oblique bedding is well-developed in the middle and lower part of this formation.

The purple quartziferous sandstone and silty mudstone usually contain a thick fine-grained limestone/pelsparite interlayer of various thicknesses. There is a gypsum-bearing layer (including banded gypsum layer, limy gypsum rock and brecciaed gypsum layer) with a thickness of 455 m overlying the limestone interlining in the lower part of this formation in Bagerilongba, with another banded gypsum layer of 4.9 m below the limestone. A gypsum layer of corresponding location below the Qoimaco Formation was also discovered in the vicinity of the Ulan Ul Lake, which is 90 km north of the study area, and at Xiudongri, which is 35 km southeast of the study area1).

The lithology, petrology, and biota in the upper/middle part of the Qoimaco Formation vary to a great extent in the study area: in the Bagerilongba area of the south, the gypsum thick layer of the Qoimaco Formation is overlaid by purple siltstone and mudstone of pluvial facies of ca.1060 m thick. The geochemical data of Sr/Ba = 0.08–0.59, B/Ga = 2.06–5.78 suggest freshwater sediments, including abundant unionoids. In the north, in the Bagerima area, however, the middle-upper part of the Qoimaco Formation is composed of neritic shelf bioclastic limestone, whereas in the Qoimaco Lake area it is composed of delta facies sediments. In the Yanshiping area which is about 40 km east of the study area, as well as in the vicinity of Yichangma, Buqu Country, Amdo County, which is about 120km southeast of the study area, unionoids are also discovered in the middle part of the Qoimaco Formation [2, 5].

The thickness of the Qoimaco Formation varies widely, in the southwestern part of the study area, it is thicker than 2793 m in Bagerilongba, Baingoin County, Tibet; in the vicinity of Qoimaco Lake, northeast, it is only 736 m in thickness, which is the thinnest area of the whole section named after it, and it is 1163 m thick in Bagerima. The Qoimaco Formation (*sensu stricto*) and the Matuo Formation referred by previous researchers [2, 6, 7] is corresponding to the lower part and upper part of the Qoimaco Formation by "Multiple Classification and Correlation of the Stratigraphy of China" [3], followed by later authors [8−11] and this paper.

(2) Buqu Formation (J_2b) is previously named the 'Tuotuohe Formation' [2, 6, 7], but the Tuotuohe Formation referred by Bai [12] is the same as the Matuo Formation, equivalent to those upper layers in the Qoimaco Formation in this paper. The lower limit of this formation is characterized by emergence of limestone, whilst the top limit is defined by the disappearance of limestone and appearance of scarlet mudstone. As the greatest production during the marine transgression in this area, it is mainly developed as a carbonate platform (or gentle slope) sedimentary system, including local marine platform facies, open marine platform facies, platform marginal facies, fore-platform slope facies, and continental shelf sedimentary facies. Based on the lithological assemblage, this formation can be divided into three units: the lower unit is dark-gray thick-middle layers of oosparite, spararenite, bioclast limestone with a quartz sandstone interlayer, siltstone and mudstone, and exposure structure can be seen on the top, with fossils of bivalves, brachiopods and foraminifera etc.; the middle unit is mainly grey, scarlet thin layers of calcareous mudstone and siltstone, with grey interlayer-thin layers of micritic bioclast limestone, muddy limestone, clastic quartziferous

1) Institute of Exploration and Development, Jianghan Petroleum Administration Bureau. Research Report on the stratigraphic Division and Correlation of Qiangtan Basin. 1998

Figure 2 Jurassic lithologic features and bivalve preservation status in the study area. (a) Angular unconformity between conglomerates of the Qoimaco Formatiom (right side) and volcanics of the E'ertuolongba Formation (left side), east of Geladaindong Mt.; (b) intermediate layers of micritic bioclast limestone, micrite limestone, nodular micritic limestone with calcareous mudstone interlayers in the upper part of the Buqu Formation, Bed 5, Zhebazhasuoma Section, Tanggulashan Village, Golmud City, Qinghai; (c) bivalves occurring on the limestone bedding surface on the Buqu Formation, south of Danmagang, Amdo County, Tibet; (d) basic strata sequence of the lower Xiali Formation, Bed 52, Qoimaco Section, Tanggulashan Village, Golmud City, Qinghai, (e) bivalve occurrence on the marl bedding surface of the Xiali Formation, north of Geladaindong Mt., (f) bivalve occurrence on the limestone bedding surface of the Suowa Formation, north of Geladaindong Mt., (g) thin layers of acicular gypsum bedded close to the top of the Suowa Formation, Maqiaocuo, Tanggulashan Village, Golmud City, Qinghai, (h) large-scale banded cross-bedding developed in sandstone in the upper part of the Xueshan Formation, Bed 34, Darima Section, Tanggulashan Village, Golmud City, Qinghai.

sandstone, etc., with rare bivalves, and textures such as ripple bedding and oscillatory ripple marks, with only a few bivalves; the upper unit is the main body of the Buqu Formation, which is grey intermediate layers of micritic bioclast limestone, micrite limestone, and nodular micritic limestone with calcareous mudstone interlayers (Figure 2 (b)), with abundant bivalves (Figure 2(c)), brachiopods, ammonites, corals, foraminifera, gastropods, and polyzoans. In the southern area of Zaguernuma, several layers of white acicular gypsum are interbedded in the Buqu Formation.

The lithoglogic assemblage and thickness of the Buqu Formation varies in the study area. In the vicinity of the Qoimaco area on the northern wing of the Wenquan fault, the thickness of the Buqu Formation is only 438 m, with the quartziferous silty residual clastic dolomite on the top; on the southern wing of this fault, however, the thickness of the Buqu Formation is greater, such as 1005.8 m in Bolongri, with a greater proportion of grey-dark grey micrite limestone and nodular micrite limestone; in the Cuojuri area, the upper part of this formation is 311 m thick, with abundant fossils of ammonites, bivalves, brachiopods, and corals; in Zhebazhasuoma, the formation is 1007 m thick, and the clastic rocks in upper part of lower unit is relatively thick, ca. 218 m, with banded cross bedding. In Tongnama, which is close to Wenquan Fault, the Buqu Formation is 2142 m thick, with a greater proportion of sparite-micrite bioclast limestone. In the neighboring Yanshiping area, the thickness of the Formation is 1379 m [2], whereas in the Wenquan area it is 533.6 m[1)].

(3) Xiali Formation (J_2x) is named after the Mountain Xiali in the study area, located about 4 km south of Qoimaco. The lower limit is characterized by scarlet, silty mudstone with abundant sandstone interlayers, which can be clearly distinguished from the underlying Buqu Formation. The upper limit is defined by the disappearance of sandstone and steady appearance of the overlying, gradually increasing limestone of the Suowa Formation. The majority is open marine and delta sedimentary facies. The lithology is scarlet, thin layers of silty mudstone with bedded thin-medium layers of debris-quartziferous fine-grained sandstone, quartziferous siltstone (Figure 2(d)), in the bottom and top parts of the unit, there are dark grey middle-thick layers of bioclast-micrite-limestone and micrite-limestone, with relatively more bivalves in the latter (Figure 2(e)). Many ripple bedding and wave ripples are developed in the sandstone and siltstone, usually with abundant phytolite fragments. In the south, in the Zhebazhasuoma area, there are several layers of lenticular conglomerate in the lower part of this formation, which represent fluvial facies, with a few phytolites such as *Coniopsis* cf. *burejensis* (Zalessky). Several layers of storm deposits are discovered in the upper part of this formation in Qoimaco, and some layers of gypsum are found in the lower part in the Bolongzhangba area. The thickness of this formation varies drastically, with the thinnest part of 273 m in the Zhebazhasuoma area to the south; it is about 394 m thick in the Qoimaco area and 732 m in the Bolongzhanba area. In the nearby Yanshiping area, it is 607 m thick [2]. The species diversity of the bivalves is obviously lower in this formation than in the Buqu Formation and the overlying Suowa Formation.

(4) Suowa Formation (J_2s) is named after Suowa in the eastern part of the study area. Generally it is diamictite continental shelf facies sediments, bounded by appearance of great amount of limestone and the disappearance of sandstone from the Xiali Formation. The lithology is mainly grey limestone, calcareous mudstone, micrite limestone, and bioclast micrite limestone, with interlayers of siltstone, silty mudstone and fine-grained debris quartziferous sandstone, commonly with ripple beddings and parallel beddings. Abundant marine bivalves and brachiopods are discovered from the limestone (Figure 2(f)); ammonite fossils are also found locally. In the 114th maintenance station, 65 km southeast of the study area, abundant ammonites are present in the Suowa Formation.

In terms of the thickness variation of the Suowa Formation in the study area, Zhebazhasuoma, south of the Central Uplift Belt, there is a sufficient supply of terrestrial debris material, and therefore the lower part of the formation is thick layers of grey micrite limestone with thin layers of marl and calcareous mudstone. In the upper part, detrital rocks are obviously more abundant, occurring as light-grey green thin layers of silty mudstone, fine-grained debris-quartziferous sandstone with micrite biodetritus limestone or interbedding of variable thickness, and the whole thickness reaches 703 m. In the north of the study area, this formation is composed mainly of limestone, in variable bedding with mudstone, with only rare medium layers of detrital sandstone near the top or bottom. In the Qoimaco area, this formation is 438 m thick, the lower part is shelly bank formed by dark-grey medium-layer of micrite biodetrital limestone, and the upper part has comparatively more tempestites and several layers of fine-grained dolomite. In the Darima area, the thickness is about 837 m; a few thin layers of white acicular gypsum are interbedded close to the top (Figure 2(g)). In the west of the study area, in the vicinity of Junsai, a large scale gypsum deposit is also located in the Suowa Formation. In the neighboring Yanshiping area, the Suowa Formation is 670.0 m thick .

(5) Xueshan Formation (J_2xs) is the same formation described by previous researchers as Zhaworong Formation [2, 6, 7]. The name Xueshan stems from the vicinity of Wenquan, 60km east of the study area, dominated by delta facies with nearshore facies sediments, rare in continental shelf facies, and with mainly fluvial facies sediments on the top. Marked by the consistent appearance of sandstone and gradual disappearance of limestone, the bottom limit of this formation is grading into the underlying Suowa Formation with a distinct boundary. The lower part of this formation is scarlet thin layers of silty mudstone with interlayers of me-

dium-thick layers of quartziferous fine-grained sandstone, with occasional grey thick-medium sandy-biodetritus micrite limestone and rare gypsum karst breccia and gypsum layers locally, containing fossils fragments of marine bivalves, trace fossils, echinoderms and brachiopods. The upper part is light grey thick layers of detrital greywacke, with lenticular carbonate fine conglomerate; phytolite fossils are frequently observed in the sandstone, and large scale banded cross bedding is also developed (Figure 2(h)). There are a few brackish bivalves and questionable fresh- water unionoid fossil fragments. Due to the late stage erosion, this formation is not completely exposed in this area with a great change in thickness. In the south, the thickness is over 1666 m in Zhebasuozhama, where the Xueshan Formation is in unconformable contact with the overlying Paleogene Tuotuohe Formation. In the north, the thickness of this formation in the Darima and Qoimaco area is over 1195 and 1019 m, respectively. In the vicinity of Yanshiping, east of the study area, the upper part of this formation contains abundant fresh-water unionoids, with a thickness over 1248 m [2].

To sum up, in the study area, and in the vicinity of Yanshiping and Yichangma in Buqu County, Amdo County, the Middle Jurassic lithology is generally the same, all composed of three detrital rocks (Qoimaco Formation, Xiali Formation and Xueshan Formation from the top down) and two layers of carbonate rocks (Buqu Formation and Suowa Formation from the top down), which are well correlated in the different areas. And this stratigraphic division regime is widely accepted by the local geological survey and most previous researchers [2, 3, 8, 9, 12–14].

2 Bivalve faunas and geological age

Many researches on Jurassic bivalves have been carried out in the source area of the Yangtze River previously [1, 6, 7, 10, 11, 15–21]. Some researchers have established several Jurassic bivalve assemblages in the Qiangtang Basin [2]. On the basis of these assemblages, the Qoimaco Formation (*sensu stricto*) was assigned to the Bajocian, and the Matuo Formation, the Tuotuohe Formation (equivalent to the Buqu Formation in this study), the Xiali Formation, the Suowa Formation, and the Zhaworong Formation to the Upper Bajocian, Bathonian, Callovian, Oxfordian-Kimmeridgian, and Kimmeridgian-Tithonian, respectively; and this division plan is widely adopted [3, 9–11, 13, 14, 21]. Through systematic sampling in 9 measured sections and a geological survey in the area of 15500 km^2, 188 species (subspecies) of 79 genera (subgenera) in 35 families of 5 subclasses of Bivalvia have been recognized (Table 1). The study on these fossils has shown, however, that the bivalve assemblages established by previous researchers are not suitable for this area. The main problem is that some index species in several assemblages are not restricted to these specified assemblages; meanwhile some principal species from different assemblages may occur in the same horizon. Based on the geochronology provided by the bivalve fauna and the contemporary ammonites in this study, we suggest that the main Jurassic strata in the study area are Middle Jurassic Bathonian-Callovian. The possibility is not excluded that there are undiscovered fossils to define the lower part of the Qoimaco Formation and the upper part of the Xueshan Formation to include partial Bajocian and Oxfordian, respectively. Here we discuss the characteristics of bivalves from each formation and the geological age, and briefly comment on the Jurassic bivalve assemblages and their geological chronology in the Tanggula Mountains area as established previously.

2.1 Bivalves of the Qoimaco Formation

The fossils were collected from section A, section B, and section H. There are obviously different two types of bivalve groups: the marine bivalve fauna in the lower part and the freshwater bivalve fauna in the upper part. The marine bivalves include: *Propeamussium* (*Propeamussium*) *pumilum*, *Camptonectes* (*Camptonectes*) *auritus*, *Homomya* sp., *Placunopsis* sp., *Modiolus* cf. *qinghaiensis* (from section B); *Kobayashites* cf. *hayamii*, *K*. sp., *Lycettia* sp., *Modiolus* sp., *Homomya* sp. (from section H); *Camptonectes* (*Camptonectes*) ex gr. *subulatus*, *Anisocardia* (*Anisocardia*) *togtonheensis*, and *Quenstedtia*? sp. (from section A), 8 genera 11 species in all (Table 1), among which *Propeamussium* (*Propeamussium*) *pumilum* is a widespread species from the late Early Jurassic to Middle Jurassic all over the world. In southern Tibet, *Propeamussium* (*Propeamussium*) *pumilum* is found in the middle Nieniexiongla Formation,

Table 1 Statistics of Jurassic bivalves in the source area of the Yangtze River

	Palaootaxodonta			Pteriomophia			Palaeoheterodonta			Heterodonta			Anomalodesmata			Total		
	Family	Genus	Species	Family	Genus	Species	Family	Genus	Species	Family	Genus	Species	Family	Genus	Species	Family	Genus	Species
Qiomaco Fm.	0	0	0	4	7	10	2	7	12	2	2	2	1	1	1	9	17	25
Buqu Fm.	1	1	1	15	28	70	0	0	0	9	14	27	2	7	20	27	50	118
Xiali Fm.	0	0	0	8	12	18	1	1	1	5	8	14	1	1	1	15	22	34
Suowa Fm.	2	3	7	11	20	44	1	1	1	5	8	21	4	5	8	23	39	81
Xueshan Fm.	0	0	0	7	10	13	1	1	1	7	10	21	3	3	4	18	24	39
Total	2	3	8	16	38	93	3	10	15	10	19	47	4	9	25	35	79	188

which belongs to the early Middle Jurassic [15]. *Camptonectes* (*Camptonectes*) *subulatus* has been observed in the Early Jurassic in Europe, whose similar species has been found from the Matuo Formation nearby Yanshiping. *Camptonectes* (*Camptonectes*) *auritus* used to be considered as a characteristic element of Bajocian in China by previous researchers [3, 13, 18, 22]. In fact, this species was first reported in the Hettangian in southern Germany and reached its maximum in the Aalenian-Bajocian in western Europe, rarely occurs in the Bathonian, but reappears in the Callovian and Oxfordian, and extends to the Volgian [23]; however, Hallam [24] suggests that the time range of this species is Callovian-Tithonian. The comparable form of this species exists in the Bajocian in Japan [25, 26]; and in the Callovian and Oxfordian in the Cutch area, India [27], whereas in the Kachchh area, western India, it occurs in the Bajocian-Oxfordian [28]. Therefore, this species is common in the Middle-Upper Jurassic abroad. In the Qoimaco Formation in the study area, only a few samples of this species have been discovered in the Bagerima section, whereas it is very abundant in the Buqu Formation (Sections A, G, E) and in the Suowa Formation (Sections F, A). Especially in the second bed of the Buqu Formation at the Cuojuri Section (collecting number Cj-2f_1), the abundance of *Camptonectes* (*Camptonectes*) *auritus* is extremely great. Apart from *Siemiradzkia cf. matisconensis* (Lissajous), the coexisting Middle-Late Bathonian ammonites include *Neuqueniceras* cf. *yokoyamai* Kobayashi and Fukada, *Procerites* sp., etc. The Suowa Formation in the study area belongs to the Callovian (see below). So, the species *Camptonectes* (*Camptonectes*) *auritus* in the study area reaches its peak in the middle-late Bathonian-Callovian. The age of this species in the main peak area of the Tanggula Mountain is similar with that of the study area [7]. The genus *Kobayashites* was first discovered in the Hashirura Formation in the Sizukawa area, Japan [25]. Apart from the Yanshiping and Sizukawa areas, no such genus has been reported anywhere else in the world. *Kobayashites hayamii* is an endemic species established by the sample from the lower part of the Qoimaco Formation in the Yanshiping area, and is considered as the dominant species of the bivalve assemblage in the lower part of the Qoimaco Formation of Bajocian age [19]. Generally, the geological age of a new genus or new species is defined based on the coexisting fossils, and requires more information to restrict the time range gradually. In the Yanshiping Section, from where this species is first sampled and described, the main fossils that coexist with *Kobayashites hayamii* are *Protocardia hepingxiangensis*, *Astarte elegans*, *Anisocardia gibbosa*, etc. [2]. They emerge numerously in the mid-upper Bathonian Buqu Formation in the study area. Moreover, in terms of bivalves, the species range time is comparatively long, ca.15 Ma [24]; whereas each stage of the Middle Jurassic lasts 4.0, 3.9, 3.0 and 3.5 Ma, respectively; the range time of the Lower, Middle and Upper Jurassic is 24, 14.4 and 15.7 Ma [29]. Therefore, a single bivalve species of the Jurassic can only be defined to a specific Series rather than exact Stage usually. So given *Kobayashites hayami* and *Camptonectes* (*Camptonectes*) *auritus* as the typical species on which the Bajocian is based, then, assigning the Qoimaco Formation as being Bajocian in age is not persuasive enough. The freshwater bivalves include 12 species belonging to 7 genera: *Psilunio chaoi*, *P. lateriplanus*, *P. thailandicus*, *P. sinensis*, *Lamprotula* (*Eolamprotula*) sp., *Undulatula perlonga*, *U. ptychorhyncha*, *Cuniopsis* cf. *johannisbohmi*, *Solenaia tanggulaensis*, *Unio* cf. *obrustschewi*, *Margaritifera isfarensis* (sampled from Section H). These unionoid fossils are great in abundance, preserved both in disarticulated and articulated fashion and, piled together randomly, among which *Undulatula* and *Psilunio* are most abundant. This unionoid fauna is common also in the Middle Jurassic Bathonian in Yunnan, Sichuan, and Hubei [30].

According to the fossils from the Qoimaco and Yanshiping sections, previous researchers have established four Bajocian bivalve assemblages for the Qoimaco Formation (*sensu stricto*), from the bottom upward: *Anisocardia gibbosa-Protocardia truncate* assemblage, *Kobayashites hayamii-Protocardia hepingxiangensis* assemblage, *Cuniopsis sichuanensis-Psilounio-Lamprotula* assemblage, *Corbula sinensis-Neomiodon yanshipingensis-Protocardia hepingxiangensis* assemblage, the late Bajocian *Camptonectes auritus* assemblage for the bottom of the Matuo Formation and the early Bathonian *Eomiodon angulatus-Isognomon* (*Mytiloperna*) *bathonicus* assemblage for the main part of the Matuo Formation [2]. Recently these assemblages have been regarded as the main evidence of the Qoimaco Formation as indicating Bajocian in the Qiangtang area [9, 10, 12, 13]. Nevertheless, even following the age represented by the assemblages mentioned above, the Qoimaco Formation described in this study includes Bajocian and Bathonian, rather than Bajocian exclusively. Apart from the confirmed early Bathonian bivalves *Eomiodon angulatus-Isognomon* (*Mytiloperna*) *bathonicus* assemblage, the early Bathonian brachiopods *Burmirhynchia gutta-Holcothyris subovalis* assemblage in the basal limestone (9 m thick) in the Matuo Formation from the Yanshiping area has proved this point. The latest research about the bivalves and coexisting ammonites have shown that, the guiding species and principal species of Bajocian bivalve assemblages in Tanggula Mts. area suggested by previous authors, such as *Anisocardia gibbosa*, *Protocardia hepingxiangensis*, *Camptonectes auritus*, *Neomiodon yanshipingensis*; *Pleuromya subelongata*, *Astarte elegans*, *Ceratomya bajociana*, *Homomya gibbosa*, *Lucina* cf. *despecta*, *Gervillella orientalis* [1, 2, 18], occur in the middle-upper Bathonian Buqu Formation in great abundance, whereas *Pleuromya subelongata* is discovered in the Xiali Formation of the Changhong River Section [13]. In fact, *Protocardia hepingxiangensis* and the index species of another assemblage, *Corbula sinensis* were both first discovered in the Hepingxiang Formation in the Lanping-Simao area, Yunnan. This formation is Bathonian rather than Bajocian [30] in age. The non-marine unionoid assemblage belongs to the *Cuniopsis sichuanensis*-*Psilounio*-*Lamprotula* assemblage and to the Bathonian as well [30]. Thus, the bivalve assemblages from the Qoimaco Formation (*sensu stricto*) and from the bottom of the Matuo Formation are most probably to be assigned to the Bathonian instead of the Bajocian.

In summary, this study ascribes the Qoimaco Formation into the Middle Jurassic Bathonian, most possibly early Bathonian. In the Cuojuri area, abundant middle-late Bathonian ammonites in the overlying Buqu Formation offer strong support for this age.

Given that no fossils have been found in the lower part of the Qoimaco Formation, 575 m of thickness in Section B (up to 49.5% of the whole formation), and 1090 m in Section H (up to 39% of the whole), and 124 m in section A (17% of the whole), accurate age determination cannot be ruled out yet, they may contain partial Bajocian or even Early Jurassic sediments.

2.2 Bivalves of the Buqu Formation

The Buqu Formation has the highest bivalve diversity in the study area, including 27 families, 50 genera, and 118 species (Figure 3, Table 1). The specimens were collected from Sections A, C, E, G, I and another 10 geological spots. This fauna is characterized by high abundance of Pteriomorphia, which accounts for more than a half of all taxa, up to 15 families 28 genera 70 species (Figures 3 and 4). Among them, some common species for the Bathonian occur, including *Camptonectes* (*C.*) *lameinatus*, *Isognomon* (*Mytiloperna*) *patchamensis*, *I.* (*M.*) *bathonicus*, *Acromytilus bathonicus*, *Protocardia strickland*; there are also a few common members for the Bajocian, such as *Ceratomya bajocina*, *Quenstedtia oblita*, *Pleuromya subelongata*, *Gervillella orientalis*; and a great number of common species for the Middle Jurassic, such as *Anisocardia gibbosa*, *Camptonectes* (*Camptonectes*) *auritus*, *Liostrea birmanica*, *Ceratomya undulata*, *C. concentrica*, *Grammatodon* (*Grammatodon*) *clathratum*, *Radulopecten tipperi*, *Protocardia hepingxiangensis*, and endemics of Tibetan Middle Jurassic: *Pinna tibetica*, *P. nyainrongensis*, *Liostrea jiangjinensis*, *L. zadoensis*, *Lopha maliensis*, *L. baqensis*, *Entolium nieniexionglaensis*, *Praeexogyra* cf. *acaminata*, *Radulopecten shuanghuensis*, *Gervillella qinghaiensis*, *Pte-*

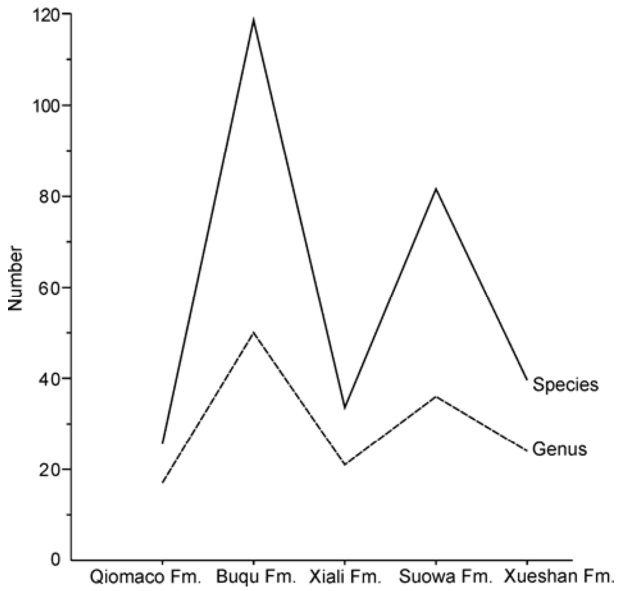

Figure 3 The abundance curve of Jurassic bivalves in the study area.

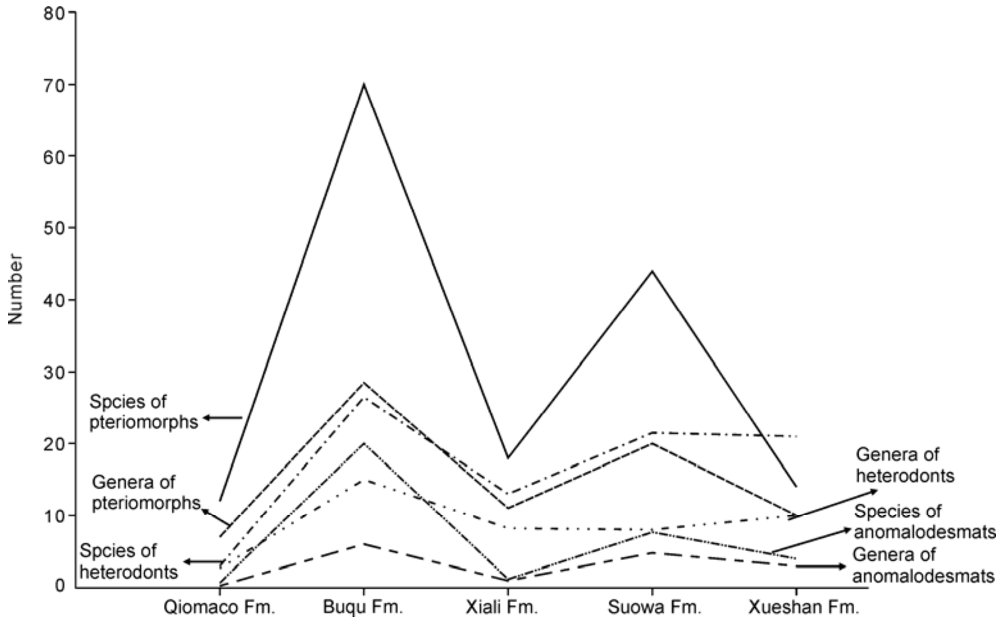

Figure 4 Variation curves of the genera and species abundance of Jurassic pteriomorphs, heterodontids and anomalodesmats in the study area.

ria problematica, *Modiolus* (*Modiolus*) *trigonus*, *Mactrom yaqinghaiensis*, *Neomiodon yanshipingensis*, *Anisocardia* (*Anisocardia*) *togtonheensis*, *A.* (*Antiquicyprina*) *trapezoidalis*, *Pholadomya socialis qinghaiensis*. Moreover, there are a few *Myopholas multicostata*, which were thought to be mainly of Oxfordian-Kimmeridgian age. This study has for the first time found abundant middle-late Bathonian ammonites from the limestone in the upper part of the Buqu Formation, Section G and from a locality 500 m east to this section, including *Choffatia* cf. *vicenti*, *Neuqueniceras* cf. *yokoya- mai*, *Siemiradzkia* cf. *matisconensis,* and *Procerites* sp. [31]. They coexist with some of the bivalves mentioned above. Accordingly, the Buqu Formation is ascribed to the middle-upper Bathonian. Therefore, the *Radulopecten vegans-Anisocardia beaumonti* assemblage of the Tuotuohe Formation established by previous researchers belongs to the middle-late Bathonian [2].

2.3 Bivalves of the Xiali Formation

Most samples were collected from Section D and fewer from Section A. The diversity is obviously lower than that in the Buqu Formation, consisting of 15 families, 22 genera, and 34 species (Figure 3, Table 1). Bivalves of this formation are characterized by great abundance of *Radulopecten*, *Pteroperna*, *Corbula*, *Corbicellopsis*, *Astarte*, *Protocardia* and *Anisocardia*, among which *Radulopecten vagans* is a common species in the European Bajocian-Bathonian. *Protocardia stricklandi* is distributed in the Bathonian of Europe, and it is also the common species of the Middle Jurassic in Tanggula Village, Golmud City, Qinghai and in the Amdo area, Tibet in China [16, 32]. *Astarte elegans* is originally found in the Bajocian in Britain and is distributed from Toarcian to Callovian in Europe, and occurs in the Middle Jurassic in Tanggula, Qinghai and in Nyainrong and Amdo, Tibet [1, 16]. *Pteroperna costatula* occurs in the Bathonian of Britain and France, and was found in the Middle Jurassic in Yanshiping, Qinghai and in Amdo, Nyainrong, Tibet [16, 20]. In addition, there are many endemics commonly found in Chinese Middle Jurassic, such as *Gervillella quinghaiensis*, *Costigervillia minima*, *Liostrea jiangjinensis*, *Vaugonia* cf. *yanshipingensis*, *Protocardia quinghaiensis*, *Unicardiopsis amdoensis*, *Corbula yanshipingensis* etc. Based on this, the bivalves of the Xiali Formation are late Bathonian-early Callovian in age. The abundant late Bathonian-early Callovian ammonites *Wagnericeras*, *Homoeoplanulites*, *Neuqueniceras, Oxycerites orbis* (Giebel) and *Macrocephalites* cf. *macrocephalus* (Schlotheim) [13, 31] in the neighboring area offers persuasive evidence.

2.4 Bivalves of the Suowa Formation

Samples were collected from Sections A, F, I and 8 route-spots, with great abundance and high diversity: 23 families, 39 genera, 81 species, whose abundance and diversity is the second highest among the five Jurassic formations in study area (Figure 3, Table 1). The fauna is characterized by the development of pectinaceans, with the greatest abundance of *Camptonectes* and *Radulopecten*. Palaeotaxodonts were comparatively well developed, including three genera and seven species, and formed the most fossiliferous horizon of this taxon in this area. Besides, there are many *Miyagipecten*, *Placunopsis*, *Gervillella*, *Plagiostoma*, *Pseudolimea*, *Lopha*, *Liostrea*, *Protocardia*, *Astarte*, *Anisocardia*, *Amiodon*, *Pseudotrapezium*, *Homomya*, *Myopholas*. This fauna contains common Bajocian-Bathonian species, such as *Camptonectes auritus*, *C. laminate*, *Radulopecten vegans*, *R. tipperi*, *Propeamussium* (*Propeamussium*) *pumilium*, *Gervillella siliqua*, *Protocardia stricklandi*, *Placunopsis duriuscula*, *Astarte elegans*, *Amiodon khoratensis* as well as Callovian species, such as *Grammatodon* (*G.*) *clathrotum*, *Liostrea birmanica*. Moreover, there are 17 endemic species of Tibetan Middle Jurassic. Within the 64 identified species in the Suowa Formation, 35 species (about 55%) are also found in the middle-late Bathonian Buqu Formation in this area; among them, 16 species (25% of all the identified), *Pinna lanceolatus*, *Radulopecten tipperi*, *R. vagans*, *Camptonectes auritus*, *Gervillella qinghaiensis*, *Pseudolimea duplicata*, *Liostrea jiangjinensis*, *Modilus imbricatus*, *Protocardia stricklandi*, *Mactromya qinghaiensis*, *Anisocardia* (*Anisocardia*) cf. *channoni*, *A.* (*Antiiquicyprina*) *trpezoidalis*, *Amiodon fengdengensis*, *Pseudotrapezium cordiforme*, *Homomya gibbosa* and *Pluromya aldumi*, coexist with middle-late Bathonian ammonites in Section G. However, most of them are the common species of Middle Jurassic, rather than the species limited to the Bathonian. Thus, the Suowa Formation is ascribed to the Middle Jurassic Callovian, and this conclusion is confirmed by ammonites. In the “Upper part of Middle Jurassic Yanshiping Group” 22 km northwest of Chibzhang Lake, there occurs the late Callovian ammonite ?*Collotia* sp. whose appearance and ornamentations of the lateral side are rather similar to *C. petitclerci* Jeannet [9, 33]. The geological survey of 1∶250000 of the Chibzhang Co area in 2000−2002 by authors has shown that the strata, where those ammonites are distributed, belong to the Suowa Formation.

Three bivalve assemblages were established in the Yanshiping area by previous workers, and in descending order they are identified as: *Corbicellopsis laevis-Modiolus bipartitus*, *Radulopecten fibrosus-Gervillella aviculoides*, *Myopholas multicostata-Entolium corneolum*, and, based on which, the Suowa Formation was placed into the Upper Jurassic Oxfordian-Kimmeridgian [2]. However, the bivalve fauna in the study area shows some difference from those in the Yanshiping area. Among all fossils from the basal and middle-upper part of the Suowa Formation in the Yanshiping area, only *Corbicellopsis laevis* and *Radulopecten fibrosus* were found in the Xiali Formation and in the Suowa Formation in the study area; most of the other species have not been found in the study area, such as *Lopha gregarea*, *Isognomon mytiloides*, *Modiolus bipartitus*, *Myophalus douvillei*, *Pteroperna* cf. *polydon* from the lower part and *Gervillella aviculoides*, *Thracia depressa*, *Astarte nummus*, *Chlamys* (*Radulopecten*) *mides* from the upper part. Nevertheless, *Myopholas multicostata* and *Entolium corneolum*, the dominant species of top assemblage of the Suowa Formation, are considered Kimmeridgian in Europe and occur in great abundance in the Buqu Formation and Xiali Formation in the study area. And *Entolium corneolum* coexists with middle-late Bathonian ammonites. Based on this, this study suggests that the above-mentioned *Myopholas multicostata-Entolium corneolum* assemblage in the top of the Suowa Formation from the Yanshiping area does not belong to the Late Jurassic Oxfordian-Kimmeridgian, but to the Middle Jurassic.

Abundant bivalves are discovered from the Suowa Formation in the Tuolamu area, Shuanghu County, Tibet, west of the study area, and the *Myopholas multicostata-Protocardia stricklandi-Chlamys* (*Radulopecten*) *vagans* assemblage was established there, which includes mostly common species for the Middle Jurassic. *Myopholas multicostata* is one of the zonal index fossils in the Late Jurassic, therefore the age can be constrained into Callovian-Kimmeridgian [22]. However, as stated above, there is a great number of *Myopholas multicostata* in the Buqu Formation and Xiali Formation in the study area, indicating that this species had already been blooming since Middle Jurassic Bathonian-early Callovian in this area. Therefore, at least in the Qiangtang Basin, it cannot be identified as a Late Jurassic zonal fossil. Apart from that, another dominant species, *Protocardia stricklandi,* and the principal species *Radulopecten tipperi* in the Suowa Formation of the Tuolamu area are both considered as the zonal fossils of the Bathonian Buqu Formation in the Maliaoshan area, north of the Qiangtang Basin [21]. Another zonal fossil, *Chlamys* (*Radulopecten*) *vagans*, on the other hand, is considered the dominant species in the Bathonian Buqu Formation of the Yanshiping area [2]. The other members of this assemblage, such as *Astarte* cf. *elegans*, *Entolium demissium*, *Lopha* cf. *costata*, *Modiolus* cf. *imbricatus*, *Pholadomya carina*, *Arcomytilus* cf. *bathonicus*, *Pseudotrapezium cordiforme,* are all common species of the Bajocian-Bathonian in other parts of the world. According to this, we think the bivalve assemblage in the Suowa Formation of Tuolamu area should be Callovian, and may not include Oxfordian-Kimmeridgian.

About 65 km south of the study area, in the vicinity of 114th maintenance station of the Qinghai-Tibet Highway in Amdo County, Tibet, there are five layers containing ammonites in the Suowa Formation, and in the upper part the ammonites are (early) Callovian, and in the lower part mostly late Bathonian [31]. Moreover, between the 114th and 115th maintenance station of the Qinghai-Tibet Highway, the upper part of Middle Jurassic Yanshiping Group contains the ammonites *Kellawausites* sp. and *Dolikephalites* sp. [33]. Later on, Westermann and Wang [34] redefined them as *Reinenckeia* sp. and *Macrocephalites* sp., and described a newly-discovered species *Choffatia* cf. f*unata* (Oppel), and pointed out that these fossil-bearing strata may be middle Callovian. Hence it can be deduced that the Suowa Formation of this area includes middle Callovian. In terms of stratigraphic regionalization, the vicinity of the 114th maintenance station of the Qinghai-Tibet Highway belongs to the South Qiangtang stratigraphic region and the Jurassic lithology shows some discrepancy with the study area. But when analyzed with the timing of those ammonites discussed above, the strata may be comparable to those of the ammonite-bearing Suowa Formation in the northwestern area of Chibzhang Co Lake.

2.5 Bivalves of the Xueshan Formation

The marine bivalves are collected from the middle-lower part of this formation of Sections A, F and I, including 18 families, 24 genera, and 39 species. There are species commonly reported from the Bajocian, Bathonian, and Callovian all over the world, such as *Bakevellia waltoni*, *Gervillella orientalis*, *Quenstedtia cf. oblita*, *Astarte* cf. *elegans*, *Pleuromya uniformis, Protocardia stricklandi, Pseudolimea duplicate*, *Modilus* (*Modiolus*) *imbricatus*; there are also Callovian-Oxfordian species such as *Placunopsis duriuscula* and *Corbicellopsis laevis*, which were found in the Bajocian-Tithonian of Europe. Eleven Middle Jurassic endemic species of the Tibet-Qinghai Plateau were observed in great abundance: *Meleagrinella nieniexionglaensis*, *Quenstedtia* cf *dingriensis*, *Lopha maliensis*, *Miyagipecten laevis*, *Gervillella qinghaiensis*, *Protocardia qinghaiensis*, *Macromya qinghaiensis*, *Astarte togtonheensis*, *Anisocardia* (*Anisocardia*) *togtonheensis*, *Anisocardia* (*Anitiquicyprina*) *trapezoidalis quadrata,* and *Tancredia triangularis*. The first two species were found for the first time in Middle Jurassic of the Dingri, Nielamu area, South Tibet, among the remaining 9 species, apart from *Lopha maliensis*, which was found for the first time in the lower part of the upper Bajocian-lower Callovian Liuwan Formation in Luolong, East Tibet [35], all the other were found for the first time in Middle Jurassic strata in the upstream area of the Tuotuohe River, Yanshiping area of South Qinghai, and in the Amdo-Tumen areas of Tibet [16]. These 11 endemics are distributed in the study area in this way: 7 species are found in the Qoimaco Formation, Buqu Formation and in the Xiali Formation, 1 species in the Suowa Formation as well. Only *Meleagrinella nieniexionglaensis*, *Quenstedtia* cf *dingriensis*, *Tancredia triangularis* are restricted to the Xueshan Formation. In the 15 identified non-endemic species, apart from 2 species which are restricted to the Xueshan Formation, the other 13 species also appear in the Buqu Formation and in the Xiali Formation in the study area. And *Pseudotrapezium cordiforme* is the dominant species of the bivalve assemblage in the lower part of the upper Bajocian-lower Callovian Liuwan Formation in the Mali area, Lhorong County, East Tibet [35], and it occurs in the upper Toarcian-middle Oxfordian of Europe [24]. In summery, among in all the 26 identified species of the Xueshan Formation, 19 (taking up 73%) occur in the Middle Jurassic Bajocian-Bathonian Qoimaco Formation, Buqu Formation and in the Xiali Formation of the study area, in which 6 species of 6 genera (taking up 23%) including *Mactromya qinghaiensis*, *Anisocardia* (*Anitiquicyprina*) *trapezoidalis quadrata*, *Pseudolimea duplicate*, *Protocardia stricklandi*, *Pseudotrapezium cordiforme*, *Pholadomya carinata* coexist with middle-late Bathonian ammonites, and one species (taking up about 4%) appears in the Callovian Suowa Formation. It can be seen that 77% of the bivalves in this formation are common Middle Jurassic species in other parts of the world; only *Corbicellopsis laevis* was reported in the Bajocian-Tithonian of Europe. Therefore, the lower part of the Xueshan Formation with those marine bivalves mentioned above should be placed into the Middle Jurassic, probably upper Callovian. However, this study has not yet found fossils that are preserved well enough to be identified in the main part over those mentioned marine bivalves of the Xueshan Formation (the thickness of the main part takes up 64%, 46% and 89% of Sections A, F and H, respectively); therefore, even it is ascribed into the Middle Jurassic for the moment, the possibility still cannot be ruled out that these strata include partial Oxfordian.

3 Relationship between the distribution and diversity of bivalves and depositional environments

Middle Jurassic strata in the source area of the Yangtze River are dominated by epicontinental neritic facies detrital sediments, and each formation has various depositional environments with a low consistency. Those variations are reflected by the bivalve faunas. This study focuses on the relationship between the distribution, development of bivalves and the sedimentary facies.

Bivalves have a strong ability to adapt to their living environment; however, in the study area, the distribution and diversity of Jurassic bivalves were obviously controlled by depositional environment and sedimentary facies. Generally, the Qoimaco Formation is dominated by foreshore facies, nearshore facies and delta sedimentary systems, the Xiali Formation by non-barrier open-sea and delta sedimentary systems, and the Xueshan Formation by the nearshore facies. They contain bivalves, whose diversity is obviously lower than that of the Buqu Formation, which is dominated by carbonate platform (gentle slope) sedimentary facies (including local restricted platform facies, open marine platform facies, platform marginal facies, fore-platform slope facies and continental shelf sedimentary facies, etc). And the Suowa Formation, consisting of shelf facies, fore-delta facies and delta frontier facies, has a bivalve diversity between those two mentioned above (Figure 3).

Among the five subclasses of Bivalvia in the study area, Pterimorphia is most developed, whose genera and species account for 47.5% and 49.2% of all taxa respectively, and its diversity difference between different formations is more obvious than those in other subclasses (Figure 4, Table 1). Of this subclass, the variation of Pectinacea, which possesses epifaunal byssal attachments, usually close to normal salinity, is most outstanding. Diversity of this superfamily is the highest in the Buqu and Suowa Formations, whereas it is the lowest in the Qoimaco and Xueshan Formations (Figure 5). The second most developed subclass is the Heterodonta, whose generic and species number takes up 23.75% and 24.86% of all taxa respectively, and the most prolific are three genera, i.e., *Astarte* of Asttartidae Veneroida, *Protocardia* of Cardiidae, and *Anisocardia* of Arcticidae, occurring in great abundance, widespread in all formations except for the Qoimaco Formation, showing their strong ability to adaptation. Anomalodesmata contain 4 families, 10 genera, and 26 species, in which the diversity of Pholadomyacea is comparatively distinctive among different formations (Figure 6). Three species of *Pholadomya,* whose extant species usually live in deep water, have been found in the study area, are almost confined to the Buqu Formation; they occur in great abundance in Section G, coexisting with various ammonites and brachiopods. There are also a few *P.* cf. c*arinata* in the lower part of the Xueshan Formation. Palaeotaxodonta and Palaeoheterodonta are particularly less developed, and the former only occurs in the Suowa Formation, the latter belongs only to the fresh-water unionoids.

The distribution of certain bivalves in the study area

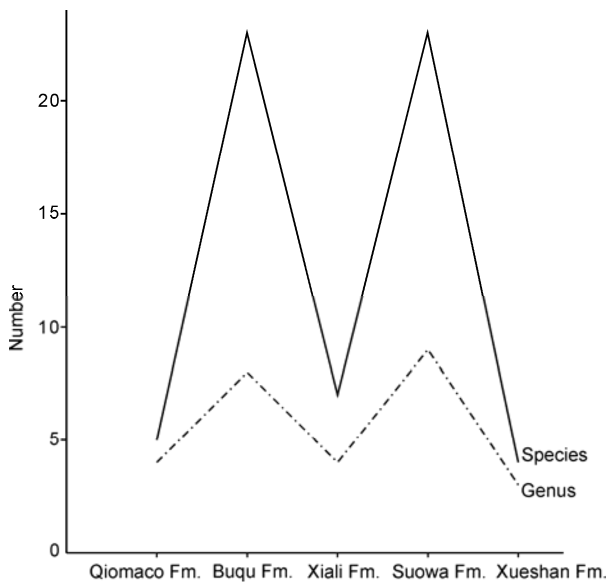

Figure 5 Variation curve of the genera and species abundance of Jurassic Pectinacea in the study area.

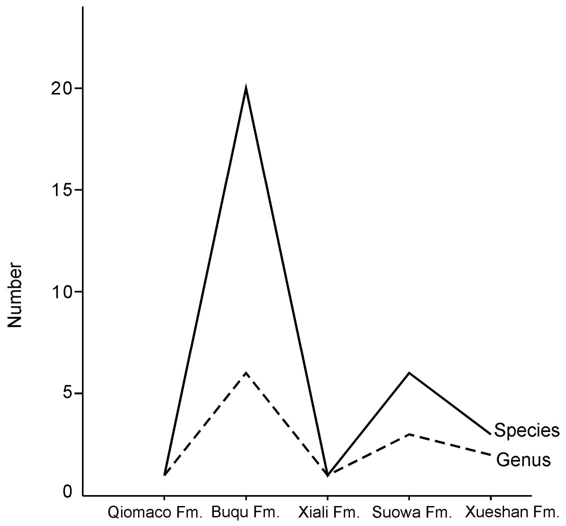

Figure 6 Variation curve of the genus and species abundance of Jurassic Pholadomyacea in study area.

shows a preference to specific sedimentary facies. For example, *Mesosacella*, *Pinna*, *Entolium*, *Lucina*, *Isognomon* (*Mytiloperna*), *Lopha*, *Pholadomya*, *Ceratomya*, and *Inoperna* only appear in carbonate platform (gentle slope) sedimentary facies; *Camptonectes Radulopecten*, *Miyagipecton*, *Placunopsis*, *Liostrea*, *Plagiostoma*, *Pseudolimea*, *Arcomytilus*, *Modiolus*, *Protocardia*, *Astarte*, *Anisocardia*, *Quenstedtia*, *Mactromya*, *Myophalus*, and *Pleuromya* flourished both in carbonate platform (gentle slope) sedimentary facies and in lagoonal sedimentary facies; and *Bakevellia*, *Gervillella*, *Costigervillia*, and *Kobayashites* mainly occurred in lagoonal sedimentary facies.

4 Conclusions

(1) Jurassic strata in the source area of the Yangtze River include the Qoimaco Formation, the Buqu Formation, the Xiali Formation, the Suowa Formation, and the Xueshan Formation, which are assigned respectively to early Bathonian, middle-late Bathonian, late Bathonian-early Callovian, Callovian, and late Callovian, based on the bivalves and ammonites. No diagnostic fossils have been found from the lower part of the Qoimaco Formation or upper part of the Xueshan Formation yet, which may contain partial Bajocian and Oxfordian sediments respectively.

(2) All the 5 formations in the study area contain multiple layers of gypsum, with various thicknesses and horizontal extension. These frequent gypsum sedimentations may be related to lagoons of different size formed by developed barriers and the general dry climate during Middle Jurassic in the study area. Once fresh water poured in at great volumes; some lagoons evolved into freshwater lakes, which were suitable for the habitat of unionoids.

(3) The study area experienced a continuous transgression during Bathonian, with most widespread and normal (deepest) seawater in Middle Jurassic. While the region located in the northern periferal area of Gondwana including southern Tibet, Bathonian was commonly passing through a regression [22, 36, 37, 38]. Therefore, the transgression and regression of sea water within the stud area during the Bathonian is not consistent with other parts of the world.

Bai Y S, Bu J J, Gan J M, Duan W J from Wuhan Center of Geological Survey took part in the fieldwork, Professor Yin J R from China University of Geosciences (Beijing) identified the ammonites, and Dr. Tan J J translated part of the manuscript, whose works are highly appreciated here. Prof. Dr. Bernd-D. Erdtmann, TU Berlin, Germany edited the final manuscript. This study was supported by National Natural Science Foundation of China (Grant Nos. 40772022, 40972006), and State Key Laboratory of Palaeobiology and Stratigraphy (Nanjing Institute of Geology and Paleontology) Chinese Academy of Sciences (Grant No.10311).

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