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Geology of the petroleum and coal deposits in the Junggar (Zhungaer) basin, Xinjiang Uygur Zizhiqu, northwest China

By

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ABSTRACT

The Junggar (Zhungaer) basin contains rich petroleum deposits and high-quality bituminous coal resources; it was developed as a peripheral platform basin on the Paleozoic continental crust of the Variscan fold system during the late Variscan orogeny. The initial platform depositional framework was intensely faulted and downwarped at the end of Permian time. Subsequently, the basin was filled with continental fluvial and lacustrine deposits of fine to very coarse detrital rocks, which contain the thick Permian, Jurassic, and Paleogene petroleum source rocks and the high-quality bituminous coal beds of the Lower and Middle Jurassic. The present form of the basin was established in the late Permian and was further modified during the Mesozoic and Cenozoic.

Principal structural features of this basin consist of the Northern Platform in the north and the Northern Tian Shan Foredeep in the south. The Northern Platform is a southerly dipping folded belt and covers about two-thirds of the basin. The region contains the presently known rich petroleum resources. Generally, up-dip migration of petroleum is common throughout the region. The Northern Tian Shan Foredeep evolved initially from graben faulting in Permian time; it contains the thickest basin filling in which mineable Jurassic coal beds are found.

Current petroleum exploration is concentrated in the northwestern part of the basin. Future exploration for petroleum in plays similar to those already discovered in Karamay oil field will lie in the area between Xiazijie and Dishuiquan of the Northern Platform. Other areas in the basin have petroleum potential from other types of plays.

Source rocks of this basin consist chiefly of lacustrine deposits of more than 1,000 m of Permian oil shale and shale, and of 600 to 1,500 m of Triassic and Jurassic rocks as well as Paleogene mudstone, shale and oil-shale. Adequate quantities and richness of source rocks appear to be present to accommodate normally expected amounts of recoverable petroleum for this type of basin.

Although studies of the characteristics of the Permian organic matter are not available, nor are temperature conditions, the Permian shales likely have reached maturity considering their depth of burial. In general, the petroleum pools have shale and mudstone seals. The traps are most commonly fault or stratigraphic types with some small fields on the south flank being anticlinal.

The thickest coal beds are present largely in the Lower and Middle Jurassic Badaowan, Sangonghe, and Xishanyo Formations. I tentatively estimate the bituminous coal resources to be at least 270 x 10^9 metric tons, of which the recoverable coal resources are approximately 18 x 10^9 metric tons.

Table 1.--Orogenic cycles of China (After Huang et al., 1980, table 4, p. 106).

Geologic chronology		Isotopic age (m.y.)	Orogenic cycles	
Cenozoic	Quaternary	1.5	H_2	Himalayan (H)
	Tertiary	67	H_1	
Mesozoic	Cretaceous	137	Y_3	Yanshanian (Yenshanian) (Y)
	Jurassic	190	Y_2, Y_1	
	Triassic	230	I	Indosinian (I)
Paleozoic	Permian	280	V_4	Variscan (V)
	Carboniferous	350	V_3, V_2	
	Devonian	405	V_1	
	Silurian	440	C_2	Caledonian (C)
	Ordovician	550	C_1	
	Cambrian	570		Xingkaiian (Hsingkaiian)
Proterozoic	Sinian	770		Yangziian (Yangtzeian)
	Qingbaikou	1100		
	Jixian	1400		?
	Nankou	1700		Wulingian
	Changcheng / Hutuo	1950		Zhongtiaoian (Chungtiaoian)
	Wutai	2500		Wutaiian
Archean	Fuping			Fupingian

INTRODUCTION

General Statement

The Junggar (Zhungaer) basin is a triangular depression in the northern part of Xinjiang, northwest China (fig. 1). Its initial depositional framework developed as a wedge-shaped platform basin near a plate collision on a Paleozoic continental crust during the episode, V_3, of the Variscan orogeny (table 1) (Huang and others, 1980) (Wang and others, 1983) (Zhang and others, 1984). Subsequently, at the end of the Permian, the Junggar became an intermontane basin receiving detrital influxes from the adjacent highlands, and subsequently developed into its present form through tectonic movements of the Indosinian, Yanshanian, and Himalayan orogenies (table 1) (fig. 2).

The Junggar basin was filled chiefly with upper Paleozoic marine (Devonian to Upper Permian) and continental Upper Permian sediments and with Triassic to Quaternary continental fluvial, swamp, and lacustrine detrital sediments (fig. 2). The petroleum source rocks are the mudstone and shale of the Late Carboniferous, Late Permian, Late Triassic to Middle Jurassic, Cretaceous, and Miocene to Pliocene ages. Bituminous coal beds occur chiefly in the Lower and Middle Jurassic sedimentary sequences. Peat beds have been found locally in the Holocene sedimentary sequences.

Regional Setting

The Junggar basin occupies about 130,000 sq km and is about 500 m above sea level. It is confined within lat 44°00' to 46°30' N. and long 84°30' to 91°00' E. and is bounded on the south by the Tian Shan and the Bogda Shan, on the west by irregular mountain ranges, and on the north and east by the Altay (Altai) (Aertai) Mountain Range and the Kelameili Mountains (figs. 1 and 2).

In the Junggar basin, the post-Devonian sedimentary cover is generally more than 15,000 m in the foredeep along the front of the Northern Tian Shan. Since the early 1950's, this basin has been explored extensively for petroleum. Discovery wells in the Permian, Triassic, and Lower Jurassic coarse clastic reservoirs near Karamay in the western part of the basin in 1956 promoted a concentration of exploratory effort in the northwestern and northern parts of the basin. Jurassic coal beds are thick in this same foredeep.

The basin has a continental climate; there is little rainfall, and temperature variations are rapid. During the winter season, the average temperature is generally below -20° C. Stabilized sand dunes are common in the central and south-central parts of the basin.

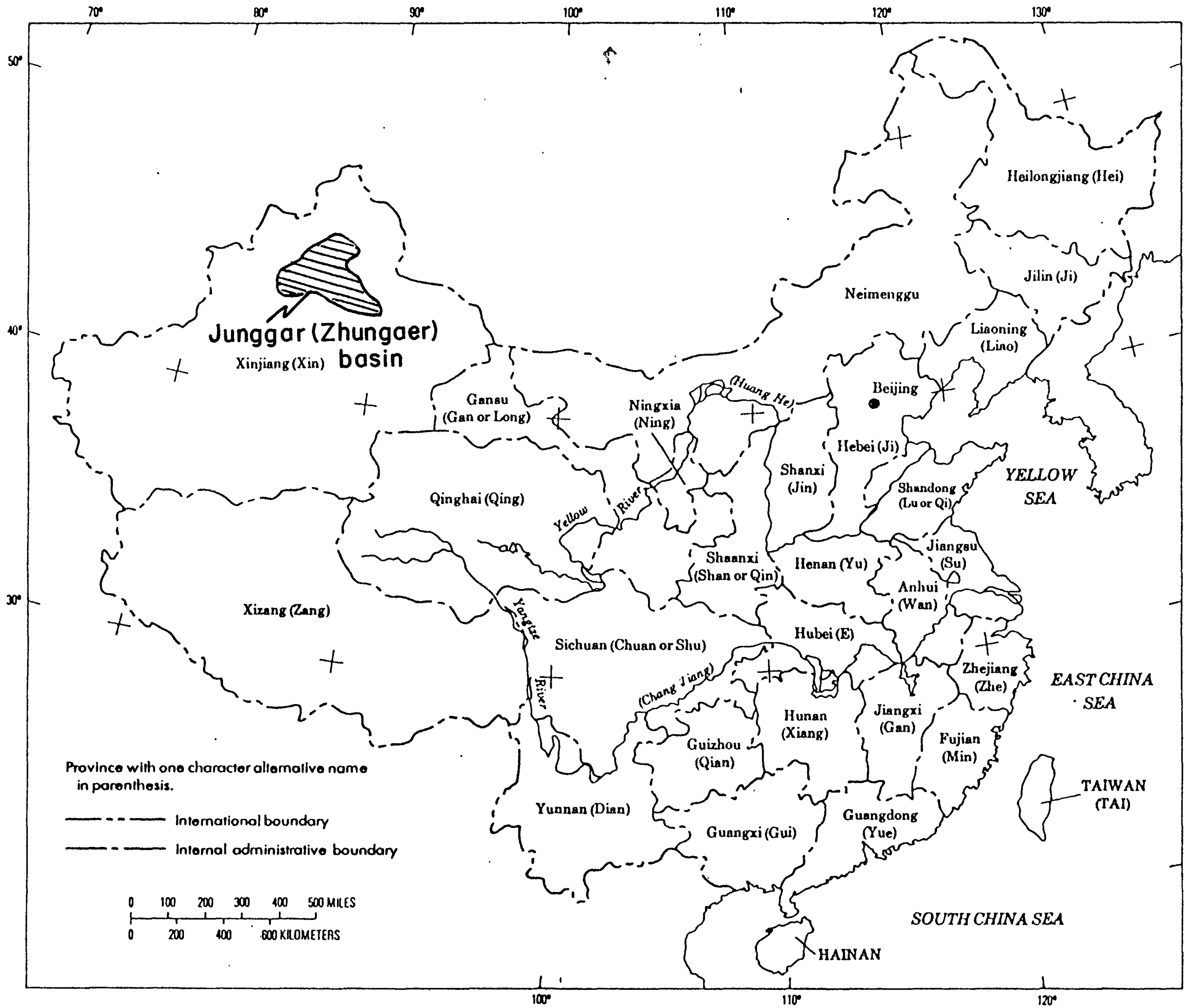

Figure 1. Index map of China showing the location of study area.

Purpose, Scope, and Method of the Report

The primary purpose of this report is to provide a synthesis of the available current literature on the geology of petroleum and coal deposits in the Junggar basin. As a whole, the report is based on selected current Chinese literature in order to provide a perspective for understanding geological factors relating to resource assessment. The Pinyin system from the Gazetteer of the People's Republic of China (1979) is used for Chinese name transliteration, and the Chinese Dictionary for Geographic Names is used for those names not listed in the Gazetteer. In some cases, a conversion of the Wade-Giles system to Pinyin is made in parentheses; also some prominent geographic names in other forms of transliterations are in parentheses.

STRATIGRAPHY

The stratigraphic section of the Junggar basin, based of surface and subsurface investigations and geophysical surveys, is divided, in ascending order, into pre-Carboniferous, Carboniferous, Permian, Mesozoic, and Cenozoic volcanics and sedimentary rocks (table 2) (fig. 2). The pre-Carboniferous basement of the basin consists chiefly of Devonian sedimentary and metamorphic complexes. The Lower Carboniferous rocks are dominantly volcanic, followed by Upper Carboniferous marine flysch with only a scattering of volcanic beds, including ash. Marginal marine sedimentation continued in the central and southwestern parts of the basin; but by Late Permian time, the marine seaway was completely withdrawn, giving way to continental intermontane sedimentary processes. Mesozoic and Cenozoic continental fluvial and lacustrine deposits of coarse to fine clastics are very thick in the area east of Manas Lake and in the Northern Tian Shan Foredeep (fig. 2).

Pre-Carboniferous

The stratigraphy of the pre-Carboniferous strata consists of undifferentiated lower Paleozoic metamorphic complexes and Devonian marine sedimentary rocks and basic volcanic rocks. A general stratigraphic discussion of these units is given below.

Lower Paleozoic

The lower Paleozoic stratigraphy consists of undifferentiated Ordovician and Silurian metamorphosed sedimentary sequences. The rock types are dark gray mica schist, light-gray quartzite, gray slate, green phyllite, and, locally, metavolcanic rocks. They are well exposed along the western and southeastern borders of Junggar basin (fig. 2).

Devonian

The Devonian strata are present in the basin and are exposed sporadically in the highland areas adjacent to the basin. Rock types consist chiefly of gray and green tuffaceous sandstone intercalated with small amounts of conglomerate, tuff, slate, basic volcanic rocks, and, locally, fossiliferous limestone (fig. 2).

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Table 2.--Upper Paleozoic to Cenozoic stratigraphic correlation of the Junggar Basin, Xinjiang, Northwest China (after Chinese Academy of Geological Sciences, 1982; Chang, 1981; Wang et al., 1983; Wang and Liu, 1980; Zhao, 1980; and Zhao, 1982).

ERA	SYSTEM	SERIES	SOUTH	NORTHWEST	EAST
Cenozoic	Quaternary	Holocene	Eolian, lacustrine, alluvial & diluviel deposits of silt, clay, sand, & gravel. Mud volcano deposits at Dushanzi. Locally evaporites.		
		Pleistocene	Desert gravel, glacial till & outwash sand & gravel. Eolian loess, and paleosoils. 330-3,000 m		
	Tertiary	Neogene	Conglomerate. 90-1,500 m	Changjihe Gp. Ms., Sts. & Ss. with Cgl. & Ls. 30 m	Fluviel & lacustrine deposits of more than 600 m
			Dushanzi Fm. Ms. & Ss.; locally Cgl. 1,027 m		
			Taxihe Fm. Ms., Ls. & Ss. 100-320 m	Suosuoquan Fm. Ms., Ss. & Cgl. 15-400 m	
		- - - - - - -	Shawan Fm. Ms. 150-500 m		
		Eogene (Palaogene)	Anjihaihe Fm. Ms., marl & Ss. 40-800 m	Ulungurhe Fm. Ms. & Ss. 35-555 m	Lacustrine deposits of clastic rocks
			Ziniquanzi Fm. Ms. & clastic rocks. 15-850 m	Honglishan Fm. Ss. & Cgl. 107 m	
Mesozoic	Crataceous	Upper Cretaceous	Donggou Fm. Ms., Ss. & Cgl.; some marl & Ls. 300-1,000 m	Ailika Fm. Ms., Ss. & basal Cgl. 62 m	
		Lower Cretacaous	Tugulu Gp. Lianmuqin Fm. Ms., Sts. & Ss. 350 m	Tugulu Gp. Lianmuqin Fm. Ss. & Ms. 431 m	Tugulu Gp. Breccia, 50 m
			Shenginkou Fm. Sts., Ss., Sh., & Ms. 100 m	Shenjinkou Fm. Ss. & Ms. 250 m	
			Hutubihe Fm. Ms. with Sts. 300 m	Hutubihe Fm. Ss. & Ms.; basal Cgl. 147 m	
			Quingshuihe Fm. Ms. & Ss.; basal Cgl. 300 m		
	Jurassic	Upper Jurassic	Kalaza Fm. Cgl. with Ms. & Ss. 200-272 m	Kalaza Fm. Cgl. with Ms. & Ss. 0-200 m+	Shishugou Gp. Ms. & Ss.; basal Cgl. 306 m
			Qigu Fm. Ms. with Ss. 300-414 m	Qigu Fm. Ms. with Ss. 40-200 m±	
		Middle Jurassic	Toudunhe Fm. Ms. with Ss. & Cgl. 427-1,000 m	Toudunhe Fm. Ms. with Ss. & Cgl. 50-800 m	Toudunhe Fm. Ms. with marl, Ss. & Cgl.
		- - - - - - -	Xishanyao Fm. Ss. & Cgl. with Coal & Ms. 629-1,000 m	Xishanyao Fm. Ss. & Cgl. with Coal & Ms. 300-600 m	Xishanyao Fm. Ss. Cgl. & Coal. 100-200 m
		Lower Jurassic	Sangonghe Fm. Cgl., Ss., Ms., & Coal. 400-486 m	Sangonghe Fm. Cgl., Ss., Ms., & Coal. 100-200 m	Sangonghe Fm. Ss. & Cgl.
			Badaowan Fm. Ms., Ss., & Cgl. with Sh. & Coal. 390-500 m	Badaowan Fm. Ms., Ss. & Cgl. Sh. & Coal. 60-200 m	Badaowan Fm. Ms., Ss., & Cgl.
	Triassic	Upper Triassic	Haojiagou Fm. Ss., Sh., & Ms., Coal. 300-600 m	Haojiagou Fm. Ms. with Ss. 31-100 m	Xiaoquangou Gp. Ms., Sh., Ss., & Cgl. 150 m
			Huangshanjie Fm. Ss. & Ms. 200-300	Huangshanjie Fm. Ss. & Ms. 40-300 m	
		Middle Triassic	Kelamayi (Karamay) Fm. Ms. & marl. 350-485 m	Kelamayi (Karamay) Fm. Cgl., Ss., & Ms. 50-450 m	
		Lower Triassic	Shangcanfanggou Gp. Shaofanggou Fm. Ms., Ss., & Cgl. 100-395 m	Baikouquan Fm. Cgl. & Ss. with Ms. 130-200 m	Conglomerate with Ms.
			Jiucaiyuan Fm. Ms. with Ss. 250-700 m		
Paleozoic	Permian	Upper Permian	Xiacanfanggou Gp. Xiaolongkou Fm. Ms. with Ss. & marl. 115-158 m	Uarho Gp. Diluvial detrital rocks. 1,100 m	Pingdiquan Gp. Cgl., Ss., Sts., & Sh. 350-800 m
			Wutonggou Fm. Ms. with Ss. 252 m		
			Quanzijie Fm. Ms. with Cgl. 160-210 m		
			Shangjijicaozi Gp. (Shangjijicao Gp.) Hongyanchi Fm. Ms. with Ls. & Cgl. 50-460 m		
			Lucaogou Fm. Sh. & Oil-Sh. with Ls., Sts., & Ss. 300-640 m		
			Jingjingzigou Fm. Ss., Sts., & Ms. 500 m		
			Wulapo Fm. Ss., Sts., Ms., & Ls. 900		
		Lower Permian	Xiajijicaozi Gp. (Xiajijicao Gp.) Ss., Cgl., Ms., Ls & sh.	Xiazijie Gp. Diluvial detrital rocks. 430 m.	Chidi Gp. (Rotliegends Gp.) Ms., Ss., & Cgl. 100-2,100 m.
	Carboniferous	Upper Carboniferous	Aotuer Fm. Ss. & Sts., some Ls. 260-1,000 m	Jiamuha Gp. Cgl., Ss. & volcanic flows. 400-3,000 m	Shiqiantan Gp. Cgl., Ss., Ms., & Sh. 200-1,500 m
			Qijiagou Fm. Ls., Ss., & Cgl. 534-970 m		
			Liushugou Fm. Ss., volcanic breccia, & volcanic rocks. 2,000-3,330 m		
			Julideneng Fm. Ss., Cgl., & Sts. 1,080-2,000 m		
		Lower Carboniferous	Nanmingshui Fm. Ss., Slate, & Ls. 600-3,500 m		Dishuiquan Fm. Ss., Cgl. & Sh. Locally marl & volcanic flows.
			Jiangbasitao Fm. Ss. & Cgl. 650 m		
			Donggulubasitao Fm. Ss., Sts. & Cgl. Some Ls. >30-1,500 m		
	Devonian	Undifferentiated marine and continental deposits of sedimentary rocks, volcanic rocks, metasedimentary rocks.			

Fm.= Formation Gp.= Group Ss.= Sandstone Sts.= Siltstone Ms.= Mudstone Cgl.= Conglomerate Ls.=Limestone Sh.= Shale

Upper Paleozoic Carboniferous and Permian

The Carboniferous and Permian systems in the Junggar basin consist of a series of littoral marine and continental facies and silicic to basic volcanic rocks. The thickest deposits are in the northeastern part of the basin (figs. 2 and 3) (table 2).

Carboniferous

The Carboniferous System of the Junggar basin consists of Lower Carboniferous littoral marine lithofacies and, locally, volcanic rocks; and of Upper Carboniferous continental and marine sedimentary rocks and intermediate silicic to intermediate basic volcanic rocks. The Early Carboniferous sea came from west and northwest of the basin. At the end of the Early Carboniferous, as the sea retreated southeastward along the northern front of the Bogda Shan, the Junggar basin was gradually uplifted becoming greatly deformed; this was accompanied by an extensive eruption of silicic to basic volcanic rocks and the deposition of continental detrital rocks. At the close of the Late Carboniferous, the Junggar region again subsided, and the Permian Sea re-entered the basin from the east.

The Carboniferous System is divided into Lower Carboniferous and Upper Carboniferous sedimentary sequences. A discussion of the stratigraphy follows in accordance with the regional distribution, which includes the southern, northwestern, and eastern parts of the basin (table 2) (fig. 2).

Lower Carboniferous

The Lower Carboniferous strata are present in the southern and eastern parts of the basin, but they are generally absent in the northwestern part (table 2).

In the southern part of the basin, the Lower Carboniferous strata are represented in ascending order by the Donggulubasitao, the Jiangbasitao, and the Nanmingshui Formations. These formations are well exposed along the northern flank of the northern Tian Shan.

The Donggulubasitao Formation is made up chiefly of sandstone, siltstone, and tuffaceous sandstone conglomerate; generally it is intercalated with lenticular limestone beds in the lower part. It contains invertebrate fossil fauna: *Gattendorfia sp.*, *Merocanites sp.*, *Syringothyris sp.*, *Spirifer tornacensis*, *Neozaphrentis sp.*, and *Cyathoxonia sp.* The thickness ranges from 30 m to 1,500 m.

The Jiangbasitao Formation consists of tuffaceous sandstone, tuffaceous and carbonaceous conglomerate, and conglomerate. Brachiopod fossils are *Neospirifer sp.*, *Linoproductus sp.*, *Syringothyris altaica* and *S. Textus*. Thickness is 650 m.

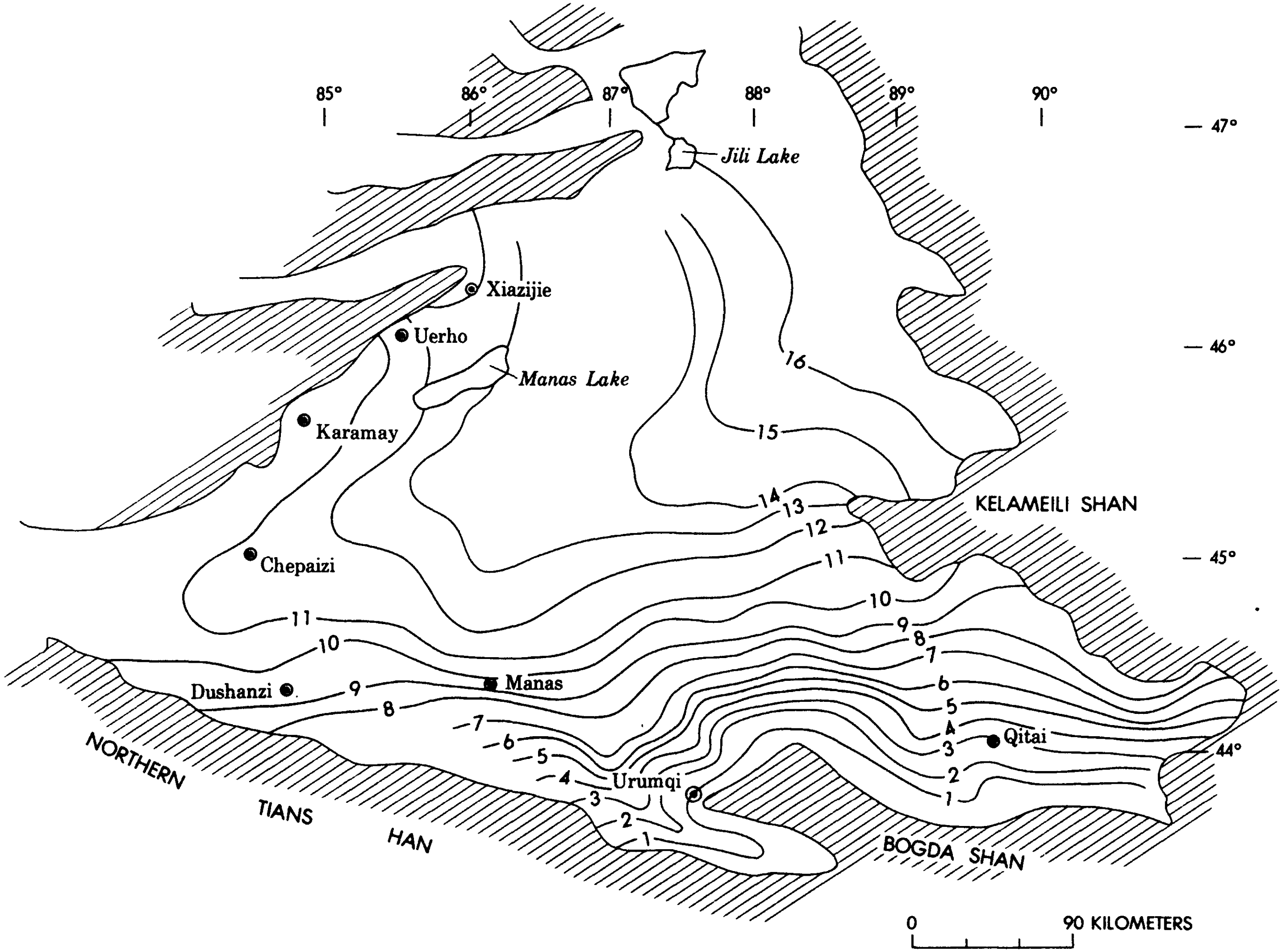


Figure 3. Isopachs of the Upper Paleozoic strata in the Junggar basin, Xinjiang, NW China (after Chinese Academy of Geological Sciences, 1982; and Han and Yang, 1980).

5 in kilometers

The Nanmingshui Formation comprises chiefly gray tuffaceous sandstone, very compact sandstone, siliceous slate, and limestone. This formation contains invertrebate fossil fauna: Gangamophyllum sp., Carcinophyllum sp., Gigantoproductus sp., Dictyoclostus sp., and Linoproductus sp.

The Lower Carboniferous of the eastern part of Junggar basin is represented by the Dishuiquan Formation. This formation consists of a series of littoral marine deposits of black carbonaceous shale intercalated in the lower part with shale, sandstone, and thin-bedded limestone and, in the upper part, with purplish-red or gray tuffaceous sandstone, conglomerate, tuff, and volcanic flows. This unit is very thick and well distributed along the flank of Kelameili Shan (figs. 2 and 3) (table 2).

Upper Carboniferous

The Upper Carboniferous strata consist chiefly of continental detrital sediments deposited as the Carboniferous sea retreated from the basin to the southeast; these are widely distributed throughout the basin. A detailed study has been done on the southern part of the basin. A general lithologic description is available for the northwestern and eastern parts of the basin (table 2) (fig. 2).

The Upper Carboniferous strata of the southern part of the basin overlie unconformably the Lower Carboniferous sedimentary sequences and are represented, in ascending order, by the Julideneng, the Liushugou, the Qijiagou, and the Aotuer Formations. The lower part of the Julideneng, however, is Lower Carboniferous (Chinese Academy of Geological Sciences, 1982, table 10).

The Julideneng Formation consists chiefly of grayish-green, grayish-black sandstone, conglomerate and siltstone intercalated with very compact sandstone, tuffaceous sandstone, and carbonaceous siltstone. It contains Calamites nudulatus, Eoasianites sp., and Dictyoclostus sp. Thickness of this unit ranges from 1,080 to 2,000 m.

The Liushugou Formation is made up of grayish-green tuff, tuffaceous sandstone, volcanic breccia, and intermediate to basic volcanic rocks intercalated with cherty nodules and limestone. This formation contains fossil fauna: Gastrioceras sp., Dictyoclostus sp., Caninophyllum amplexoides, and Caninia ornata. Thickness ranges from 2,000 to 3,330 m.

The Qijiagou Formation is generally widely distributed and consists chiefly of grayish-green and gray limestone, tuffaceous conglomerate and sandstone. The limestone is fossiliferous and contains Fusulina sp., Ozawainella mosquensis, Pseudostaffella cf. ozawai, Caninia cf. vigilans, and Multythecopora penchiensis. Thickness ranges from 534 to 970 m.

The Aotuer Formation comprises sandstone and siltstone intercalated with thin-bedded limestone. Fossil fauna are the Choristites, Somolites, Neopronorites, and Cyathocarinia. Thickness ranges from 260 to 1,000 m.

In the northwestern part of the basin, the Upper Carboniferous is represented by the Jiamuhe Group. This Group is undifferentiated and consists of continental deposits of orange-red conglomerate intercalated with grayish-green mudstone, siltstone, fossil plant-bearing sandstone, sheeted volcanic flows, and, locally, thin coal. The unit is 400 to 3,000 m thick, with a maximum thickness in the Manas Lake area.

In the eastern part of the basin, the Upper Carboniferous sedimentary sequence consists of littoral marine and marine and continental lithofacies. As the Upper Carboniferous sea regressed toward the southeastern part of the basin, shallow marine and continental deposits of conglomerate, sandstone, mudstone, limestone, and carbonaceous shale with abundant fossils were deposited chiefly in areas south of the Kelameili Mountain and to the northern front of the Bogda Mountain (fig. 2). This unit is 200 to more than 1,500 m thick.

Permian

The Permian System is distributed throughout the Junggar basin and is represented by the Lower Permian littoral marine lithofacies in the southern and eastern parts of the basin, by continental deposits, chiefly in the northwestern part of the basin, and by Upper Permian continental sediments in the southern, the northwestern, and the eastern parts of the basin. A discussion of the stratigraphy follows the regional distribution (fig. 2) (table 2).

Lower Permian

The Lower Permian strata of the basin generally lie unconformably on the Upper Carboniferous sedimentary rocks, except locally in the southern part where the contact is conformable.

In the southern part of the basin, the Lower Permian is represented by the Xiajijicaozi (Xiajijicao) Group (fig. 2) (table 2). The Xiajijicaozi Group is undifferentiated and consists of littoral marine grayish-green, fine-grained sandstone, shale, and mudstone, which, in the lower part, are intercalated with feldspathic sandstone and conglomerate, in the middle part with carbonaceous shale and siltstone, and in the upper part with lenticular oolitic limestone beds and mudstone. This unit contains Neospirifer and the fossil plant Noeggerathiopsis (Wang and Liu, 1980, p. 212). Thickness is more than 1,000 m.

The Lower Permian of the northwestern part of the basin is represented by the Xiazijie Group, which is undifferentiated and is made up chiefly of continental deposits of orange-red, fine to coarse siltstone, sandstone, and conglomerate. The thickness ranges from 430 to about 2,000 m.

In the eastern part of the basin, the Lower Permian is represented by littoral marine and marine and continental transitional lithofacies of the Chidi (Rotliegende) Group. This group is well exposed along the eastern basin border and consists chiefly of gray, grayish-green and red mudstone, sandstone, and conglomerate, which are intercalated with shale. Thickness ranges from 100 to 2,100 m.

Upper Permian

The continental lithofacies of the Upper Permian sedimentary sequences were deposited in fluvial and lacustrine environments and occur throughout the basin. The thickest sediments are found in the Manas Hu, Central, Wucaiwan, and Santai depressions; the areal coverage of each depression is about 10,000 to 20,000 sq km, and the maximum thickness of individual deposits ranges from 3,500 to 5,000 m (Zhao, 1982, p. 75-76) (figs. 4 and 5).

In the southern part of the basin, the Upper Permian is represented by the Shangjijicaozi (Shangjijicao) Group in the lower part and by the Xiacangfanggou Group in the upper part. In ascending order, the Shangjijicaozi Group is divided into the Wulapo, the Jingjingzigou, the Lucaogou, and the Hongyanchi Formations. The Xiacangfanggou Group is divided, in ascending order, into the Quanzijie, the Wutonggou, and the Xiaolongkou Formations. Generally, the Upper Permian strata are well exposed along the flank of the Bogda Shan (Chao, 1980, p. 1-38) (table 2).

The Wulapo Formation consists chiefly of grayish-green and purple feldspathic sandstone, siltstone, mudstone, and thin-bedded fossiliferous limestone. The lithofacies of this unit changes rapidly and laterally into a series of variegated coarse-grained sandstone and conglomerate. The unit is exposed along the northern flank of the Bogda Shan. Thickness is estimated at about 900 m.

The Jingjingzigou Formation is made up chiefly of feldspathic sandstone interbedded with siltstone, shale, and mudstone. The thickness is about 500 m.

The Lucaogou Formation is represented chiefly by lacustrine deposits associated with fluvial sandstone beds. In the lower part, the lithofacies consists of brown siltstone, fine-grained sandstone and dark shale intercalated with limestone and oil shale; in the upper part, of black oil-shale and shale intercalated with limestone and feldspathic siltstone and sandstone. Vertebrate fauna are Tienshaniscus longipterus and Turfania taoshuyuanensis. The Lucaogou generally ranges from 300 to 640 m in thickness and locally reaches up to 1,000 m. Cone-in-cone structure is present in the limestone near the top of the unit.

The Hongyanchi Formation is made up of grayish-green shale and sandstone in the lower part intercalated with marl and conglomerate at the base; and of grayish-green, dark-red mudstone and fine-grained sandstone in the upper part intercalated with shale, marl, conglomeratic sandstone and conglomerate. The unit ranges from 50 to 460 m thick.

The Quanzijie Formation is disconformably in contact with the underlying Hongyanchi Formation or Lucaogou Formation. This formation consists, in the lower part, of a purplish-red conglomerate intercalated with green conglomerate and purplish-red mudstone, and, in the upper part, of grayish-green and purplish-red mudstone intercalated with brown conglomerate, grayish-green sandstone and brown marl. The unit contains ostracods, plant fossils, and Kunpania scopulusa. Its thickness ranges from 160 to 210 m.

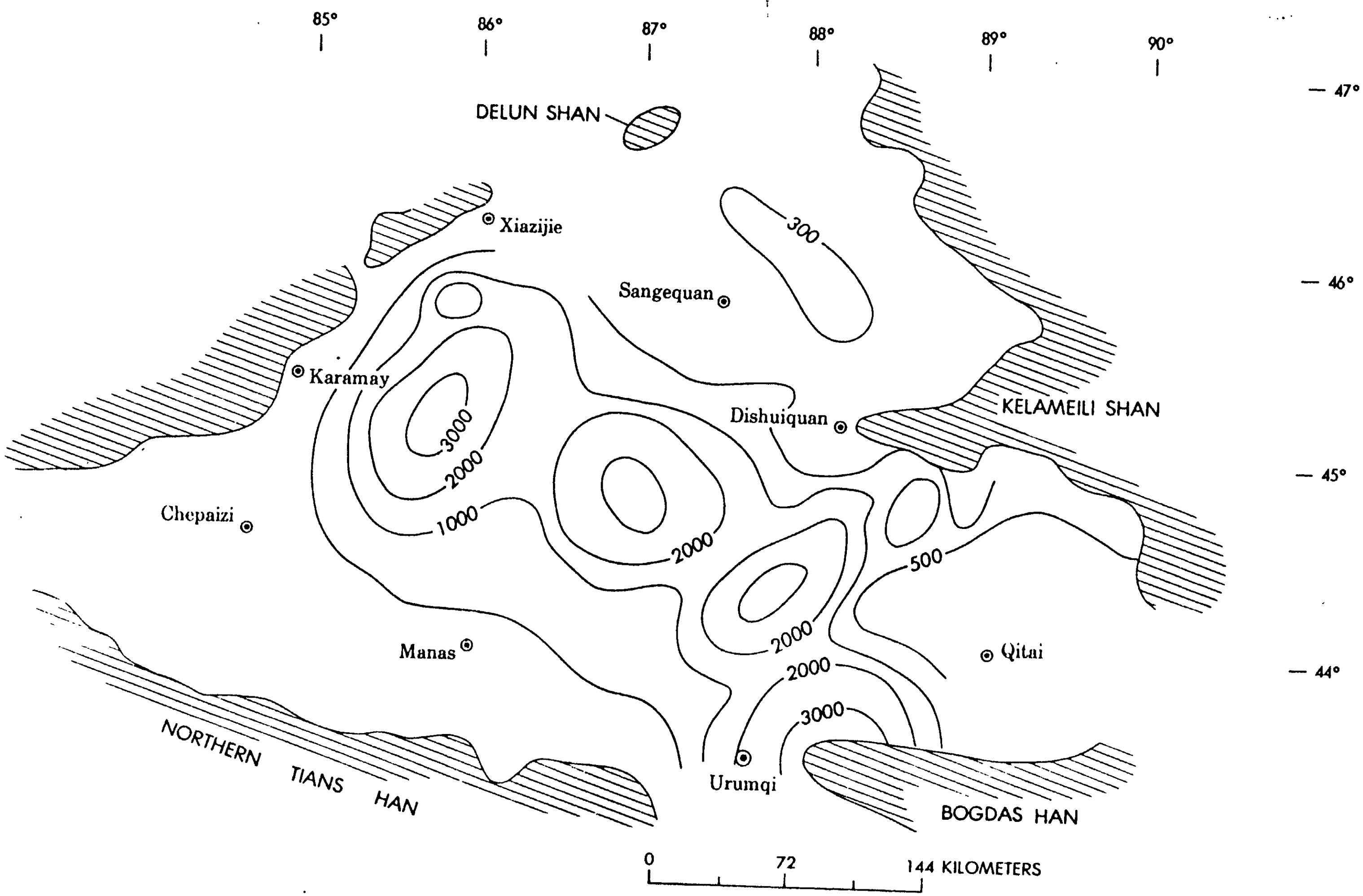
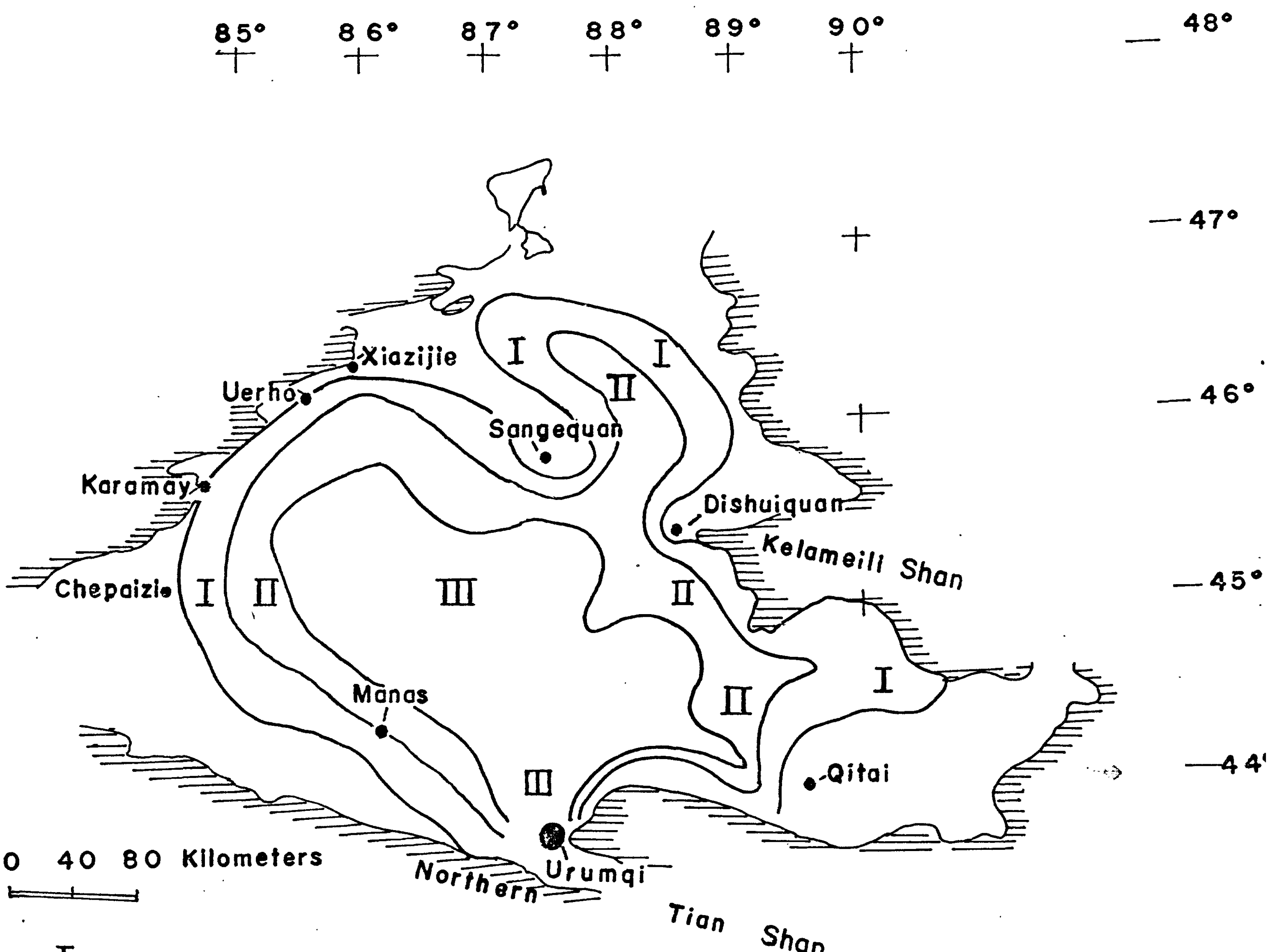


Figure 4. Isopachs of the Upper Permian strata in the Junggar basin, Xinjiang, NW China (after Zhao, 1982).

1000 in meters



I. Coarse detrital rock facies. II. Sandstone and mudstone facies.
III. Mudstone and shale facies.

Figure 5. Upper Permian lithofacies of the Junggar basin, Xinjiang, Northwest China (data after Zhao,1982; Fig. 2, P. 76)

The Wutonggou Formation is represented by a series of grayish-green mudstone and conglomeratic sandstone interbedded with grayish-green sandstone and basal conglomerate. This unit contains vertebrate fauna; its thickness is about 250 m.

The Xiaolongkou Formation consists chiefly of variegated mudstone intercalated with grayish-green sandstone and marl. Locally, brown basal conglomerate 2 m thick is present. Identified vertebrate fauna are Dicynodontia sp., Striodon magnus, and Jimusaria sinkianensis. Thickness ranges from 115 to 158 m.

The Upper Permian strata of the northwestern part of the basin are represented by the Uerho Group. This group comprises chiefly continental deposits of fine- to coarse-grained siltstone, sandstone, and conglomerate, which were deposited near the Permian basin margin (fig. 5). Thickness of this unit is estimated to be 1,100 m.

The Upper Permian strata of the eastern part of the basin are well exposed along the western flank of Kelameili Shan and are represented by the Pingdiquan Group. This group consists chiefly of continental deposits of orange-red sandstone and conglomerate intercalated with sandy mudstone and siltstone. The thickness ranges from 350 to 800 m.

Mesozoic

The Mesozoic sequence of the Junggar basin consists of more than 7,000 m of Triassic, Jurassic, and Cretaceous continental sedimentary sequences (figs. 2 and 6) (table 2). During the past decades, the stratigraphy of this basin has been studied in detail; the type sections are well exposed in its southern and northwestern parts. The Upper Cretaceous, however, is absent in the eastern part of the basin (table 2).

Triassic

Generally, sedimentation between the Permian and Triassic systems in the southern part of the basin was continuous, but in the northwestern and eastern parts of the basin, the Triassic strata are in unconformable contact with the underlying Permian sedimentary rocks. The Triassic system is divided, in ascending order, into the Lower, Middle, and Upper Series (table 2).

Lower Triassic

The Lower Triassic strata of the southern part of the basin are represented by the Shangcangfanggou Group. This group is divided, in ascending order, into the Jiucaiyuan and Shaofanggou Formations. The unit is well exposed in the vicinity of Urumqi (Wulumuqi).

The Jiucaiyuan Formation consists of brick-red and purplish-red silty mudstone intercalated with grayish-green sandstone, conglomeratic sandstone,

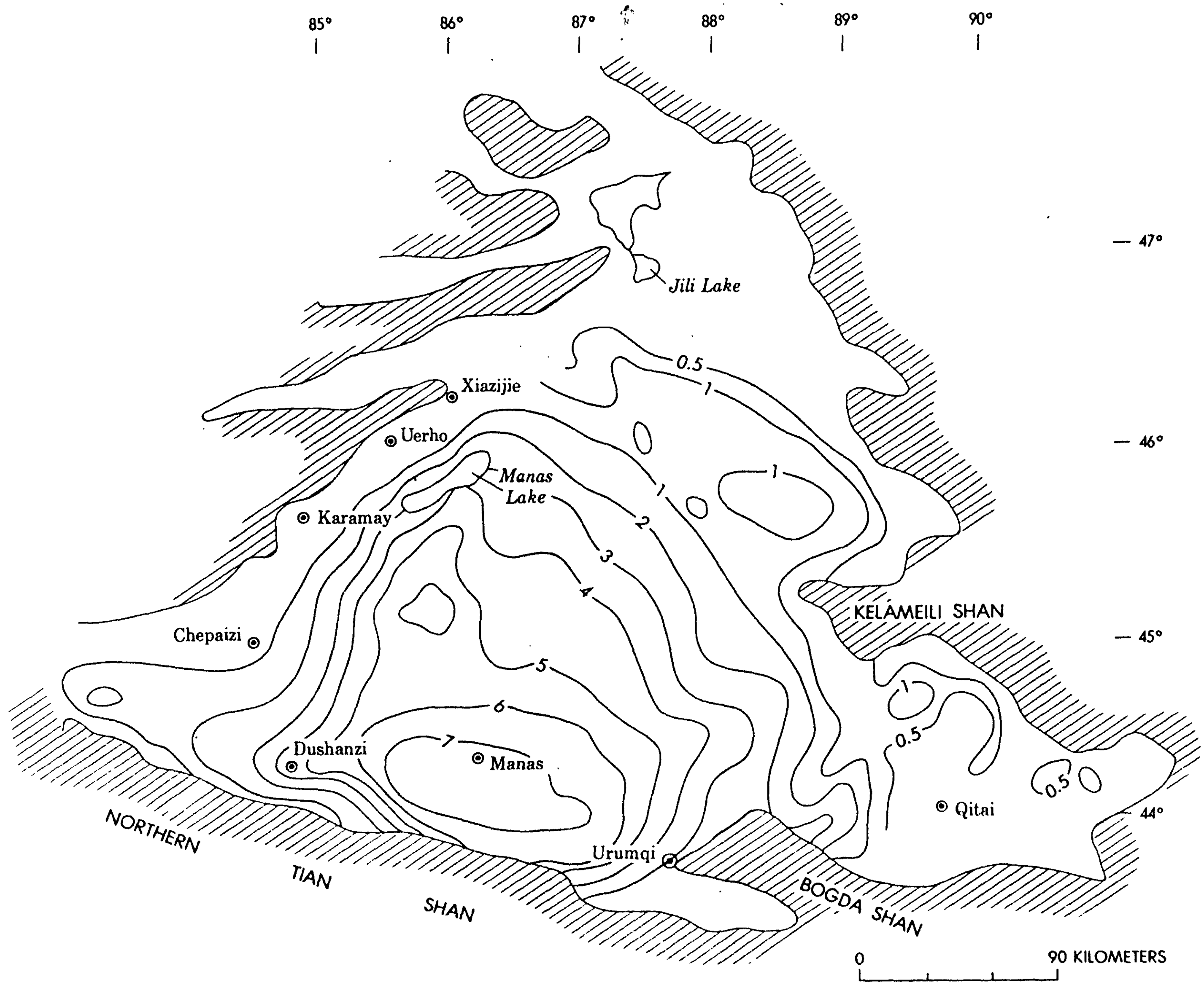


Figure 6. Isopachs of the Mesozoic strata in the Junggar basin, Xinjinag, NW China (after Zhang, 1983).

2 in kilometers

and conglomerate. The base of the formation is not exposed at the type section, Jiucaiyuan, Urumqi. Vertebrate fauna are: Lystrosaurus sp., L. hedini, Santaisaurus Yuani, Prolacertoides jimusarensis, and Chasmatosaurus sp. Thickness averages 250 m; the maximum is about 700 m.

The Shaofanggou Formation is made up, in the lower part, of brick-red mudstone intercalated with a subordinate amount of grayish-green, grayish-purple sandstone and sandy mudstone with concretion-bearing basal conglomeratic sandstone; and in the upper part, of brick-red mudstone intercalated with a small amount of grayish-green conglomeratic sandstone and argillaceous sandstone. Vertebrate fauna, Lystrosaurus sp and Chasmatosaurus sp. are present. Thickness averages 100 m and the maximum is 395 m.

The Lower Triassic of the northwestern part of the basin is represented by the Baikouquan Formation. This formation consists chiefly of continental red, dark purplish-red and orange-red conglomerate, sandstone, and mudstone. Thickness of the unit ranges from 130 to 200 m at the Karamay (Kelamayi) oil field (Chang, 1981).

The Lower Triassic of the eastern part of the basin is exposed in an area northwest of Jiangjunmiao. Generally this unit is represented by dark orange-red conglomerate intercalated with mudstone. The thickness is unknown.

Middle Triassic

The Middle Triassic strata of the southern part of the basin are represented by the Karamay (Kelamayi) Formation. This formation consists chiefly, in the lower part, of purplish-red mudstone, sandstone, and conglomeratic sandstone with basal conglomerate; and in the upper part, of variegated mudstone and shale intercalated with light-green, conglomeratic sandstone and siltstone. Identified vertebrate fauna are Parakannemeyeria brevirost, Parotosaurus sp., and Kannemeyeriidae. Thickness ranges from 350 to 485 m.

The Middle Triassic strata of the northwestern part of the basin are also represented by the Karamay Formation. It is made up in the lower part of 20 to 40 m of conglomerate, which has graded bedding; and in the upper part, of interbeds of brown or red conglomerate, conglomeratic sandstone, sandstone, mudstone, and siltstone. Thickness of the unit ranges from 50 to 450 m.

In the eastern part of the basin, the Xiaoquangou Group (table 2) represents both the Middle and Upper Triassic stratigraphic units and is not divided. The group consists of brownish-red, orange-yellow and light yellow conglomerate, siltstone, shale, mudstone, and sandstone. Thickness is estimated to be about 150 m.

Upper Triassic

The Upper Triassic sedimentary section of the southern part of the basin consists in ascending order of the Huangshanjie Formation and the Haojiagou Formation.

Generally the Huangshanjie Formation lies disconformably on the Karamay Formation. This formation comprises variegated mudstone and yellowish-green and black shale intercalated with grayish-yellow and grayish-green sandstone, siltstone, and basal conglomeratic sandstone and conglomerate. The section is well exposed in the vicinity of Urumqi. The unit ranges from 200 to 330 m in thickness.

The Haojiagou Formation consists, in the lower part, of dark-gray, grayish-yellow and grayish-green shale and mudstone; interbedded carbonaceous shale contains plant fossils. In the upper part it consists of light-brown, gray feldspathic sandstone and grayish-brown mudstone; interbeds of carbonaceous shale and lenticular siderite concretions are present near the top of the sequence. Locally mineable coal beds are found in this formation. Thickness ranges from 300 to 600 m.

In the northwestern part of the basin, the Upper Triassic is represented also by the Huangshanjie and the Haojiagou Formations.

The Huangshaujie Formation consists of a series of interbeds of grayish-green sandstone, conglomeratic sandstone, yellowish-gray siltstone, and light-gray and orange-red mudstone. At the Heiyoushan of Karamay, the formation contains about 10 m of conglomerate in the upper part. This conglomerate consists chiefly of angular rock fragments in the basal part and lies unconformably on Paleozoic metamorphic rocks. Thickness of this unit ranges from 40 to 300 m.

The Haojiagou Formation comprises chiefly grayish-yellow, light-grayish-yellow, silty mudstone intercalated with thin-bedded conglomeratic sandstone and sandstone. The unit contains Palaeoniscidae fauna. It is from 31 m to about 100 m thick.

Jurassic

The Jurassic system is represented by a series of fluvial and lacustrine deposits, more than 4,000 m thick, of fine to coarse detrital rocks throughout the Junggar basin; these contain economic petroleum and coal resources. A detailed study has been done in the southern and northwestern parts of the basin. This system is divided, in ascending order, into the Lower, Middle, and Upper series (table 2) (fig. 7).

Lower Jurassic

The Lower Jurassic strata are generally in conformable contact with underlying Upper Triassic sedimentary rocks in the southern part of the basin. In this region, the Lower Jurassic section is represented, in ascending order, by the Badaowan Formation, the Sangonghe Formation, and the lower part of the Xishanyao Formation (table 2) (Han and Yang, 1980, p. 294-299).

The Badaowan Formation is made up of light-gray and grayish-green sandstone and conglomerate and dark-gray, purplish-red mudstone and siltstone,

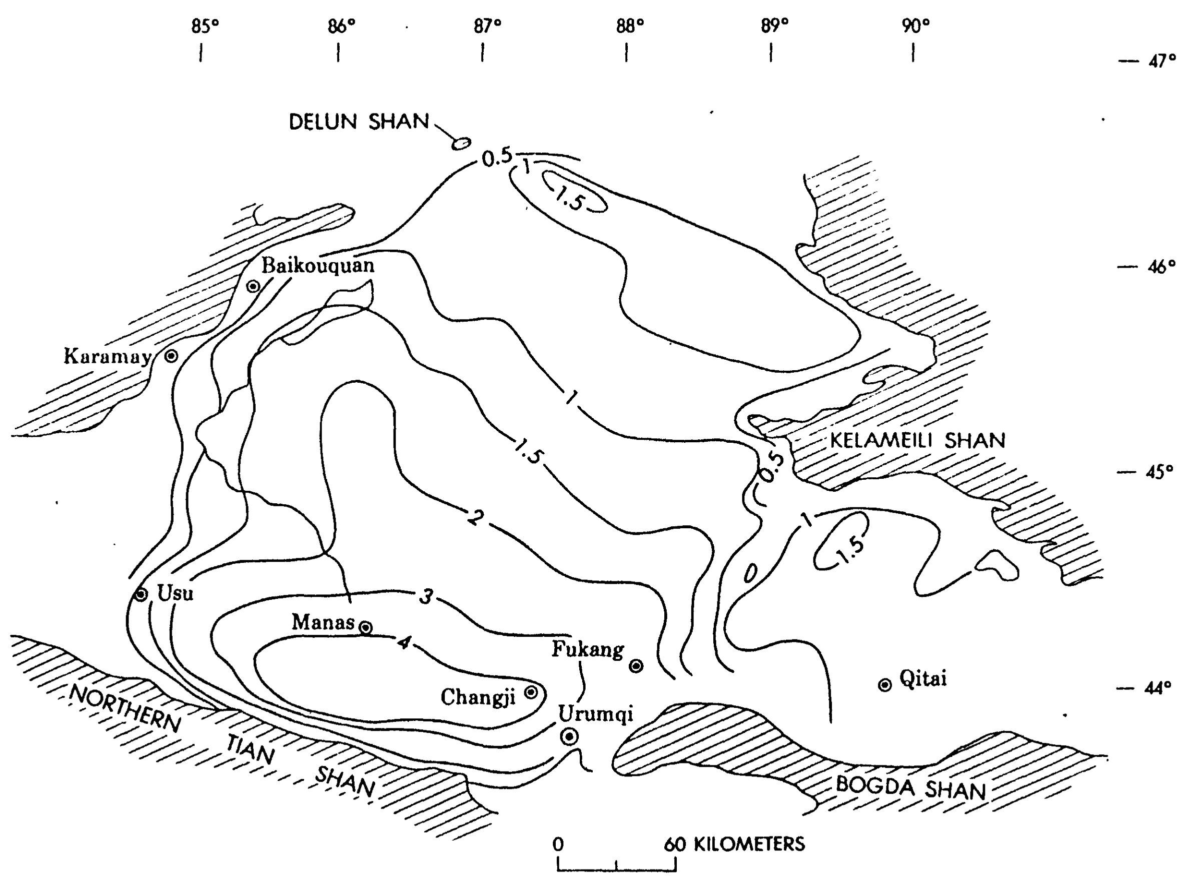


Figure 7. Isopachs of the Jurassic strata in the Junggar basin, Xinjiang, NW China (after Han and Yang, 1980).

2 in kilometers

intercalated with coal beds, carbonaceous mudstone, and siderite beds. The thickness of the unit ranges from 390 to 500 m; at the type locality Badaowan, it is 660 m thick; the thickness at the depositional center, near the town of Manas, reaches up to 1,000 m; very thin coal beds are present here.

The Sangonghe Formation consists chiefly of light-yellow and grayish-green mudstone, sandstone, conglomeratic sandstone, and conglomerate intercalated with thin coal beds, carbonaceous mudstone, siltstone, and cone-in-cone limestone layers. Thickness generally ranges from 400 to 486 m and locally it is 700 m thick.

In the southern part of the basin, the Xishanyao Formation was assigned an Early-Middle Jurassic age by Zhao (1980). This formation comprises a coal-bearing series of grayish-green and light-gray sandstone and conglomerate, and grayish-green, black and carbonaceous mudstone and coal intercalated with siderite beds. Thickness as a whole ranges from 629 to 1,000 m (fig. 8).

The Lower Jurassic strata of the northwestern part of the basin are represented, in ascending order, also by the Badaowan Formation, the Sangonghe Formation, and the lower part of the Xishanyao Formation (table 2).

The Badaowan Formation of the region consists of thick basal conglomerate, grading upward into sandstone, siltstone, and mudstone. Thickness ranges from 60 to more than 200 m.

The Sangonghe Formation comprises grayish-green and gray mudstone, siltstone, sandstone, conglomeratic sandstone and conglomerate. This unit is 100 to about 200 m thick.

The Xishanyao Formation represents the upper part of the Lower Jurassic and consists chiefly of coal-bearing grayish-green, gray sandstone and conglomerate intercalated with mudstone. The unit as a whole is from 300 to 600 m thick.

The Lower Jurassic strata of the eastern part of the basin are represented in ascending order by similar formations to those noted in the southern and northwestern parts of the basin, but detailed stratigraphy is not available. The Badaowan and Sangonghe Formations comprise fine to coarse clastic rocks. The thickness of these formations is not available. The Xishanyao Formation consists of coal-bearing sandstone and conglomerate, which has an Early-Middle Jurassic age. Thickness of the formation as a whole in this region ranges from 100 to 200 m.

Middle Jurassic

The Middle Jurassic strata of the southern part of the basin are represented in ascending order by the upper part of the Xishanyao Formation and the Toudunhe Formation. A lithologic description of the Xishanyao was given under the heading, Lower Jurassic.

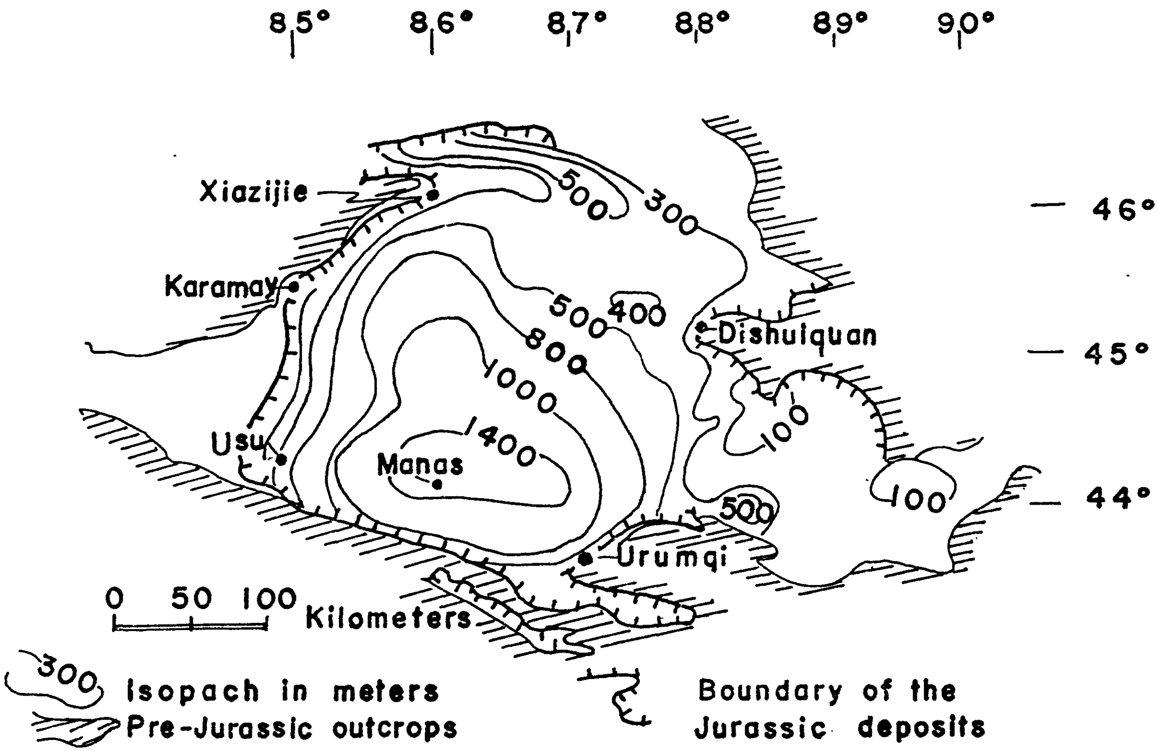


Figure 8. Isopachs of the Jurassic Xishanyao Formation in the Junggar basin, Xinjiang, Northwest China (after Department of Coal Teaching and Researches, Wuhan College of Geology, 1980; Fig. III-92, p.108).

The Toudunhe Formation of the southern part of the basin is comprised of purplish-red, grayish-green and sandy mudstone intercalated with grayish-green conglomerate and light-gray quartzose sandstone. Generally in the upper part of the formation, interbeds of gray quartzose sandstone and yellowish-green sandy mudstone are common. Thickness of this unit ranges from 427 to about 1,000 m.

The Middle Jurassic strata of the northwestern part of the basin are also represented by the upper part of the Xishanyao Formation and the Toudunhe Formation. A lithologic description of the Xishanyao was given under the heading, Lower Jurassic.

The Toudunhe Formation of the area consists chiefly of purplish-red, grayish-green, sandy mudstone, siltstone, and sandstone intercalated with conglomerate. Thickness is from 50 to about 800 m.

The Middle Jurassic sedimentary rocks of the eastern part of the basin are also represented by the upper part of the Xishanyao Formation and the Toudunhe Formation. A lithologic description of the Xishanyao was stated under the heading, Lower Jurassic.

The Toudunhe Formation of the area is made up chiefly of gray and grayish-green mudstone and siltstone intercalated with marl, sandstone, and conglomerate. Locally, conglomerate and sandstone are dominant. Thickness is unknown.

Upper Jurassic

The Upper Jurassic strata of the southern part of the basin are represented, in ascending order, by the Qigu and Kalaza Formations.

The Qigu Formation consists, in the lower part, of purplish-red mudstone intercalated with green sandstone; in the middle part, of purplish-red mudstone with basal conglomeratic sandstone; and in the upper part, of interbeds of purplish-red, sandy mudstone and sandstone. This unit contains the fossil fauna Mesosuchia and Darwinula. Thickness is from 300 to 414 m.

The Kalaza Formation comprises a series of orange-red grayish-green, light-yellow conglomerate intercalated with grayish-green and purplish-red mudstone and sandstone. The unit is about 200 to 272 m thick.

The Upper Jurassic sedimentary beds of the northwestern part of the basin are also represented by the Qigu and the Kalaza Formations, the same as those in the southern part of the basin but generally they are relatively thin.

The Qigu Formation generally consists of variegated sandy mudstone intercalated with coarse feldspathic sandstone. The unit is from 40 to about 200 m thick.

The Kalaza Formation is made up of variegated conglomerate intercalated with grayish-green and red mudstone and feldspathic sandstone. Thickness ranges from 0 to about 200 m.

The Upper Jurassic of the eastern part of the basin is represented by the Shishugou Group, which is not subdivided. This group is made up, in the lower part, of grayish-yellow, brownish-yellow mudstone intercalated with light-gray sandstone and conglomerate at the base, with the fossil Tienshanosautus chitaiensis; and in the upper part, of light-green, purplish-red and orange-red mudstone intercalated with sandstone. Thickness of the unit is about 306 m.

Cretaceous

The Cretaceous system is represented by a series of lacustrine and fluvial fine to coarse detrital rocks more than 2,000 m thick. The system is well exposed in the southern and northwestern parts of the basin and is divided in ascending order into the Lower and Upper series (table 2) (fig. 2).

Lower Cretaceous

The Lower Cretaceous of the southern part of the basin is represented by the Tugulu Group. This group is divided, in ascending order, into the Qingshuihe, Hutubihe, Shengjinkou, and Lianmuqin Formations (table 2) (fig. 2).

The Qingshuihe Formation comprises, in the lower part, grayish-green sandstone intercalated with mudstone and basal variegated conglomerate; and in the upper part, grayish-green, yellowish-green mudstone interbedded with yellowish-gray, fine-grained sandstone, which contains the vertebrate Paralligatoridae fossil fauna. The unit is 300 m thick.

The Hutubihe Formation consists chiefly of interbeds of dark-purple, purplish-brown, grayish-green sandy mudstone and grayish-green, clayey siltstone intercalated with a small amount of marl in the middle part. The thickness is 300 m.

The Shengjinkou Formation consists, in the lower part, of fossil fish-bearing, grayish-green, yellowish-green, sandy mudstone, and in the upper part, of grayish-green, yellowish-green siltstone, sandstone, shale, and sandy mudstone containing fossil fish, Siyuichlhys tuguluensis. The unit is 100 m thick.

The Lianmuqin Formation comprises grayish-green, brownish-red and purplish-brown, sandy mudstone interbedded with siltstone and sandstone. Locally, fossil fish are found. The unit is 350 m thick.

The Lower Cretaceous strata of the northwestern part of the basin are represented also by the Tugulu Group (table 2). This group is divided, in ascending order, into the Hutubihe, Shengjinkou, and Lianmuqin Formations. The Qingshuihe Formation is missing in this region (Zhao, 1980, p. 64) (table 2).

The Hutubihe Formation consists of light-green, light-yellow, and grayish-green, fine- to medium-grained sandstone interbedded with mudstone. The mudstone is variegated and intercalated with calcareous concretions and secondary gypsum beds. Identified vertebrate fauna in the mudstone are Dsungaripterus weii, Edentosuchus tienshanensis, Sinopliosaurus weiyuanensis, Tugulusaurus facile, Kelmayisaurus petrolicus, Wuerhosaurus homhemi, and Phaedrolosaurus ilikensis. This unit is 147 m thick. Locally, it overlies unconformably metamorphosed Paleozoic rocks.

The Shengjinkou Formation comprises chiefly grayish-green, light-yellow, fine- to medium-grained sandstone intercalated with grayish-green and light-green compact mudstone. Thin gypsum layers are present locally. In the mudstone, vertebrate fauna are: Noripterus complicidens, Sinemys wuerhoensis, and Dsungeripterus weii. The unit is 250 m thick.

The Lianmuqin Formation is made up chiefly of grayish-green, gray, medium-grained very compact sandstone intercalated with gray, light reddish-brown and brown, sandy mudstone and siltstone. Calcareous concretions and gypsum beds are scattered throughout this sequence. Abundant vertebrate fauna are found in the lower part of the sequence, such as Edentosuchus tienshanensis, etc. The unit is 431 m thick.

The Lower Cretaceous strata of the eastern part of the basin are represented by the Tugulu Group, which is, however, not divided and is absent locally. This group consists chiefly of dark grayish-green, calcareous breccia, which is about 50 m thick.

Upper Cretaceous

The Upper Cretaceous strata of the southern part of the basin are represented by the Donggou Formation. This formation consists, in the lower part, of brick-red, brownish-red mudstone interbedded with orange-red, medium-grained sandstone and basal conglomerate; in the middle part, of brick-red, orange-red, calcareous sandstone and siltstone, containing Oolithes elongatus; and in the upper part, of orange-red, light-brown and dark-green siltstone, sandstone, and conglomerate, containing calcareous concretions. The thickness of this unit is between 300 m and 1,000 m in the west of this region. Generally, this formation is conformable with the overlying Tertiary strata in the region.

The Upper Cretaceous strata of the northwestern part of the basin are represented by the Ailike Formation. This formation is made up, in the lower part, of dark-green, semi-compact conglomerate in which rock fragments are metamorphic rock and quartz, intermixed with sand grains and cemented by calcite; in the middle part, of sandstone and mudstone interbeds containing Hadrosauridae fauna; and in the upper part, of light-brownish-red, grayish-yellow and light-brown mudstone intercalated with grayish-green, light-gray, light-yellow, medium-grained and quartzose sandstone. The unit is 62 m thick and lies unconformably on the Lower Cretaceous Tugulu Group.

The Upper Cretaceous strata of the eastern part of the basin are missing.

Cenozoic

The Cenozoic section of the Junggar basin consists chiefly of continental fluvial, lacustrine, glacial, and eolian deposits. Generally, Cenozoic sedimentary rocks are widely distributed within the basin. The thickest Tertiary system of more than 8,000 m occurs in the Northern Tian Shan Foredeep. The Quaternary system is generally scattered throughout the basin and ranges in thickness from 330 to 3,000 m. A discussion on individual stratigraphic systems is given below, in ascending order (Huang, 1982) (Chinese Academy of Geological Sciences, 1982) (fig. 2) (table 2).

Tertiary

The Tertiary section of the basin is divided, in ascending order, into Paleogene (Paleocene-Oligocene) and Neogene (Miocene-Pliocene). A detailed study was done in the southern and northwestern parts of the basin. In the southern part of the basin, sedimentation between the Late Cretaceous and Paleogene was continuous, but it is discontinuous in the northwestern and eastern parts of the basin (table 2).

Paleogene

The Paleogene strata of the southern part of the basin are represented, in ascending order, by the Ziniquanzi (Ziniquan) and Anjihaihe Formations and the lower part of the Shawan Formation (table 2).

The Ziniquanzi Formation consists of orange-red, sandy mudstone and sandstone intercalated with conglomerate. It contains the fossil *Limnocythere*. The thickness of this unit is from 15 to 850 m.

The Anjihaihe Formation is made up of grayish-green mudstone intercalated with sandstone, marl, and bioclastic limestone. The unit contains *Cypria* and *Bothriodon* fauna and reaches a thickness of from 40 to 800 m.

The Shawan Formation has a Paleogene-Neogene age, but the lower part of the formation represents the Late Paleogene. Generally, the Shawan as a whole consists of orange-red, sandy mudstone intercalated with conglomerate. The Shawan contains the *Dzungariotherium* fauna; the unit is from 150 to 500 m thick.

The Paleogene strata of the northwestern part of the basin are represented, in ascending order, by the Honglishan and Ulungurhe Formations and the lower part of the Suosuoquan Formation (table 2) (Xiang, 1958, fig. 3).

The Honglishan Formation is made up chiefly of light-gray, medium-grained sandstone and orange-red mudstone intercalated with conglomerate near the base. This unit is 107 m thick.

The Ulungurhe Formation generally consists, in the lower part, of soft coarse-grained quartzose sandstone intercalated with small amounts of red mudstone and basal light-brown conglomerate; and in the upper part, of light-gray fine-grained quartzose sandstone, grayish-green mudstone and sandstone interbeds. The unit ranges from 35 to 555 m thick.

The Suosuoquan Formation has a Paleogene-Neogene age. Generally, the Suosuoquan lithology is made up chiefly of dark-gray, grayish-green and orange-red mudstone and sandstone intercalated with conglomerate. Thickness of the unit ranges from 15 to 400 m.

The Paleogene strata of the eastern part of the basin consist of continental fluvial and lacustrine fine to very coarse clastic sedimentary rocks. A detailed division of these detrital rock sequences is not available.

Neogene

The Neogene strata of the southern part of the basin are represented, in ascending order, by the upper part of the Shawan Formation, the Taxihe and Dushanzi Formations, and the Conglomerate (table 2). A lithologic description of the Shawan Formation was given under the heading, Paleogene.

The Taxihe Formation consists chiefly of grayish-green mudstone, green, fine- to medium-grained sandstone intercalated with bluish-gray bioclastic impure limestone, gray sandstone, and basal conglomerate. The mudstone contains abundant ostracods. Thickness of the unit ranges from 100 to 320 m (Huang, 1982).

The Dushanzi Formation comprises chiefly brownish-red, light orange, yellowish-red, light-yellow, calcareous thick-bedded mudstone and a small amount of sandstone, locally intercalated with thin or lenticular beds of conglomerate and basal limestone breccias. This unit contains abundant ostracods, pelecypods, and plant remains. Thickness is 1,027 m.

The Conglomerate sequence is commonly present on top of the Neogene in this region. It consists of gray, light-orange, thin or lenticularly bedded conglomerate. The unit is about 1,500 m thick.

The Neogene strata of the northwestern part of the basin are represented, in ascending order, by the upper part of the Suosuoquan Formation and the Changjihe Group. A lithologic description of the Suosuoquan Formation was given under the heading, Paleogene.

The Changjihe Group is made up chiefly of dark-brown mudstone, siltstone, and sandstone interbeds intercalated with thin-bedded conglomerate and brecciated limestone beds. Thickness of the unit is about 30 m in this region.

The Neogene strata of the eastern part of the basin consist of fluvial and lacustrine fine to very coarse clastic sedimentary rocks. This sedimentary sequence is about 600 m. thick.

Quaternary

The Quaternary stratigraphy of the Junggar basin is divided, in ascending order, into Pleistocene and Holocene (table 2) (fig. 2). A general stratigraphic description is given below. The thickness of the Quaternary system ranges from 330 to about 3,000 m (Chinese Academy of Geological Sciences, 1982, p. 423-424, table 20).

Pleistocene

The Pleistocene stratigraphic sequences throughout the basin comprise glacial moraine gravel and kame sand in the early Pleistocene, glacial moraine drifts and interglacial clayey sandy detrital sediments in the middle Pleistocene, and loess, moraine drifts, paleosoils, and desert gravel layers in the late Pleistocene.

Holocene

The Holocene deposits of the basin consist chiefly of alluvial, fluvial, eolian, and lacustrine fine- to very coarse-grained detrital sediments. They are well distributed in the lowland areas throughout the basin.

GEOTECTONICS AND EVOLUTION OF THE BASIN

The Junggar basin evolved in the Late Paleozoic Variscan fold system during the plate collision between the Cathaysian (Tarim) paleoplate on the south and the Angaraian paleoplate on the north prior to the Permian sea transgression (Huang and others, 1980, p. 41-43), (Li, 1980, 1981), (Klemme, 1980), (Zhang and others, 1984, p. 302-303). Because of the effects of the Variscan movement, the initial wedge-shaped platform was faulted and subsided. Subsequently, basin fillings were generally controlled by tectonic movement (figs. 2 and 9).

Tectonics and Sedimentation

Study of all available geophysical and geological evidence leads Chinese geologists to believe that the basement rocks of the Junggar basin consist of Ordovician and Silurian metamorphic complexes of crystalline gneiss and schist, and of Devonian and the lower part of Lower Carboniferous metamorphosed sedimentary rock sequences. The Upper Carboniferous continental and marine sediments and the Permian marine and continental sediments were deposited unconformably on the faulted and metamorphosed crystalline basement as the subsequent middle and late Variscan orogenic movement proceeded.

At the end of the Carboniferous period, uplift and faulting of the continental crust were extensive throughout the region except in the southern part of the basin where the stratigraphic contact between the Carboniferous and Permian is generally conformable. In the northern and eastern parts of

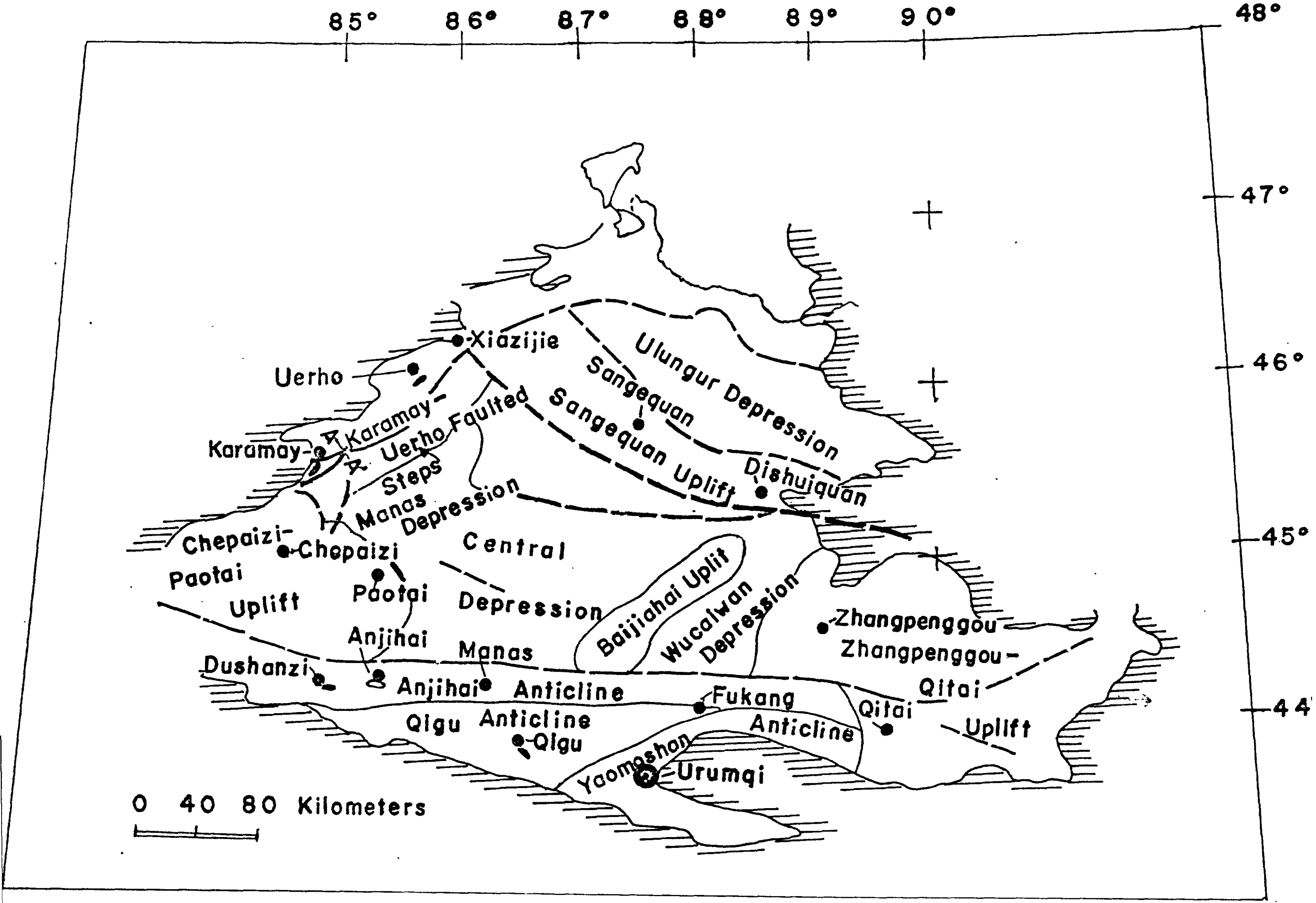
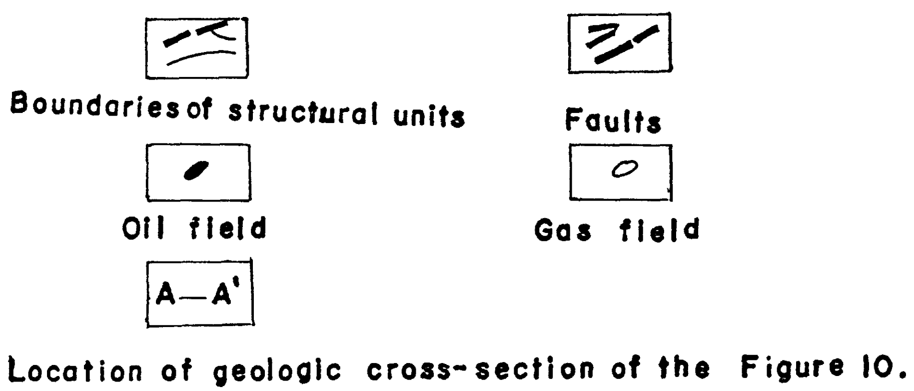


Figure 9. Structural units of the Junggar basin, Xinjiang, Northwest China (after Lu, 1983; Zhao, 1979; and Wang et al, 1983)



the basin, uplift is indicated by the Permian strata unconformably overlying the Upper Carboniferous sedimentary sequences.

The Permian sea entered into the Junggar basin from the east and withdrew from the basin in the vicinity of Urumqi (Wulumuqi) at the end of Early Permian time. During the Early Permian, sedimentation was generally controlled by active overthrust fault zones at Chepaizi, Karamay, Uerho, and Xiazijie (figs. 2 and 9); the sedimentary cover extended over an area of about 86,000 sq km. Within the basin, the positive structural elements of the Permian are the uplift areas of Sangequan in the north, Baijiahai in the center, Chepaizi-Paotai in the southwest, and Zhangpenggou-Qitai in the southeast; the negative structural elements are chiefly the Manas, Central, Wucaiwan, and Santai (Fukang) depressions, which are probably grabens in a northwest-southeast alignment (figs 4 and 9), (Zhao, 1982). Each depression occupies about 10,000 to 20,000 sq km. The maximum thickness of the Permian strata in each depression ranges from 3,500 to 5,000 m.

The Early Permian littoral marine waters covered most of the basin and were in confluence with the Late Carboniferous residual ocean water in the Santai (Fukang) depression (Zhao, 1982, p. 76) (fig. 2). Principal lithology of the Lower Permian in the northern part of the basin consists of a series of orange-red, coarse detrital rocks with a thickness up to 2,000 m, and in the southern part of the basin, of sandstone, conglomerate, and mudstone, which are 2,000 m thick and contain abundant fossil corals. This southern marine sequence is intercalated with limestone and volcanic rocks.

During the Late Permian, the Junggar basin changed into a continental depositional environment, indicated in the upper sedimentary sequences by a series of organic rich gray mudstone and clayey shale, oil-shale, siltstone, and sandstone intercalated with conglomerate. The fluvial and lacustrine deposits contain abundant fossil fish, pelecypods, and ostracods. Zhao (1982, p. 76) inferred three lithofacies zones from the border to the center of the basin (fig. 5), the outer zone consisting chiefly of orange-red and grayish-green fluvial conglomerate intercalated with lakeshore sandy mudstone. This zone is characterized by a rapid lithofacies change laterally and vertically. The intermediate zone is made up chiefly of a series of grayish-green, grayish-yellow sandstone and grayish-green mudstone, which were deposited in the shallow, near-shore and fluvial deltaic environments. The inner zone consists of a series of gray to dark-gray mudstone, clayey shale and oil-shale intercalated with sandstone and were encountered in the subsurface in the Wucaiwan and Santai (Fukang) depressions. Sedimentary rocks of this inner zone were deposited in a semi-deep to deep lake environment. These three lithofacies zones might change their pattern of distribution due to the presence of pre-Permian uplift area in the Central depression, such as the Baijiahai uplift, etc. As shown by field data (Zhao, 1982), the Upper Permian strata of the Manas, the Central, the Wucaiwan, and the Santai (Fukang) depressions reach up to 3,000 to 4,000 m in thickness (fig. 4).

During the latest episode, V_4, of the Variscan orogeny from the Late Permian, large-scale uplift occurred throughout the Junggar basin (table 1). It then became an intermontane basin and received chiefly fluvial and lacustrine deposits of detrital sediments from the Upper Permian and Triassic through the Quaternary.

The Indosinian movement affected most parts of the Junggar basin, especially in the northwestern and northern parts of the basin, where the uplift was extensive and was accompanied by rejuvenated Permian thrust faults, basement block faulting, and intense basin-margin rifting, such as the forming of the Karamay-Uerho step-faulted monocline (figs. 9 and 10). The growth faults in the basin were active during sedimentation of the Jurassic and Cretaceous sedimentary rocks. In the southern part of the basin, the Variscan accretionary Tian Shan fold belt was uplifted, and at the same time, the framework of the Northern Tian Shan Foredeep was established. Uplift of the highlands adjacent to the basin is indicated by Lower Triassic to Middle Triassic deposits, 900 to 1,300 m thick, of red conglomerate and sandstone along the basin border. In Late Triassic, the inland lakes expanded, and a series of lacustrine, swamp, and marsh deposits of 400 to 1,000 m of fine detrital sedimentary strata unconformably overlapped onto the Paleozoic rocks. During the Triassic, there were two depocenters. The first one was east of Manas Lake in the north, and the second was south of Jimsar in the south of the basin (Lu, 1983, p. 209). The maximum thickness of the Triassic strata is more than 2,000 m.

The extent of the Jurassic lake was greater than that of the Triassic, and the deposition of detrital sediments buried basement faults along the basin border (Wang and others, 1983, p. 302). Beginning in Early Jurassic, the depocenter moved toward the southern part of Junggar basin and remained there during Middle and Late Jurassic time. The Permian depression in the central part of the basin (figs. 4 and 9), however, then changed into a southerly dipping sloping terrane (Wang and others, 1983, p. 302-304). The Jurassic coal-bearing sedimentary sequences of mudstone, tuff, sandstone, and conglomerate reached a thickness of from 163 to 1,836 m in the southwestern part of the basin, from 779 to 4,624 m in the southern part of the basin, and 1,826 m in the eastern part of the basin (Wang and others, 1983). In the northwestern part, the area from Karamay to Xiazijie was uplifted, folded, and faulted by the Yanshanian movement at the end of the Jurassic.

During Early Cretaceous, the Junggar basin again subsided, and the widespread Tugulu Group was deposited unconformably on top of metamorphic complexes in the basin boundary and on the Triassic-Jurassic strata in the basin. The extent of the Cretaceous lake was similar to that of the Jurassic, but the water depth was relatively shallow (Wang and others, 1983, p. 302). A series of grayish-green sandstone, siltstone, and mudstone reached a thickness at the southern basin margin of 189 to 2,454 m and, in the northern basin border, of 275 to 1,200 m (Wang and others, 1983, p. 302). During the latest episode of the Yanshanian orogeny from late Early Cretaceous to early Late Cretaceous, the sedimentary strata folded and faulted in the south of the basin causing enlargement of the Tian Shan Foredeep; in the north part of the basin, locally, uplift occurred along the basin border, with extensive overlapping of the Tugulu Group in the Karamay region.

At the beginning of the Paleogene, the lake was smaller than during the Cretaceous. The eastern part of the basin was generally an emergent landmass. The depocenter was located in the area between Anjihai and Duzhanzi, with deposition of potential source rocks (Wang and others, 1983, p..302). As a result of the collision to the south between the Indian and Eurasia continents,

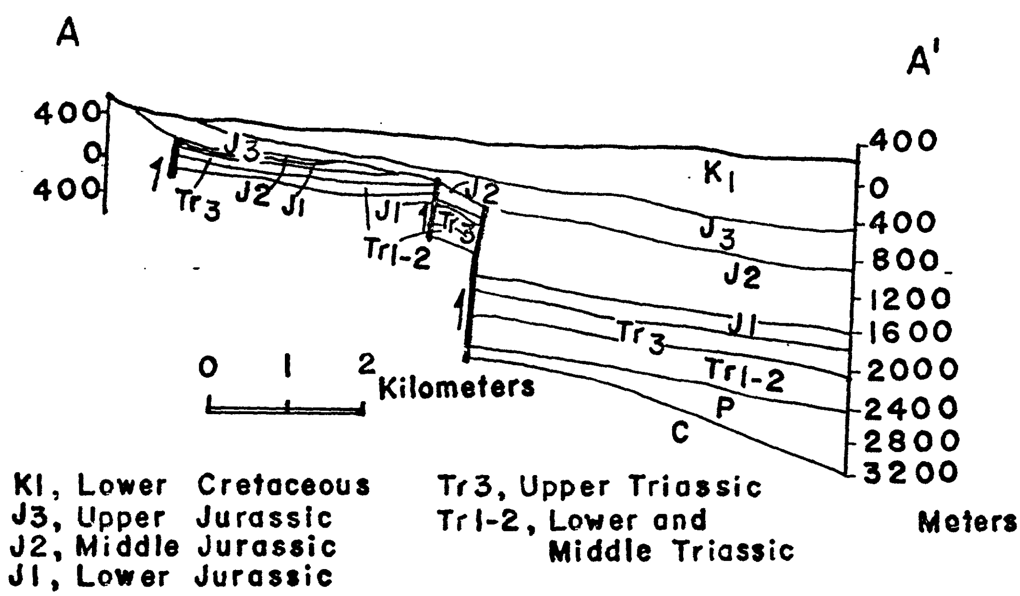


Figure 10. Geologic cross-section, A-A', northeast Karamay oil field, Junggar basin, Xinjiang, Northwest China (after Department of Coal Teaching and Researches, Wuhan College of Geology, 1980 ; Fig.III-93, P.109).

in the Paleogene early stage of the Himalayan orogeny, the denuded Tian Shan was uplifted. Synkinematically, the Tian Shan Foredeep further subsided and was filled with 5,000-m of a redbed molasse. The sedimentary strata of the foredeep were subsequently folded into a series of anticlines and synclines broken by thrust faults. The folding axes are generally in alignment with the trend of the Tian Shan (fig. 9). The remaining part of the basin was gently folded into a series of belts giving the basin its present-day form.

Structure

The structural features of the Junggar basin consist chiefly of the Northern Tian Shan Foredeep in the south and the Northern Platform in the north. These units are probably separated by an east-west concealed fault zone and were subsequently truncated and broken by normal faults, strike-slip faults, and high- and low-angle thrust faults known in the northwest and the south of the basin (figs. 2, 9, 10, 11, and 12).

Northern Platform

The Northern Platform dips gently to the south; it covers about two-thirds of the Junggar basin. The early development of the basement faulting systems of the basin generally played a major role in the development of a southerly gently dipping structural trend of the Northern Platform. On the basis of the structural characteristics in relationship to the distribution of the basement fault system, the structural features in the northern part of the basin are divided into seven structural units and described as follows (Wang and others, 1983, p. 302-303) (fig. 9).

Chepaizi-Paotai uplift.--This is an east-west nose-shaped uplift, easterly plunging and truncated by faults. The upthrow side consists of post-Jurassic sedimentary strata, whereas the downthrow side is made up of Carboniferous through Cenozoic sedimentary sequences.

Karamay (Kelamayi)-Uerho step-faulting monocline.--This fault system consists of normal faults and thrust faults along the western and northwestern margins of the basin (figs. 9, 10, and 11). The thrust-fault system has been called the Karamay-Uerho overthrust, in which the Carboniferous and Permian strata initially thrusted onto the Lower Triassic strata prior to the deposition of Middle-Upper Triassic and Jurassic sedimentary rocks during the Indosinian orogeny (fig. 11). It is believed that this thrust-fault system was pushed eastwards into the basin interior and then changed by the same compression stress into a series of upthrust step-faults (fig. 10), as well as then broken by tension stress normal to thrust cross-faults reponsible for graben-faulting in the basin. Because of the activity of faulting, several nose-shaped dome structures were formed where petroleum has accumulated, such as in the Karamay and Uerho oil fields (Wang and others, 1983, p. 303).

Ulungur faulted depression.--This is a faulted and flat-surface depression and contains 2,000 to 4,000-m of Permian through Cenozoic sedimentary rocks (Wang and others, 1983, p. 303).

Sangequan uplift.--This uplifted area is bounded by a faulted, narrow, steeply sloping rim on the north and by a faulted, wide, gently sloping rim on the south. Sedimentary cover is 1,100 to 4,000 m thick. The Permian through the Cenozoic complete sedimentary sequences occur only on the southern rim of this area. Nose-shaped structures are present (Wang and others, 1983, p. 303).

Qitai-Zhangpenggou uplift.--This uplifted area has been affected by a series of complicated tectonic deformations. The basement fault system was active during uplift and was accompanied by the formation of northeasterly-trending nose structures.

Baijiahai uplift.--This is a symmetrical and gently inclined uplifted area with a complete Permian through Cenozoic sedimentary section (Wang and others, 1983, p. 303).

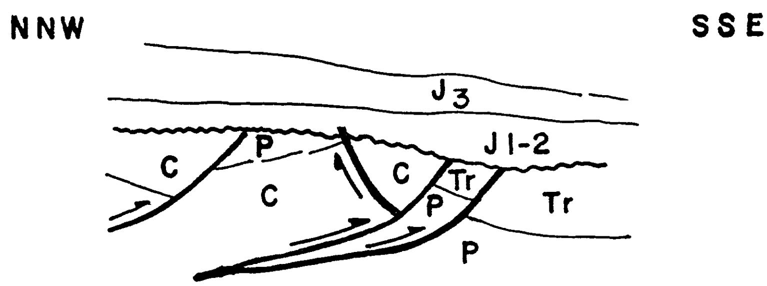
Central depression.--This depression contains three principal Permian depressions: Manas, Central, and Wucaiwan (figs. 4 and 9), with a 5,000-m thickness of Carboniferous through Quaternary sedimentary section (Wang and others, 1983, p. 303).

Northern Tian Shan Foredeep

The Northern Tian Shan Foredeep is bounded by the northern Tian Shan fault system on the south (fig. 9). This depression evolved initially from faulting in Permian time, and subsequently it was deepened and expanded by compression stress during crustal thinning (Wang and others, 1983, p. 303-304). Because of repeated uplift of the Northern Tian Shan, the depocenter in this region shifted northwesterly during the Mesozoic and Cenozoic. For instance, the Permian depocenter was located between Fukang and Urumqi; the Triassic, between Fukang and Hutubi, which is located in the middle between Fukang and Manas; the Jurassic, between Hutubi and Manas; the Cretaceous, west and northwest of Manas; and the Tertiary, between Anjihai and Usu, 45 km northwest of Dushanzi. As a whole, the maximum depth of the foredeep is generally located in the Manas area where the sedimentary section reaches a thickness of more than 13,000 m (figs. 2 and 9).

Throughout the Northern Tian Shan Foredeep, the folding movement was prominent. As a result of the Indosinian and Yanshanian orogenies, the structural framework of the eastern part of this region was firmly established. The present shape of the foredeep, as a whole, developed during the Himalayan orogeny; in particular, numerous sets of east-west surface anticline and syncline folds were formed. According to structural characteristics and stratigraphic sequences, three major anticlinal folds are defined as below (fig. 9) (Wang and others, 1983, p. 304).

Yaomoshan anticlinal zone.--This zone consists chiefly of tightly folded Permian, Triassic, and in part Jurassic sedimentary strata. Commonly, the folded axial parts were broken by faulting. Some of the northern limbs were overturned toward the south.



J3, Upper Jurassic

J1-2, Lower and Middle Jurassic

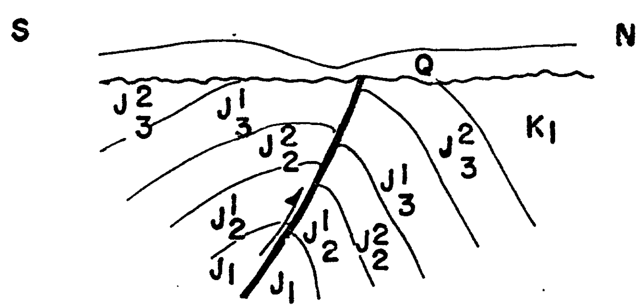
Tr, Triassic

P, Permian

C, Carboniferous

Thrust fault

Figure 11. Schematic cross-section showing the structural features of the Karamay-Wuerhe faulted steps in the Junggar basin, Xinjiang, Northwest China (after Wang et al, 1983, Fig. 4-8-21, p. 231).



Q, Quaternary

K1, Lower Cretaceous

J_3^2, Upper part of Upper Jurassic

J_3^1, Lower part of Upper Jurassic

J_2^2, Upper part of Middle Jurassic

J_2^1, Lower part of Middle Jurassic

J_1, Lower Jurassic

Figure 12. Schematic cross-section showing the structural features of the Qigu oil field in the Junggar basin, Xinjiang, Northwest China (after Wang et al, 1983; Fig. 4-8-18, p. 229).

Qigu anticlinal zone.--This comprises elongated and linear folds chiefly of Jurassic and Cretaceous sedimentary rocks. Although the axial parts were locally broken by faults, most of the anticlinal folds developed good closures, such as the anticlinal trap in the Qigu oil field (fig. 12).

Anjihai anticlinal zone.--This zone consists of surface en echelon folds. The folds are grouped into north and south sets. The magnitude of the south set is relatively larger than that of the north set, and the axial zones were broken by parallel normal faults. The north set is small in scale and developed anticlinal structures favorable for petroleum accumulation, such as those in the Dushanzi oil field (fig. 9).

PETROLEUM AND COAL DEPOSITS

Petroleum and coal deposits are the most important energy mineral resources in the Junggar basin. Asphalt seeps, sandy tar, and tar sands indicate the presence of petroleum deposits in the areas of Karamay (Kelamayi), Uerho, and the vicinity of Urumqi (Wulumuqi). In the early part of this century, the discovery of petroleum deposits at Dushanzi heralded further exploration in the basin by Russian geologists. Since then advanced drilling equipment has been brought into the basin. Extensive exploration was carried out throughout the basin, as well as elsewhere in Xinjiang in the 1950's by Chinese and Russian geologists. As a result, subsequent discoveries were made of the Karamay, Uerho, and Qigu oil fields in the western and southwestern parts of the basin.

Generally, source rocks of petroleum deposits are the lacustrine mudstone and oil-shale of Carboniferous, Permian, Triassic, Jurassic, and Tertiary age. The occurrence of oil and gas reservoirs is chiefly confined to conglomerate, conglomeratic sandstone, and sandstone of the Permian, Triassic, Jurassic, and Tertiary age (Chang, 1981).

The bituminous coal of the Jurassic sedimentary sequences is generally thick-bedded and mineable. The Quaternary peat deposits are thin-bedded and occur in lowland areas of the southwestern part of the basin.

Petroleum

Petroleum deposits are concentrated generally in the northwestern, western, and southwestern parts of the Junggar basin. Occurrence of oil and gas has been known in the conglomerate, conglomeratic sandstone, and sandstone of the Permian to Lower Jurassic (Chang, 1981, p. 154-170). It is believed that the continental and marine deltaic, coarse detrital sedimentary rocks of the Carboniferous to Jurassic and the Tertiary around the basin border are the most favorable rocks for petroleum exploration throughout the basin. The most favorable source rocks are the littoral marine and continental lacustrine shale, marl, and mudstone.

Source Rocks

Source rocks of petroleum in the Junggar basin are confined to the Carboniferous and Permian littoral marine and continental lacustrine fine detrital sedimentary rocks, and to the Triassic, Jurassic, and Tertiary lacustrine mudstone and oil-shale (Zhao, 1982, p. 77-80) (Wang and others, 1983, p. 327). Throughout the basin, the general burial thermal gradient is low, ranging from 2.2° to 2.3° C per 100 m (Wang and others, 1983, p. 15).

Carboniferous source rocks are in the Upper Carboniferous lacustrine grayish-green and carbonaceous mudstone and siltstone intercalated with thin-bedded limestone of the Julideneng and Aotuer Formations, which were probably deposited in the depressions of the northwestern part of the basin; the organic carbon content is up to 2.11 percent. The Upper Carboniferous littoral marine grayish-green bioclastic limestones and mudstones of the eastern part of the basin are rich in organic matter and have a thickness of more than 400 m. The organic carbon of this sequence averages 0.55 percent, and the range in 56 samples is 0.62 to 1.14 percent.

The Permian source rocks, as understood by some current seismic interpretation, are concentrated in the Manas, Central, Wucaiwan, and Santai (Fukang) depressions (fig. 9). In the Santai (Fukang) depression, the Upper Permian gray mudstone and oil shale of the Shangjijicaozi and Xiacangfanggou Groups attain a maximum thickness of 1,400 m, in which tar sands and crude oil seeps are present (Zhao, 1982, p. 78). Geochemical norms of the Upper Permian source rocks are given in Table 3.

Table 3.--Geochemical norms of the Upper Permian source rocks (after Zhao, 1982, p. 78).

Area	Geochemical norms of the Permian source rocks				
	Organic carbon (%)	Chloroform asphalt (%)	Degradation rate (K) (%)	$S^=$ (%)	Remarks
N. Tian Shan Foredeep	4.2 (80)	0.48 (10)	0.18 (80)	0.11 (40)	(80), surface sample numbers for chemical analysis.
North Platform		0.33 (5)			
East of northeastern border	1.09 (31)		0.13 (30)	0.02-0.19 (15)	(15)* subsurface sample numbers.
West of northwestern basin border	3.6 (15)*		0.24 (17)*	0.37 (10)	
Northwestern basin border	0.44 (19)*		0.07 (19)*	0.04 (29)	

These chemical data indicate that the Upper Permian contains excellent source rocks, and laterally they are widely distributed in the Northern Tian Shan Foredeep and in the west of the northeastern basin margin. Generally, the Permian source rocks are the oil-shale type, deposited in semialkaline lake water.

At the beginning of the Mesozoic, the climate changed gradually to a temperate and humid condition; the Junggar basin contained fresh water permitting extensive deposition of Jurassic coal beds and source rocks throughout the basin.

The Triassic source rocks are shale and mudstone of the Huangshanjie and Haojiagou Formations. Thickness is about 100 m. The Jurassic source rocks are the carbonaceous shale and mudstone of the Lower and Middle Jurassic sedimentary sequences in the southern and northwestern parts of the basin. Total thickness of the Jurassic source beds is estimated to be from 500 to 1,500 m. The Cretaceous source rock is considered to be mudstone and marl of the southern and northern parts of the basin. Thickness is about 400 m.

At the approach of the Cenozoic, the Junggar lake became smaller as compared with the lake water coverage of the Mesozoic. The climate gradually changed into an arid condition, and the lake water again became semialkaline (Wang and others, 1983, p. 304). The Tertiary source rocks of grayish-green mudstone reached a thickness of more than 300 m in the southwestern part of the basin.

Systematic study data on the evolution characteristics of organic matter of the source rocks in the Junggar basin are not available. It is believed, however, that the crude oil was derived from the sapropelic algal type and humus type of kerogen. By means of analyses of the Karamay natural gas, the n-butane and n-pentane indicate a deeper depth of Carboniferous and Permian source rocks and higher maturity than the type of iso-butane and iso-pentane, which show a primary product from younger source rocks without alteration and a relatively low maturity (Zhao, 1982, p. 78).

Reservoir Rocks

The oil and gas pools of the Junggar basin occur in Carboniferous sandstone and conglomerate, Permian conglomerate, Triassic sandstone-conglomerate and sandstone, and Jurassic and Tertiary sandstone (figs. 2, 10, and 13) (Masters and others, 1980, p. 209-210). Generally, oil and gas migration is chiefly controlled by basin fracture systems and widespread unconformity; the distance of migration ranges from 30 to 50 km with an 80 km maximum (Wang and others, 1983). Present productive oil and gas fields are concentrated in the structural traps and onlap oil pools of the Karamay-Uerho faulted step terrane in the northwestern and western parts of the basin (figs. 9, 10, 11, and 14) (table 4).

The oil- and gas-bearing Carboniferous metamorphic reservoir rocks formed on buried eroded hills and were discovered by drilling on uplifted areas along the northwestern border of the basin. The other Carboniferous reservoir rocks are basalt, andesite, dolomitic mudstone, tuff, and volcanic breccia (Lin, 1984). The Permian reservoir rocks are 300 to 2,500 m thick, grayish-green to orange-red conglomerate, and widely distributed as coalescing fans along the basin margin (fig. 5).

From Permian to Middle Triassic, reservoir rocks are distinguished by 60 to more than 90 percent breccia, with a sand and silt matrix and calcite cement. This breccia facies locally is intercalated with variegated mudstone lenses generally rapidly changing into fine- to medium-grained detrital sedimentary rocks in the midfan and fanbase portions of the fan sequence, such as in the Karamay (Kelamayi) oil field; this sequence ranges from 480 to 3,150 m in thickness (Chang, 1981, p. 154-155). Chang (1981, p. 164-165) further mentioned that because of syndepositional lithologic variation, the initial production potential (tons per day) had been directly affected in several development areas of this oil field where the depth of burial of reservoirs ranges from 415 to 675 m and initial formation pressures are between 63 and 100 atm. For an area with 70 percent breccia, 20 percent porosity, 118 to 2,711 (md) permeability, 19 (m) effective thickness, and a resultant 206 x $10^3 t/km^2$ reserve factor, the initial production potential per well is 8.2 to 9.1 tons per day, even though the viscosity of crude oil is 79 (cp).

The Jurassic reservoir rocks are the fluvial sandstones of the Badaowan, Sangonghe, Xishanyao, and Toudunhe Formations. The Badaowan sandstone and conglomerate are distributed chiefly in the area between the Karamay oil field on the south and the Uerho oil field on the north. The sandstone body is

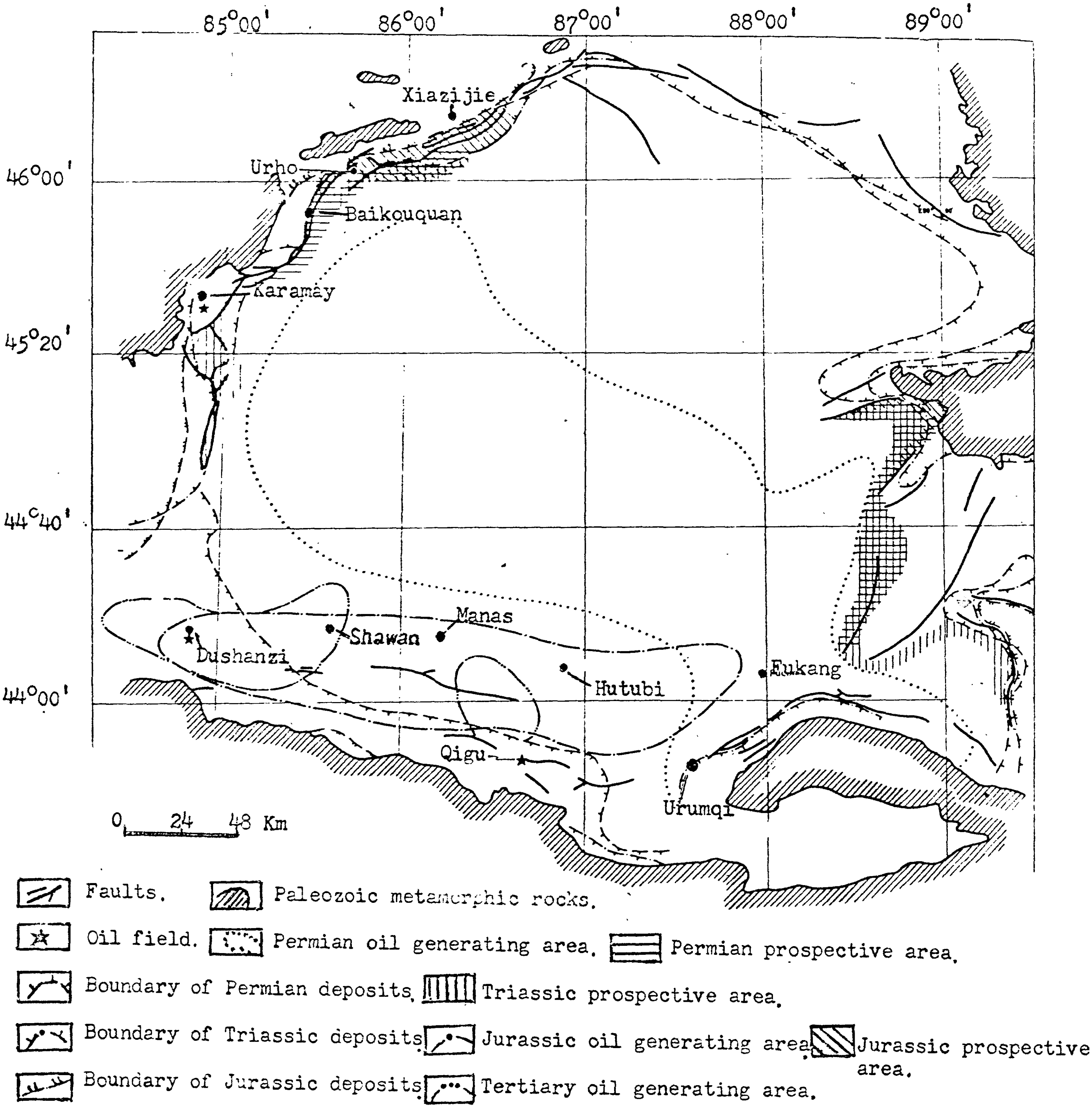
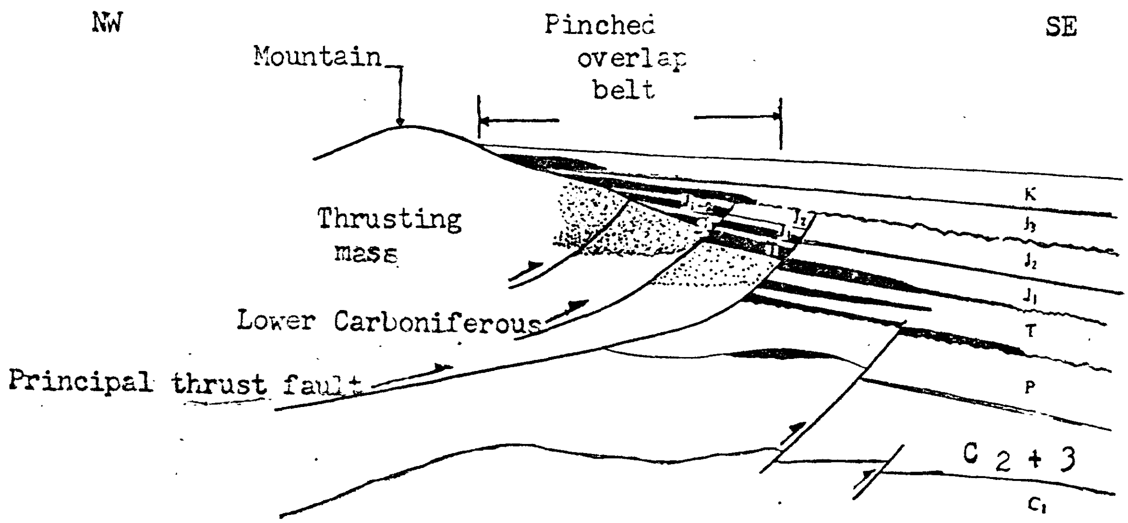


Figure 13. Exploration prospects of fluvial coarse clastic reservoir rocks in the Junggar basin, Xinjiang, Northwest China (after Chang, 1981; p. 107).



C_1, Lower Carboniferous. C_{2+3}, Upper Carboniferous.

P, Permian. T, Triassic. J_1, Lower Jurassic. J_2, Middle Jurassic.

J_3, Upper Jurassic. K, Cretaceous.

Figure 14. Sketch showing the petroleum occurrence in the Karamay - Xiazijie overthrusting belt of the northwestern Junggar basin, Xinjiang, Northwest China (modified after Lin, 1984; Figure 8, p. 6).

Table 4.--Geologic characteristics of the Karamay-Xiazijie overthrust belt in the northwestern part of the Junggar basin, Xinjiang, northwest China (after Lin, 1984, table 2, p. 7).

	Stratigraphic Characteristics						Structural characteristics	
				Properties of reservoir rocks				
Geologic structure (fig. 14)	Age	Depositional environment	Reservoir rocks	Porosity (%)	Permeability (md)	Type of porosity	Width of overlap (km)	Folds and faults
Pinched overlap belt	Cretaceous	lakeside	fine sandstone	35	1,704-3,085	intergranular		No faulting
	Upper Jurassic	lakeside	fine and medium sandstone	34	2,310-6,783			
	Lower-Middle Jurassic	fluvial	conglomerate, medium and coarse sandstone	20	112			
	Triassic	alluvial	conglomerate, medium and coarse sandstone	13-22	109-150			Commonly faulted
Thrusting mass	Lower Carboniferous	sea-floor eruption	basaltic andesite	8.8-10.4	0.37	solution cavity and fracture		Well developed, small faultings and some forming uprake faulted blocks
Thrusting belt and its uprake flank	Lower Jurassic	fluvial	conglomerate, medium and coarse sandstone	17-18	45-70	intergranular space	0.15-0.3	
	Triassic	alluvial	conglomerate, medium and coarse sandstone	13-39	144-323	intergranular space, intragranular solution space	0.04-1.0	faulted folds, east of Baikouquan
	Permian	alluvial	conglomerate	9	0.88	microfracture	8-11	
	Upper Carboniferous	gulf or lagoon	dolomitic claystone, dolomitic tuff, volcanic breccia, andesite	6	0.2	microfractures. solution space	18-30	Monocline west of Baikouquan

about 17 m thick with 20 percent porosity, and the permeability of the sandstone ranges from 61 to 113 md. The Sangonghe, Xishanyao, and Toudunhe Formations occur on the Jurassic oil-bearing structures of the southern foredeep, such as in the vicinity of Qigu. The thickness of the reservoir sandstones varies considerably; it is generally 2 to 7 m thick with a maximum thickness of 17 m. The porosity is generally 3 to 11 percent, and the permeability is 10 md (Wang and others, 1983, p. 305) (figs. 6, 7, 8, 10, and 13).

The Tertiary reservoir sandstone occurs chiefly in the area between the Anjihai and Dushanzi. In the Dushanzi oil field, eight petroleum-bearing sandstone beds are present. Each of these beds ranges from 3 to 4 m thick with a maximum thickness of 9 m. The effective porosity ranges from 12 to 18 percent (figs. 9 and 13).

Cap rocks for the reservoir generally are the Triassic, Jurassic, and Tertiary mudstone, shale, and sandy mudstones. A lateral distribution of source rocks, reservoir rocks, and cap rocks is shown by the Karamay (Kelamayi) oil field, where petroleum is thought to have been generated from the Permian Lucaogou Formation and to have migrated westward up-dip to the alluvial fan of the basin border.

Potential

The Junggar basin covers 130,000 sq km and contains a basin-filling of 393,000 cu km (Wang and others, 1983, p. 327). Adequate quantities and richness of source rocks appear to be present to accommodate normally expected amounts of recoverable petroleum for this type of basin.

In the Junggar basin, the prominent oil fields are the Karamay (Karamai) (Kelamayi), Baikouquan, Uerho, Dushanzi (Tushantze), and Qigu (Chiigu); of these the Karamay oil field is the largest (figs. 2, 9, 13, 15, 16a, 16b, and 16c).

The Karamay oil field is located at lat 45°38' N, long 85°00' E and in about the central part of the so-called Uerho-Karamay monocline (Karamay-Uerho faulted steps) (fig. 9). This monocline is a gently southeasterly plunging fold and was cut through by overthrust faults and upthrust step-faults toward the basin center (figs. 10, 11, 15, 16a, 16b, and 16c). These thrust faults indicate that the Carboniferous strata were thrusted onto the Triassic strata prior to deposition of the Jurassic sedimentary sequences during the Indosinian orogeny (fig. 11), and then onto the Triassic to Middle Jurassic strata prior to deposition of the Upper Jurassic sedimentary sequences during the middle episode of the Yanshanian orogeny (figs. 10, 16a, 16b, and 16c). During the sedimentation of the Jurassic through Tertiary sedimentary sequences, the growth of these thrust faults probably actuated the petroleum generated in the source rocks to the east to migrate upward and accumulate in the overthrust fault zones along the basin margin alluvial fan reservoir rocks of the Karamay oil field to the west.

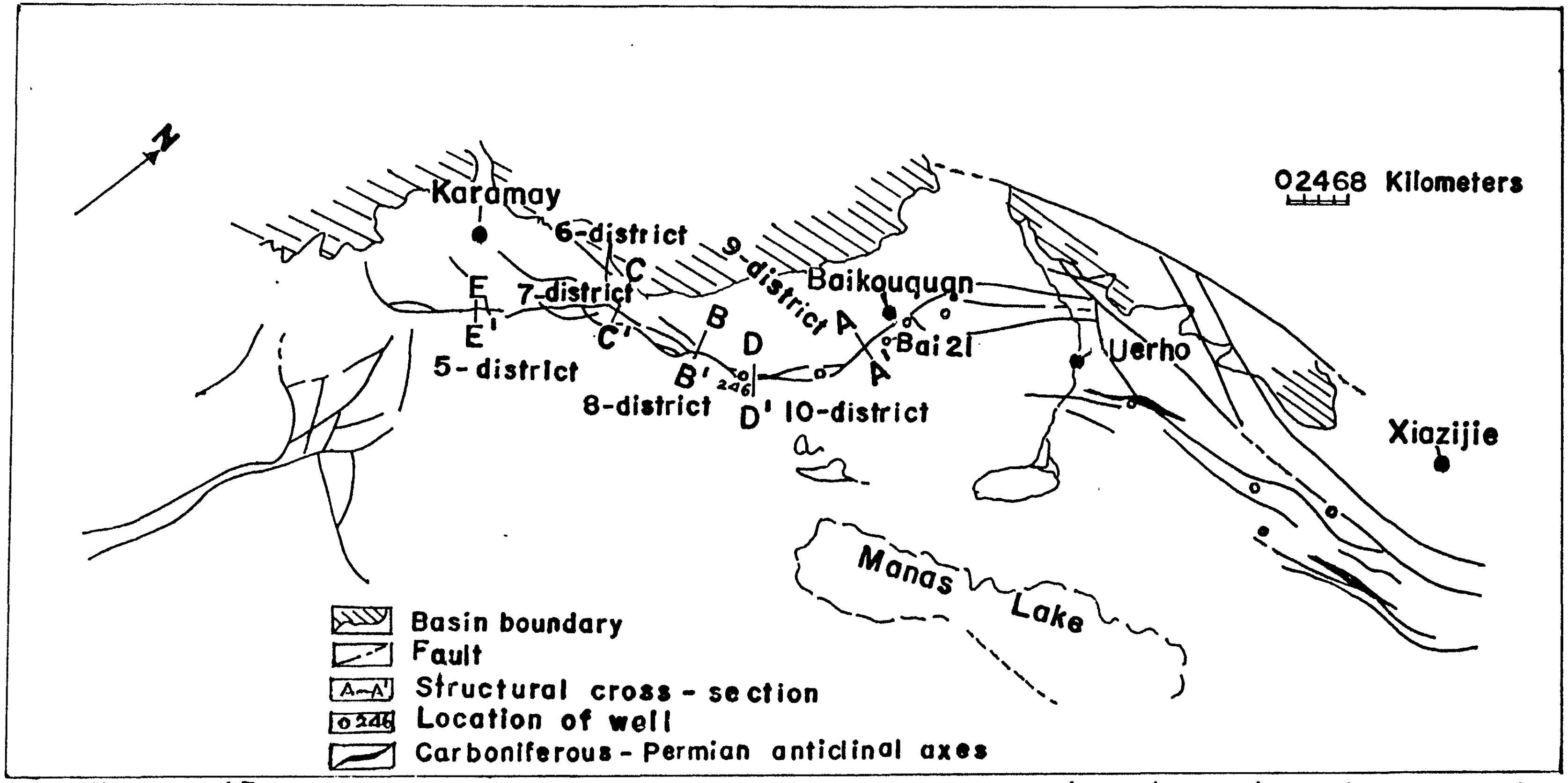
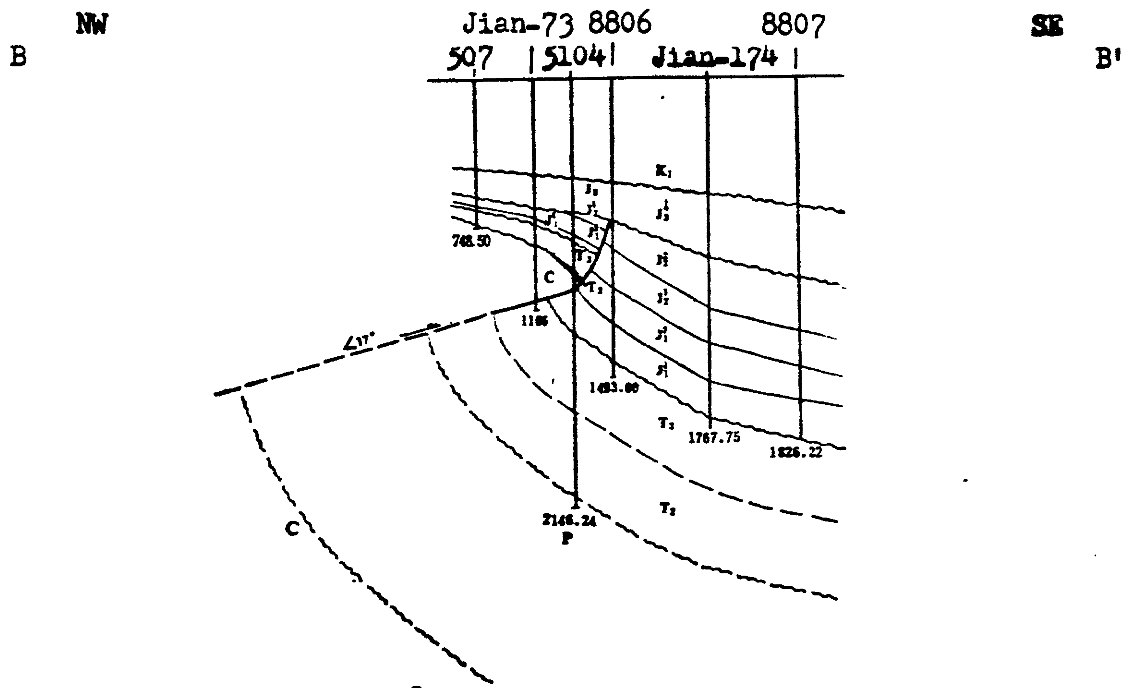


Figure 15. Location of structural cross-sections, A-A', B-B', C-C', D-D' and E-E' in the Karamay-Xiazijie overthrust belt of the northwestern Junggar basin, Xinjiang, Northwest China (after Lin, 1984; figure 1, p.1).



K_1, Lower Cretaceous. J_3^1, Lower part of Upper Jurassic.

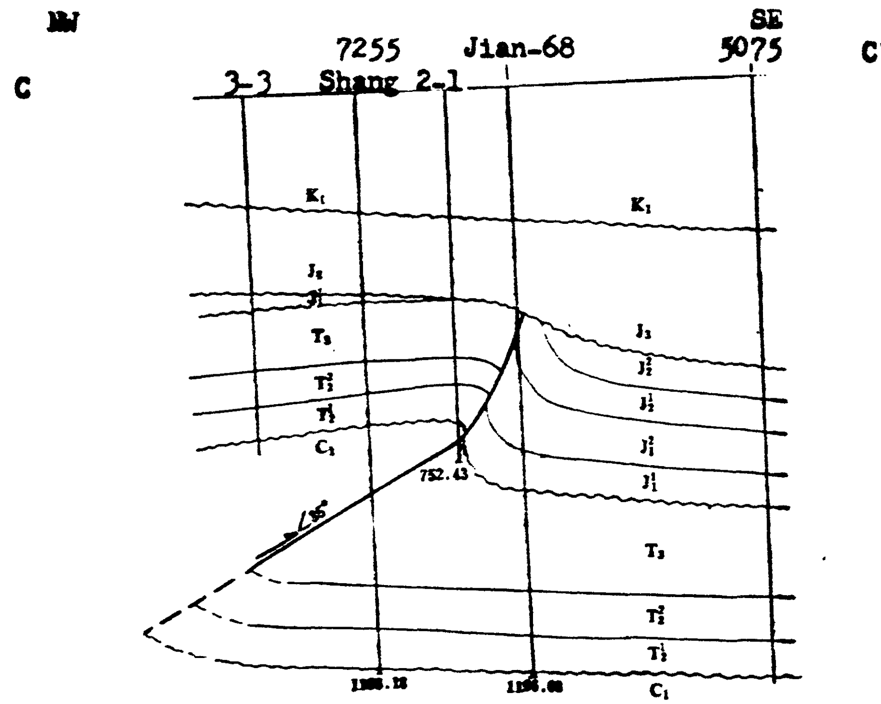
J_3, Upper Jurassic. J_2^2, Upper part of Middle Jurassic.

J_2^1, Lower part of Middle Jurassic. J_1^2, Upper part of Lower Jurassic.

J_1^1, Lower part of Lower Jurassic. T_3, Upper Triassic.

T_2, Middle Triassic. P. Permian. C, Carboniferous.

Figure 16 a. Structural cross-section of the 530 well area in the Karamay oil field (after Lin, 1984; figure 3, p. 3).



K_1, Lower Cretaceous. J_3, Upper Jurassic.

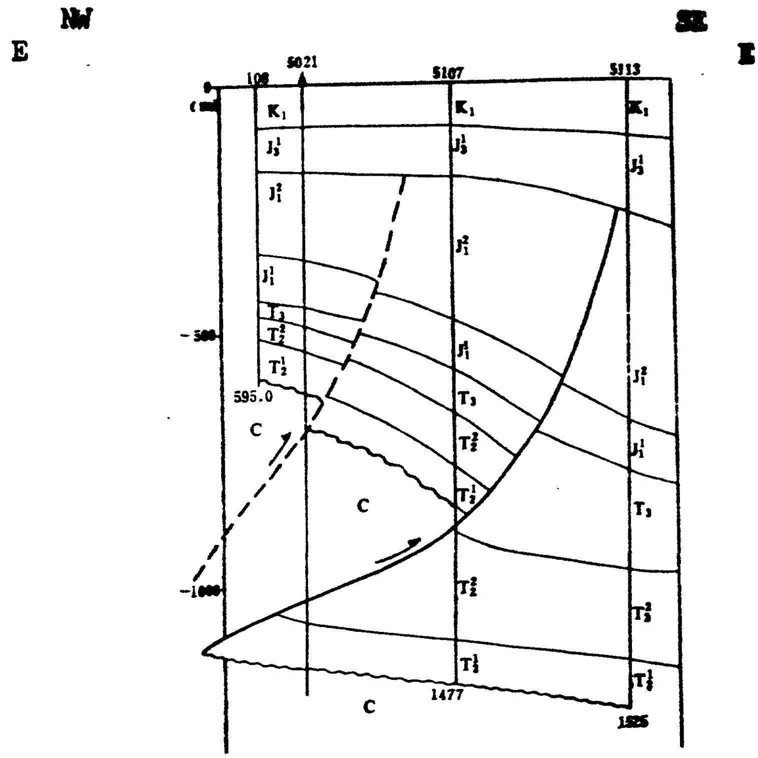
J_2^2, Upper part of Middle Jurassic. J_2^1, Lower part of Middle Jurassic.

J_1^2, Upper part of Lower Jurassic. J_1^1, Lower part of Lower Jurassic.

T_3, Upper Triassic. T_2^2, Upper part of Middle Triassic.

T_2^1, Lower part of Middle Triassic. C_1, Lower Carboniferous.

Figure 16 b. Structural cross-section of the 7255 Shang - 2-1 well area of the 7-district in the Karamay oil field (after Lin, 1984; figure 4, p. 3).



K_1, Lower Cretaceous. J_3^1, Lower part of Upper Jurassic.

J_1^2, Upper part of Lower Jurassic. J_1^1, Lower part of Lower Jurassic.

T_3, Upper Triassic. T_2^2, Upper part of Middle Triassic.

T_2^1, Lower part of Middle Triassic.

C, Carboniferous.

Figure 16 c. Structural cross-section of the Karamay fault zone in the Karamay oil field (after Lin, 1984; figure 5, p. 4).

The Karamay oil field covers an area of 3,000 sq km. Average daily production per well is approximately 61 bbl (Meyerhoff, 1982). The depth of burial of the reservoirs ranges from 415 to 675 m (Chang, 1981, p. 164). Petroconsultants (1976) gives the depth to top pay as 100 m. The maximum net pay is 150 m. Meyerhoff (1982, p. 208) mentioned that the oil density averages 0.86 g/cm^2. API gravity is 31.5°. Sulfur content is 0.19 percent and paraffin content is 0.1 percent. Oil is trapped by overthrust faults, fault blocks, and stratigraphic onlap or overlap, as well as lithofacies lenses; seals are mudstone and shale of the Jurassic. Estimated ultimate recoverable reserves are 3,000 x 10^6 bbl (Petroconsultants, 1976).

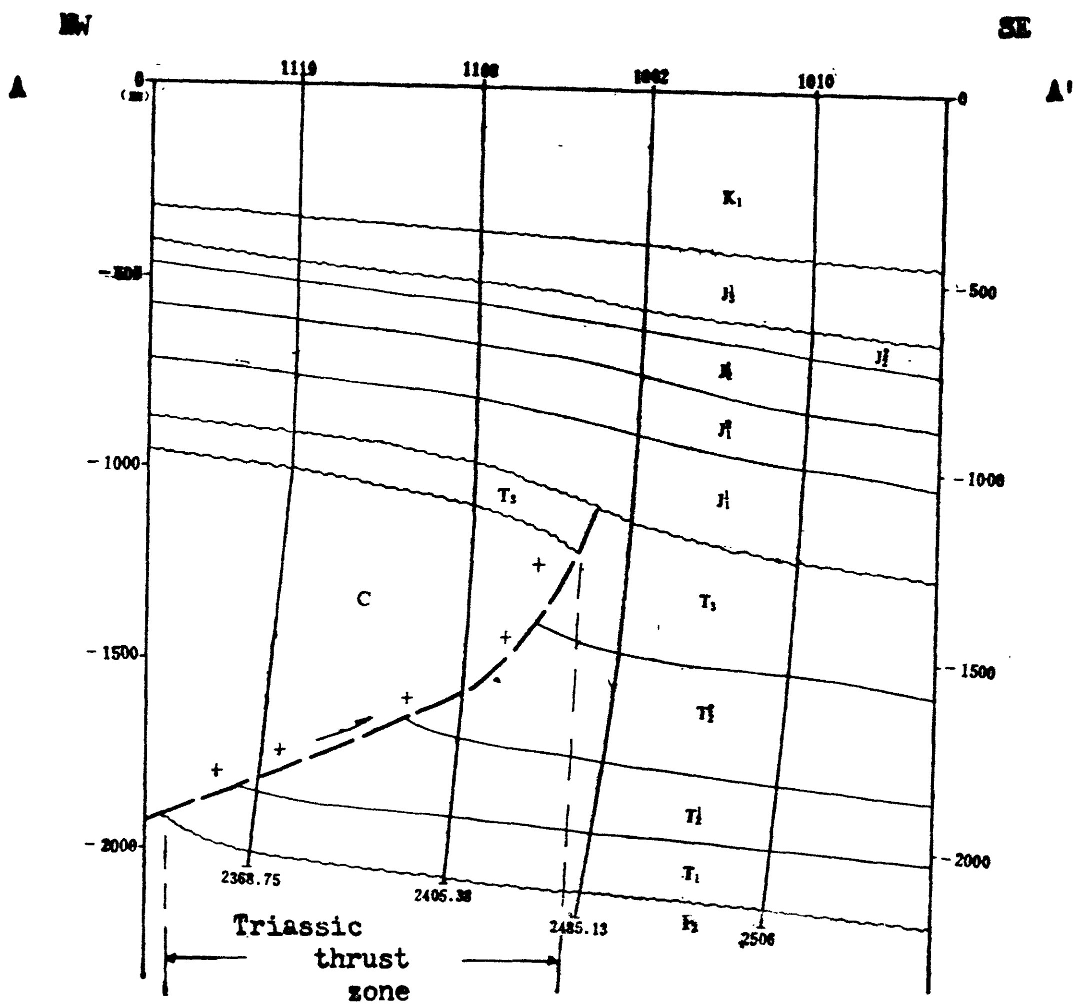
The Baikouquan oil field (figs. 15, 16d, and 16e) is located between the Karamay oil field on the south and the Uerho oil field on the north. The producing wells are in the Lower Triassic Baikouquan Formation (table 2). Detailed information of this field is not yet available, but, currently, significant activity is going on in this field.

The Uerho oil field is located at lat 46°35' N, long 85°35' E in the northern part of the Uerho-Karamay monocline. Petroconsultants (1976) provided the following data: Production area is approximately 7,400 acres and oil is trapped in the broad, faulted anticline. Annual production (1975) is roughly estimated to be 5,500,000 to 7,300,000 bbl. Estimated ultimate recoverable reserves are 200,000,000 bbl.

The Dushanzi oil field is located at lat 44°16' N, long 84°56' E in the overturned faulted anticline (figs. 9 and 13). Petroleum occurs in the Taxihe and Dushanzi Formations on structural traps (table 2). Petroconsultants (1976) gave the depth to top pay as ranging from 200 to 1,000 m. This foredeep field is 3 x 8 km with 60 to 80° north dips and 25 to 40° south dips, and is cut by high-angle reverse faults dipping 50 to 70° south (Meyerhoff, 1982, p. 208). The reservoir rock has low porosity and permeability. Meyerhoff (1982) mentioned low recovery factors (20 to 25 percent of oil-in-place). Estimated ultimate recovery reserves are 50,000,000 bbl (Petroconsultants, 1976).

The Qigu oil field is located at lat 43°55' N, long 86°31' E; oil occurs in a small anticline which is about 4 x 8 km in size (figs. 9 and 12). The reservoir rock is the sandstone of the Lower Jurassic Sangonghe and Lower-Middle Jurassic Xishanyao Formations. Petroconsultants (1976) gave the depth to top pay as 860 m.

A small amount of gas occurs in the Dushanzi Formation in the vicinity of Aujihai. Details of this gas field are unknown.



K_1, Lower Cretaceous. J_3^1, Lower part of Upper Jurassic.

J_2^2, Middle part of Middle Jurassic. J_2^1, Lower part of Middle Jurassic.

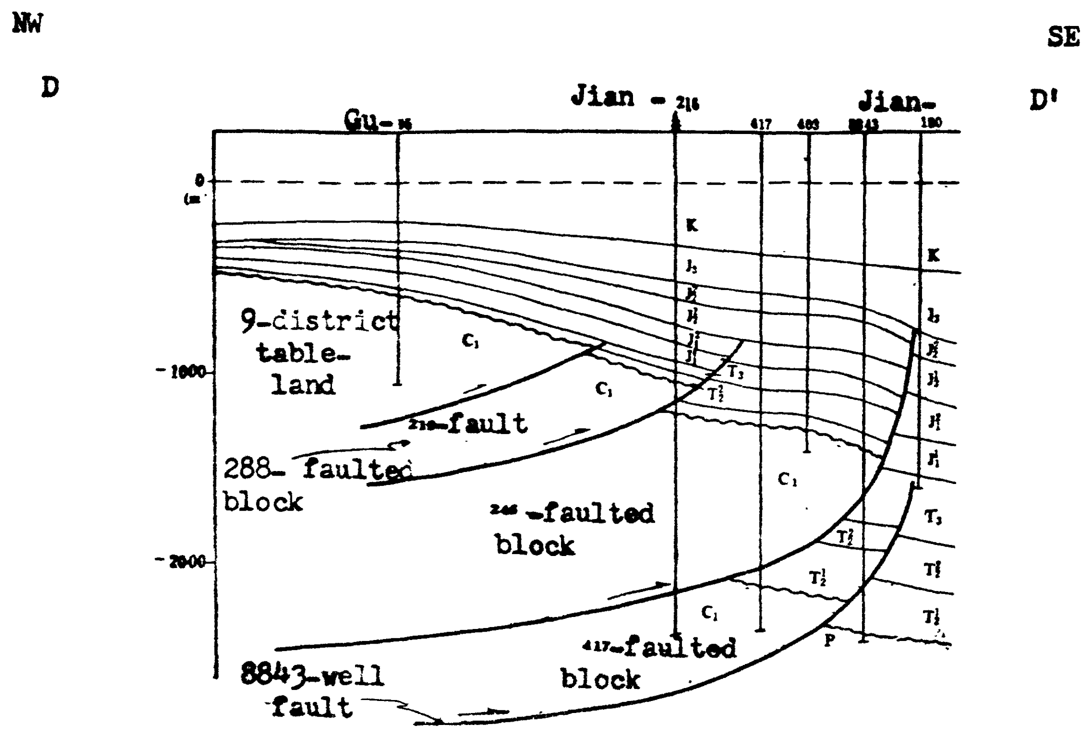
J_1^2, Upper part of Lower Jurassic. J_1^1, Lower part of Lower Jurassic.

T_3, Upper Triassic. T_2^2, Upper part of Middle Triassic.

T_2^1, Lower part of Middle Triassic. T_1, Lower Triassic.

C, Carboniferous. P_z, Paleozoic.

Figure 16 d. Structural cross-section west of the Bai 21 well in the Baikouquan oil field (after Lin, 1984; figure 2, p. 2).



K, Cretaceous. J_3, Upper Jurassic. J_2^2, Upper part of Middle Jurassic.

J_2^1, Lower part of Middle Jurassic. J_2^1, Lower part of Middle Jurassic.

J_1^1, Lower part of Lower Jurassic. T_3, Upper Triassic.

T_2^2, upper part of Middle Triassic. T_2^1, Lower part of Middle Triassic.

P, Permian. C_1, Lower Carboniferous.

Figure 16 e. Structural cross-section of the Gu-16 - Jian-180 of the 246 well area in the Baikouquan oil field (after Lin, 1984; figure 6, p. 5).

Coal

The coal deposits of the Junggar basin occur chiefly in the Lower and Middle Jurassic sedimentary sequences; this basin contains one of the largest Lower and Middle Jurassic coal resources in China. The depocenter of the coal beds is located in the foredeep of the Northern Tian Shan and extends east-west for a distance of more than 500 km. The coal is chiefly high quality bituminous coal (Han and Yang, 1980, p. 294-295) (Department of Coal Teaching and Research, Wuhan College of Geology, 1981, p. 105).

Occurrence

The Lower and Middle Jurassic coal-bearing sedimentary sequences are confined in the Lower Jurassic Badaowan and Sangonghe Formations and the Lower to Middle Jurassic Xishanyao Formation (table 2) (figs. 7, 8, and 17).

The Badaowan Formation consists of lacustrine and swamp deposits of light-gray, grayish-green sandstone and conglomerate, grayish-black, purplish-red mudstone and siltstone intercalated with coal beds, carbonaceous mudstone and siderite beds. The coal generally is thin-bedded, and the total beds attain a thickness of more than 20 m. The depocenter is located in the vicinity of Manas.

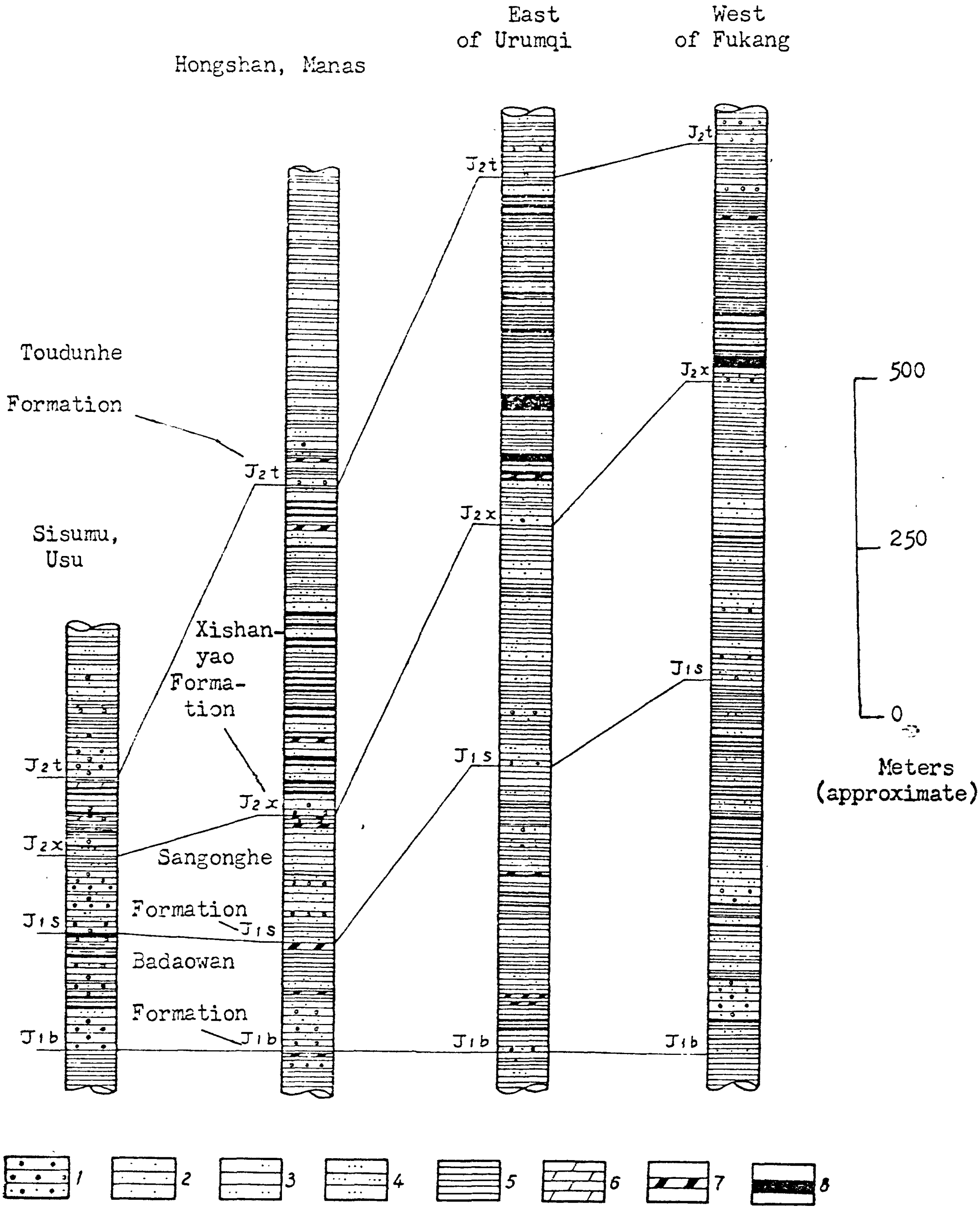
The Sangonghe Formation is made up chiefly of lacustrine deposits of grayish-yellow, grayish-green mudstone, sandstone and conglomerate, and grayish-brown sandy mudstone and carbonaceous mudstone intercalated with thin coal beds and cone-in-cone limestone. The depocenter is located east of the Urumqi (Wurumuqi).

The Xishanyao Formation contains numerous mineable coal beds and consists of a series of lacustrine and swamp deposits chiefly of grayish-green, gray sandstone and conglomerate, and grayish-green, blackish-gray mudstone and siltstone intercalated with thick to very thick coal beds and siderite lenses. Total thickness of the mineable coal beds is more than 100 m. The depocenter is located in the vicinity of Manas. The thickest coal beds are concentrated in the vicinity of Urumqi (Wurumuqi) (fig. 8).

Mineable coal beds are also present along the eastern and western basin borders. Generally these coal beds were deposited in the fluvial fanbase zone and in areas near the lake shore along the basin margin where the clastic sediments are chiefly medium-grained sandstone. Since Middle Jurassic, the Northern Tian Shan continued to uplift, extending through the Quaternary. As a result, most of the overburden was removed making the Jurassic coals mineable.

Potential

The rich coal deposits of the Junggar basin are concentrated in the Northern Tian Shan front foredeep. Coal-bearing sedimentary sequences form an east-west narrow belt across the city of Urumqi (Wurumuqi). In the foredeep, there are small-scale, elongated surface anticlines and synclines (fig. 9).



1.Conglomerate and conglomeratic sandstone. 2.Coarse-grained sandstone.
3.Medium-grained sandstone. 4.Fine-grained sandstone.
5.Mudstone and siltstone. 6.Marl. 7.Carbonaceous mudstone. 8.Coal beds.

Figure 17. Stratigraphic correlation of the Lower and Middle Jurassic coal-bearing sedimentary sequences between Usu and Fukang in the Northern Tianshan foredeep of the Junggar basin, Xinjiang, Northwest China (after Department of Coal Teaching and Researches, Wuhan College of Geology, 1981; p. 107).

Some of them are asymmetrical with southerly overturned northern limbs. The coal beds of the eastern and western basin margins are generally slightly tectonically deformed, and the bedding has gentle dips. On the basis of Wood's guidelines on classification and estimating of coal resources (Wood and others, 1983, p. 32-38), total coal resources in the Junggar basin are generally estimated to be at least 270×10^9 metric tons, and the recoverable coal resources are roughly estimated at 18×10^9 tons.

SUMMARY

The Junggar basin evolved as a peripheral basin relative to the Paleozoic continental crust of the Junggar Variscan fold system during the middle episode of the Variscan orogeny. The basin became an intermontane basin in Late Permian.

The basin fillings consist chiefly of Upper Paleozoic marine and continental platform sedimentary sequences and Late Permian to Quaternary fluvial and lacustrine detrital sediments. Syntectonic deposition of these sedimentary sequences played a major role during the basin-filling.

Principal structural units of the basin are the Northern Platform and the Northern Tian Shan Foredeep. The deep basement faulting system controlled the development of the basin.

Thick source rocks are chiefly in the Permian, Triassic, Jurassic, and Paleogene sedimentary sequences. Petroleum resources of the Junggar basin currently rank third after the North China basin and the Sungliao basin. Intense exploration has been carried out in the Karamay-Uerho monocline, where it is estimated that about two-thirds of the recoverable oil could be ultimately recovered from the Carboniferous, Permian, Triassic, Jurassic, and Tertiary sandstone and conglomerate.

Future exploration of the Upper Permian plays would be very promising in the area between the Xiazijie and the Dishuiquan of the Northern Platform.

High quality bituminous coal resources are concentrated in the Northern Tian Shan Foredeep. The total coal resources of the basin are estimated to be at least 270×10^9 metric tons, of which the recoverable coal resources are roughly estimated to be 18×10^9 metric tons.

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