

# PETROLEUM GEOLOGY OF CHINA

Zhai Guangming *et al.*

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by **Zhai Guangming** *et al* .

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# Foreword

The Twentieth century witnessed a tremendous growth of the petroleum industry, while large scale geological exploration for oil and gas in China began in the early fifties . Through its arduous efforts over more than four decades, China has achieved great success in exploration and development of oil and gas and is ranked as one of the leading producers in the world .

The complicated petroleum geology of China consists in multi-stage tectonic movements that caused a highly fragmented sedimentary cover . The major Meso-Cenozoic payzones are non-marine sedimentation and widely distributed in hundreds of small to medium basins . Exploration in such a geological setting is very difficult, however, through the painstaking efforts of our Chinese colleagues, hundreds of oil and gas fields with abundant oil and gas reserves have been discovered .

My good friend, Professor Zhai Guangming, a renowned Chinese petroleum geologist and Academician of the Chinese Academy of Engineering, co-authored with other Chinese experts and professors of petroleum geology the book, “ *Petroleum Geology of China* .” The book addresses oil and gas geology with Chinese characteristics, a comprehensive monograph integrating up-to-date theories and the latest technology of petroleum geology with the exploration practice in China . It is an authoritative treatise representing the progress of modern oil and gas geology of China .

This book is based on the practical data and systematic studies of geological exploration for oil and gas in China over nearly half a century, it begins with regional geological background, systematically discusses the stratigraphical zonation, trapping, and correlation, sedimentary development, structural evolution of the oil/ gas-bearing provinces . It focuses on further analysis of oil and gas generation, migration, accumulation, reservoir geology, hydrodynamics, geochemistry of oil/ gas/ water, types of traps, formation mechanism and distribution of oil/ gas reservoirs of Meso-Cenozoic non-marine and Paleozoic marine sedimentation . It provides theoretical insight into oil and gas geology of China, and includes illustrations and maps to facilitate reading and use .

This book will provide a ready reference on the geology of China to petroleum geologists worldwide . It is extremely beneficial to opening additional new frontiers in worldwide exploration, as well as a significant contribution to enriching the theories of oil and gas geology, especially non-marine oil and gas geology .

I extend to Professor Zhai Guangming, and his colleagues, my heartiest congratulations on an exceptional volume that will be a lasting contribution to the literature of petroleum geology of the People 's Republic of China .

September, 1997

Michel T . Halbouty

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# Preface

China is the new and major rising petroleum country . Its oil production reached up to 100 million tons in 1978 , and 150 million tons in 1996 , coming into the rank of major oil-producing countries of the world .

As far back as 2000 years ago , oil and natural gas had been discovered and utilized in the northern Shaanxi and Sichuan basins of China , and its experiences in geology and drilling stood in the forefront of the world at that time . The modern petroleum industry of China began in 1878 when the first oil well was drilled with the depth of 120 meters by steam engine in Miaoli County , Taiwan Province .

In geological survey for oil and natural gas exploration in China during the period of 1878 to 1949 some surface geological work in various degrees and drilling a few exploratory wells had been done only by a few geologists in local areas , based on the field reconnaissance survey and tracking some oil-gas seepages . Up to the end of 1949 , geological prospecting and exploratory wells for finding oil and gas had been done only in some areas of Shaanxi , Gansu , Xinjiang , Sichuan and Taiwan provinces . During this period several small oil fields such as Yanchang , Qilicun , Laojunmiao , Dushanzi , Chuhuangkeng and Zhutouqi had been discovered , and discovered other small gas fields such as Shiyougou , Shengdengshan , Liuchongxi , Niushan , and Zhudong , as well as Ziliujing , in which the largest oil field was Laojunmiao oilfield , a typical structural oilfield formed by a complete anticline . The cumulative discovered oil in place is 29 million tons , oil production and gas output are 671700 tons and 1 .17 billion cubic meters , respectively .

A large-scale geological exploration for oil and gas in China started in 1950 . Thanks to repeated practices , detail researches , and continuously deepening of understanding the knowledge of petroleum geology throughout about half a century , the course of petroleum exploration has achieved a brilliant success .

Karamay oilfield was discovered in 1955 . This discovery is the first great success derived from modern petroleum exploration , and also a significant progress of theory of petroleum geology in China .

And then , a supergiant non-marine oilfield in the world—the Daqing oilfield was discovered in the Songliao basin in September , 1959 . This discovery proved that the supergiant world-rank oil fields could be formed in both marine and non-marine sequences . During the process of exploration and development of Daqing oilfield , the theory of petroleum geology of non-marine basins in China had been developed and summarized systematically .

The focus of petroleum exploration activities of China was transformed into the Bohai Bay basin in 1964 . The practical work demonstrated that the conditions for forming its oil and gas pools are quite different from those to form the anticlinal pools of Daqing oilfield , and then the characters of composite oil-gas pools formed by faultblock and many small non-marine sand bodies here progressively recognized .

During that stage , in view of the different geological characters between Daqing and Bohai Bay oil provinces , many studies on the organic geochemistry for hydrocarbon source rocks regional tectonic setting , faulted structural belt and local structural evolution , migration and accumulation of hydrocarbons , lithology of non-marine sediments and facies belt , subsurface water properties and pool-forming mechanism have been conducted , and petroleum geological characters of these provinces have also been analyzed synthetically . Based on the results of these studies above-mentioned and due to the application of new techniques and methods and new theories , and combined with our new understanding and new train of thinking for petroleum geological exploration , new hydrocarbon-bearing regions , new hydrocarbon-bearing sequences , and new exploration domains have continuously been discovered ,

further pushing forward the petroleum exploration and development in the Songliao and Bohai Bay basins, making them become two major oil production bases of China .

Under the guidance of new idea, several new oil and gas-bearing domains have continuously been discovered in the explored basins or regions . First of all, a lot of lithologic oil and gas pools which composed of deltaic, channel and deepwater turbidite fan sandbodies, and several stratigraphic pools such as erosional monadrock, inner buried hills and buried hills on the slope were discovered in the Songliao and Bohai Bay basins, which brought us a new growth peak in oil reserves, and also promoted the hydrocarbon exploration work in the western part of China, e .g ., under the guidance of the theory of thrust faultbelt for forming oil pools, the oil-bearing area, oil reserves and oil production were increased by many times in Karamay region .

Owing to the continuous development of the petroleum geological theory and the innovation of equipment and technology in recent, some important breakthroughs obtained in new prospecting regions . For example, a number of significant discoveries were obtained respectively in small- and medium-sized grabens and rift basins of eastern China, in Eren basin, in beach-shoal area of the Bohai Bay basin, and in the hinterland of the Junggar basin .

In late 1980s, taking a commercial oil-gas flow from the Jurassic coal measures obtained by the scientific exploratory well—Well Taican-1 as a turning point, the Turpan-Hami basin has been developed into the industrial base of oil and gas production, and meanwhile, this discovery opened up a new domain for finding oil derived from coal measures in the Jurassic System .

The recent exploration and research work for the Tarim basin has proved that the basin is composed of stacked marine and non-marine sediments . Due to experience the structural evolution for a long time, the basin has the natures of multistage hydrocarbon generation and expulsion, multistage oil and gas pool formation, multistage regulation, as well as various types of oil and gas pool and petroleum system .

Recently the exploration for natural gas achieved the unprecedented grand results: a number of significant discoveries have been obtained, including a giant gasfield covering 4000 sq .km of the Lower Paleozoic carbonates in the central Ordos basin, a giant gasfield within Upper Tertiary thick sandstone in South China Sea, the vast biodegradation gas province with the Quaternary System in the Qaidam basin, western China, and many condensate gas fields in the Tarim basin . The discovered gasfields are attributed to the great progress in the latest geological studies and the works of the integrated exploration .

As above-mentioned, these demonstrate that China has abundant and widespread petroleum resources, and with great potentials of petroleum exploration; however, its geological conditions are very complex . The reason for that is oil-bearing basins in China were developed on the setting of frequently tectonic movements, with non-marine depositional characters by narrow facies belts and various facies changes .

From geological conditions of China, and on the basis of numerous data from nearly half a century exploratory practices and study results previously done from different periods, regions and scientific domains by our predecessors, this book was compiled through scientific conclusions and generalizations, which all-round and systematically demonstrates the petroleum geology with Chinese characteristics .

The book contains 12 chapters, summarizing the contents in four parts . Part one is an introduction (Chapter 1), briefly describes a general history of emergence, development and replenishment, and continuous improvement of petroleum geology in China . Part two contains Chapters 2, 3 and 4, mainly discussing the regional geological conditions of petroleum in China . Chapter 2 describes the stratigraphic division and correlation in petroleum provinces, which is a basic research work . Recently the integrated studies adopted with data from drilling make a great progress, basically getting a clear understanding of the stratigraphic relations among the major petroliferous basins throughout the China . Chapter 3 introduces the sedimentary facies in petroleum provinces, from the history

of the development of sedimentation it demonstrates the characteristics of both marine and non-marine deposition . Especially, the non-marine sediments in China here deposited in much varied sedimentary systems, forming some special sedimentary models .Chapter 4 discusses the tectonics of petroleum provinces in China, based on the characters in regional tectonic evolution it decided that classification and zonation of the basins, and discusses the controlling effects of regional tectonic evolution on petroleum geological conditions of the basin . The part three (Chapters 5 ~ 11) is the emphatic part of this book, which discusses in detail the basic geological factors for forming oil and gas pools in Chapter 5, the hydrocarbon generation, emphatically expresses the characteristics of non-marine oil and gas generation, and analyses the different geological backgrounds and types of source rocks, and thermal evolution of non-marine petroleum generation from those of widespread marine petroleum generation in abroad, fully reflecting the specific environment and model of non-marine hydrocarbon generation in China . In addition, this chapter also briefly describes hydrocarbon generation of marine facies in China .Chapter 6 describes the petroleum reservoirs, more completely discusses the characters of both marine and non-marine reservoirs . The obvious characteristics of non-marine clastic reservoirs are heterogeneous and discontinuous, being much different from those of marine reservoirs in abroad . Most major marine carbonate reservoirs of China are also assemblages of tight, fractured limestones and dolomites .Chapter 7, is upon the hydrogeology in oil and gas fields, which describes the effect of hydrochemical characteristics of oilfield water and regional hydrodynamic conditions from ancient to modern on hydrocarbon distribution . Chapter 8, is on natural gas geology, especially demonstrates the conditions for forming natural gas pools in China . Natural gas pools distributed over each basin in China are in varieties because of its different geological conditions . Although Chinese exploratory efforts and research work directed specially for natural gas started comparatively late due to the historic reasons, but the natural gas resource of China are proved very abundant based on the evaluation result of national oil and gas resources . In recent years, the geological prospecting and research work have continuously obtained new progress, its forecast with an optimistic prospect for natural gas . For this reason, natural gas geology is taken as an independent chapter in this book . Chapter 9, on crude oil properties, which is complex and varied for crude oil of China and this is one of petroleum geological characteristics in China . Crude oils of China were mostly generated from non-marine sediments, and their common properties are high wax content and low sulfur . However, owing to the influence of multistage tectonic movements the nature of crude oils changed strongly, being either extra high pour point oil or extra low pour point oil; either having considerable amount of heavy oil resources or quite a lot of condensate oil and gas reservoirs .Chapter 10, discusses the hydrocarbon migration which compiled based on a large number of the exploratory practice and analyses, experimentally discussed oil and gas migration of each petroliferous basin of China, with the aim of paying a great attention to this research . More important, further to probe the possible trend of hydrocarbon migration could provide help for guides the petroleum exploration . And the Chapter 11, is upon the oil and gas pools, especially discusses the characteristics of different types of petroliferous basin of China, thoroughly describing many types of complex condition for forming oil and gas pools and petroleum systems . Because Chinese oil and gas resources were mainly originated from the Mesozoic and Cenozoic sequences, and affected by multistage tectonic movements, the models of pool formation are characterized by multi-layer hydrocarbon source rocks, multistage hydrocarbon expulsion and migration and multistage accumulation, as well as rich and varied types of oil-gas pools . It will be of great benefit to deeply understand the geological patterns of Chinese oil and gas pool formation and combination for further improving the effectiveness of oil and gas prospecting . Part four is the Chapter 12, which briefly indicates the characteristics of Chinese petroleum geology and prospect of Chinese oil and gas industry .

Authors of this book are academician Zhai Guangming and senior geologists et professors Gao Weiliang, Song Jianguo, as well as (in order of surnames) include An Zuoxiang, Cheng Keming, Dai Jinxing, Guan Deshi, Liu

Fanghuai, Li Jinchao, Qiu Yinan, Tang Xianghua, Tong Zhenyan, Wang Xiaoling, Wu Shaohua, Xu Shubao, Xu Zhichuan, Xue Chao, Xue Shuhao, Ying Fengxiang, Zhang Dajiang, and Zhou Kun .

English translators of this book are professor Guo Yangsheng(Chapters 1, 5, 7, 8, 12 and part of Chapter 9), Fu Xiaowen(Chapters 6, 10, 11 and part of Chapter 9), Zhang Tingshan(Chapter 2), Mu Shuguang(Chapter 3) and .Jin Jiuqiang(Chapter 4) . The full translated text was examined and corrected by Professor Li Hanyu, and the figures and tables were checked and corrected by Gao Weiliang and Xue Chao *et al* . . The book was initially normalized and compiled by Gao Weiliang, and was finalized by Zhai Guangming .

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July 20, 1997

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## Foreword

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# Chapter 1 Introduction

China is one of the earliest countries to have discovered and made use of petroleum in the world. Over two thousand years ago, oil and gas were respectively found and utilized in northern Shaanxi and Sichuan provinces. China played a leading role in this aspect in the world.

In modern times, however, due to the long period in feudalistic rule and invasion and oppression of imperialism, China progressed slowly in petroleum industry. She was way behind advanced industrial countries of the world.

The founding of the People's Republic of China has brought a totally new period of development for petroleum geology, which has grown at an unprecedented speed. On the basis of massive petroleum exploration, a great number of petroliferous basins and oil-gas fields have been successively discovered (Fig. 1—1).

Over forty years of repeated practice and research in petroleum geology has made it possible for a distinctive and systematic Chinese petroleum geology to emerge.

The appearance and development of Chinese petroleum geology have been closely linked to oil and gas exploration, and have experienced approximately the following stages: ancient germination (before 1878); recent introduction (1878 ~ 1949); and birth of Chinese petroleum geological theory; systematic approach to perfection (1950 ~ 1996). Therefore, the following survey of the birth and growth of Chinese petroleum geology will start from the progress of geological exploration to the development of the corresponding theories.

## 1.1 Ancient Germination of Oil and Natural Gas Geology (Before 1878)

### 1.1.1 Discovery and Utilization of Oil and Natural Gas

#### 1.1.1.1 Discovery and utilization of oil

China is one of the earliest countries to have dis-

covered oil in the world. The earliest extant record of oil is found in *Accounts of Geography*, one volume of the *Chronicles of Han Dynasty*, written by Ban Gu, a historian of the Later Han Dynasty from AD 32 to AD 92. In *Accounts of Geography*, it records that "In Gaonu there is the Wei river, whose water can burn."

The Gaonu is located in today's Yanchang county, Shaanxi Province, and the Wei river is a tributary of the modern Yan river. Actually the discovery and utilization of oil should have been much earlier than the recorded history. It may be concluded, therefore, that oil should have been discovered and known to burn well over two thousand years ago in China.

There are also various historical records of the discovery of oil in other regions of China. For example, *The Chronicles of Later Han Dynasty*, written in the Western Jin Dynasty by Sima Biao (? - AD 306), bears an account of oil found in the Yumen region, Gansu Province, which records "in the south of Yanshou county" in Jiuquan prefecture, "there is a mountain, and a spring runs out of its rocks. The water, ever-bubbling, is as oily as meat soup, it looks like ointment, and can burn brightly. It is inedible and the natives call it rock-lacquer." A lot of more and extremely detailed records, written from and after the Tang Dynasty, can be found of oil in Yumen.

Accounts of oil in the Xinjiang region are first found in *The Chronicles of Wei Dynasty* written by Wei Shou of the Northern Qi Dynasty: "The State of Qiuci, an old kingdom of the Han Dynasty, whose capital is Yancheng, is located 85 kilometers away from the south of the White Mountain in the northwest of Yuli (city)... In its northwestern mountains, there is a river of something like ointment that runs several kilometers into the earth. It is like Tihu (a paste), and smells strongly..." *The Chronicles of Wei Dynasty* was finished from AD 386 to AD 550, and the state of Qiuci situated around present Kuqa county of Xinjiang region. It can be seen here that oil in the area of Kuqa, was discovered over 1500 years ago.

More accounts of oil in Xinjiang are available. In *The New Chronicles of the Tang Dynasty: Annals of*

The national boundaries of China on this book are drawn after 1:4M *Relief map of the People's Republic of China*, Published by China Cartographic Publishing House in 1989.

*Geography*, written in the Song Dynasty by Ouyang Xiu et al., there is mention of oil in the area of the Jing river, which borders on the southernmost of the Junggar basin. The paragraph records that to go west from the now Jimsar county to the now Yining (Gulja) city, Xinjiang, one has to cross the "Rock Lacquer river", i.e., the now Jing river. "Rock lacquer" is the ancient name for petroleum. Here a conclusion can be drawn that oil had been found at that time in the Jing river.

Oil in those ancient times was used chiefly for lighting, lubricating, producing ink, medicine, anti-septic purposes and war, etc.

### **1.1.1.2 Discovery and utilization of natural gas**

China is the first country of the world to have discovered and utilized natural gas.

As early as in the Western Han Dynasty, in digging salt wells, natural gas was found to diffuse and burn. Such wells were called "fire wells". According to *The Chronicles of the Han Dynasty: Annals of Offering Sacrifices to Heaven*, in the first year of the reign of Shenjue (61 BC), the Western Han Dynasty, a sacrificial ceremony "to offer the Tianfengyuan firewell was held in Hongmen." The chapter *Annals of Geography* of the same book also carries an account that, in Hongmen county of Xihe prefecture, "There is a firewell temple called Tianfengyuan, whose fire comes from underground." Hongmen county of the Han Dynasty was located about in the now Shenmu and Yulin counties in Shaanxi Province.

Shortly before or after the discovery in Hongmen, "firewells" were also found in Sichuan Province. Yang Xiong (BC 53 ~ AD 18), the writer of the Western Han Dynasty, wrote in his *poetry on the Capital of Shu* (Sichuan), "The land of Shu was called Liangzhou in ancient times... In its east is Bacong, which is inhabited by the Baipu people. Here are (Mount) Tongliang, (Mount) Jintang, the Firewells, the Dragon Pond..." Mount Tongliang is in the now Qu county, and Mount Jintang in the now Xindu county of Sichuan. When Yang juxtaposed the "firewells" with the famous mountains and the "Dragon Pond", the popularity of the firewells needs no more emphasis.

In *Records of Nature Studies* (AD 267) written by Zhang Hua in the Western Jin Dynasty, there is mention of natural gas found in Yumen, Gansu Province: "The mountain in the south of the county is called Fire Spring, whose fire burns like a torch."

In the north China plain, natural gas showings were successively discovered in ancient times. The volume 19 of *The Chronicles of Jin Dynasty: Annals*,

compiled in the Tang Dynasty by Fang Xuanling et al., records that "In the 5th lunar month of the first year of the reign of Guangxi (AD 306), there was fire coming from underground in the land of Fanyang, which could be used to cook." Fanyang is in the now Dingxing county of Jizhong (Central Hebei) depression, where not only was natural gas produced but the gas was also used to cook.

Natural gas was also found in the Mengzi county, Yunnan Province. In *Sketches of Yong Tong*, written by Zhu Guozheng in the Ming Dynasty, there is an account that "there are firewells in Amizhou. Smoke mixed with water springs out of them. Cast bamboo slips or wood into them and they are burned..."

The coastal areas of southeastern China also witnessed natural gas showings. As is noted in *Annals of Shanghai county* compiled by Ye Tingjuan in the Qing Dynasty, "on the winter solstice, the 11th month of the lunar year," in the 7th year of the reign of the Emperor Zhende in the Ming Dynasty AD 1512, "there was a roaring blaze on the sea, which spread as far as Beicai, and there could be heard sounds of arms and armors..."

Long ago in Tainan county, Taiwan Province, natural gas was discovered in early time. The *Annals of Taiwan Province*, written by Fan Xian in AD 1747 (the 12th year of the reign of the Emperor Qianlong in the Qing Dynasty), records that "at the foot of the back of Mount Yu'an there is a hill, beneath which waters and rocks crisscross. Water springs out of the crevices of the rocks, and fires, blazing day and night and over one meter high, smokeless, run out of the springs."

The chief use of natural gas in ancient times was for cooking and decocting salt. For instance, on the printed bricks of the Han Dynasty mausoleums excavated in Sichuan, there are two drawings describing gas recovery for salt decoction (Fig. 1—2). The one Left is a painted brick from the Memorial Archway in Qionglai county, from which one can see there is a brine pit at the lower corner on the left. The derrick is two-storied, on each of which two men are operating face to face. They are turning the windlass to fetch brine. On the right side of the second story is a rectangle trough. The brine fetched from the well is first sent to this trough, where it flows through the pipes into the brine pan. The one right is a painted brick from outside the West Gate of Chengdu city. Although the upper corner on the right is missing, what remains shows pretty clearly that at the door of the kitchen range stand side by side three or four bamboo pipes, which reach the bottom of the brine pan. After detail

study of domestic and foreign experts conclude that the pipes are used to transport natural gas to the bottom of the pan to heat .

From above mentioned it can be seen that two thousand years ago, Chinese people were already using natural gas to decoct salt . This is further recorded in *Records of Nature Studies* :“ There is one fire well in Linqiong, more than one meter wide and 5 - 7 meters deep . The well is located several tens of kilometers away from the south of the county . In the past, people cast bamboo slips and wood into it to make fire . Prime Minister Zhugeliang once went there for inspection; Later the fire was used for heating, puted the brine pan on the well head to get salt... ”

The use of natural gas for cooking finds its reference cited above .

## **1 .1 .2 Germination of Oil and Natural Gas Geology**

With long term practice, ancient Chinese “ mountain craftsmen ” acquired much of experience in finding oil and gas, and gradually developed some oil and gas geological consciousness to guide their locating of wells and drilling operations . This can be regarded as the germination of Chinese oil and gas geology, which may well be summed up as following four aspects .

### **1 .1 .2 .1 Preliminary understanding and knowledge of the source of petroleum**

With the development of oil and gas exploitation and utilization, the occurrences, flowing and lithologic properties of oil and gas derived were gradually much

observed and surveyed . Shen Kuo (AD 1031 ~ 1095), the scientist of the Northern Song Dynasty, said in his *Notes from the Dreaming Creek* that “ Unlike pine trees that sometimes come to exhaustion, there is no end of petroleum ( rock oil ) generated under the ground, ” and that “ (petroleum) emerges among waters, sands and rocks . It is usually mixed with spring waters, bubbling out endlessly .” Here Shen Kuo took the lead in associating petroleum with geology, seeing that petroleum was not something floating upon water but something generated in the subsurface deep level among water and sandy rocks . And he is the first to have given that something a scientific and commonly accepted name “ petroleum ” ( rock oil in the Chinese original) .

### **1 .1 .2 .2 Locating wells by observing the “ arteries and veins of the dragon ”**

As early as 2200 years ago, during the Spring and Autumn Period and Warring States Period, Li Bing, from the state of Qin, was said to “ be well-learned in astronomy and geography . . .and also well-informed in the arteries and veins of the rivers, according to which one located all the ponds and pools of the salt-wells in Guangdu .” This shows that at that time one had to know the “ arteries and veins ” in drilling salt-wells, i . e ., deciding on the location of wells by following the mineral veins as reflected by the given geological and geographical features . Legends still remain in the region of Ziliujing (in Sichuan) that in ancient times “ mountain craftsmen ” should be invited first to observe

Fig 1—2 Picture of one painted brick of the Han Dynasty (From Art of Painted Bricks in the Han Dynasty)

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Institute of Natural Science History of China ed ., The Achievement of Modern Science and Technology in China .308 p . Science and Civilization in China . Vol 4 . Part 2 . Fig . 396 .

Written in AD 267 by Zhang Hua of the Western Jin Dynasty .

“ the arteries and veins of the dragon ” before a well was dug . This is of course reasonable . When the locations of ancient gas-wells are cast unto the structural maps of Artesian Wells drawn nowadays, one is sure to find that most of those wells are located at the major axis of the structures, while wells located at the lower levels are few . It is clear that the “ arteries and veins of the dragon ” located by the “ mountain craftsmen ” are at the long-axis of the anticlinal structure, where natural gas is most abundant . The Mozi Well, completed in 1840, is actually located at the highest point of the structure .

### **1 .1 .2 .3 Well-cleaning and well-cuttings logging and establishment of stratigraphic sequence**

Before the Northern Song Dynasty, all the wells dug had been wide in diameter and shallow in depth, so that the strata could be observed with the naked eye . From the Northern Song Dynasty, people began to drill small-bore churn drilling wells, which became increasingly deeper . Gradually the method was invented to use bamboo tubes to fish up cuttings . The purpose was to clear the bottom of the well to ensure further drilling, and then, by observing the cuttings fished up, to establish the stratigraphic sequence and lithological section . In volume two, *Notes of Salt Wells*, of the *Annals of Salt Laws in Sichuan*, written during the years of the reign of the Emperor Shenzong in the Ming Dynasty, there is a paragraph describing the process of fishing up cuttings with tubes: “ At the beginning drilling is helped by pouring water into the well . When it comes to near ten meters deep, there is no need to pour water in since water wells in from every side of the bore, and wherever the drill rod contact, it is all muddy water . The rod is lifted every time it drills near one meter further, and a three-meter-long bamboo tube, with joints poked through, and a rope tied to its ends when put it into the well, and use a leather valve covered the tube the rope is pulled, the leather gives way, and water and mud rush into the tube, which is lifted up when filled . After the bottom of the well is cleaned, the rod is run down again to continue drilling .” In fact, this method had already been adopted as early as in the 12th and 13th centuries, which is recorded in *Notes by Dongpo* written in the Southern Song Dynasty .

“ Bamboo tubes ” in those early days were used to clean the bottom of the well in order that drilling could continue . From the Ming and Qing dynasties, they became an important tool with which to know the strata, to determine marker horizons and to guide drilling operation .

*Notes on the Artesian Wells*, written by Li Rong

in the Qing Dynasty, says that “ While drilling one must observe and examine the underground rocks . First one comes upon red rock, then brick-gray rock, then gingerlike-yellow rock, and then there is rock oil . Next one comes upon grass-whitish rock, then yellow sandstone, and then there is turf fire ( i . e . , small amount of natural gas ) . Still next one comes upon bluish sandstone, then white sandstone, and then there is yellow water . Further one comes upon coal-like rocks, then carbonate rock, then black smoky rock, then mung bean-like rock, and then there is black water . . . All these are not necessarily present in one single wellbore except gingerlike-yellow and mung bean-like rocks, which do exist in every one . . . .” This account clearly illustrate underground strata, lithological sequences and marker formations . We know from it that “ All these ( rocks ) are not necessarily present ( in one single well ) ”, whereas the gingerlike-yellow rock ( limestone of the Dongyuemiao Formation ., i . e . , the now Jurassic key bed ) and mung bean-like rock ( of the Leikoupo Formation ., i . e . , the now Triassic key bed ) “ do exist in every well ” . Also the locations and characteristics of the oil-, gas- and water-bearing zones are clearly shown . This knowledge is extremely significant as a guide to drilling .

### **1 .1 .2 .4 Fire from vertical fractures and water from horizontal fractures**

“ Fire ( natural gas ) from vertical fractures and water from horizontal fractures ”, this is the knowledge gained from long term practice of the patterns of subsurface fluids distribution . In the early Qing Dynasty, drilling techniques files in the form of “ well head reports ” began to be established at artesian wells . Large amount of records about “ vertical fractures ” and “ horizontal fractures ” were kept in the reports, some of which recorded “ fire ( comes ) from vertical fractures ” and “ water from horizontal fractures . ” This knowledge of the characteristics of fluids distribution is very close to ours in modern times . Natural gas is mostly and abundantly present in vertical fractures, while water is mostly found in horizontal ones .

As is seen from above, China boasted glorious achievements in ancient times in the oil and gas discovery, utilization, drilling and development of geology, contributing, with its leading role, much to the human history . Unfortunately, under the long feudalistic rule and closed-door policy, oil and gas industry developed so slowly that in modern times it lagged way behind that in the advanced countries of the world .

## 1.2 Modern Scientific Theories of Oil and Gas Geology: Introduction and Development (1878 ~ 1949)

In year 1878 the completion of the first modern 120-metre-deep well was drilled within one month by employing two foreign technicians with a set of bought cable tools driven by a steam engine in Miaoli, Taiwan Province, and which has been generally regarded as the beginning of modern Chinese petroleum industry .

### 1.2.1 Modern Oil and Gas Geological Exploration

The way for modern Chinese petroleum geological exploration was crooked and difficult due to the fact that there were neither unified planning, nor advanced equipment and nor guarantee of funds, with a small number of experts, guided by certain modern petroleum geological ideas, doing a little surface geological survey and less drilling in a few areas . By the end of 1949, petroleum geological exploration had been conducted merely in some local regions in northern Shaanxi, Gansu, Xinjiang, Sichuan and Taiwan provinces, etc . .

Data show that by the end of 1949, only the following oilfields had been found: Yanchang in northern Shaanxi, Laojunmiao in Yumen, Gansu, Dushanzi in Xinjiang, Chuhuangkeng in Taipei of Taiwan and Zhutouqi in Tainan, Taiwan Province . Gasfields had merely included: Shiyougou in Baxian county, Shengdengshan in Longchang and Ziliujing (discovered already in ancient times), Sichuan Province; Liuchongxi and Niushan in Tainan, Zhudong and Jinshui, among others, in Taipei, Taiwan . The discovered oil in place had amounted to  $29 \times 10^6$  t, the cumulative production of crude oil is  $67.17 \times 10^4$  t, and natural gas cumulative production is  $1.17 \times 10^9$  m<sup>3</sup> .

The earliest modern Chinese petroleum geological exploration carried out on mainland was in northern Shaanxi .

In northern Shaanxi, investigation and drilling started in the year 1907, when the Government of the Qing Dynasty employed some foreign technicians and bought cable tools to drill the first oilwell in August of that year . Then, two other wells successively proved to be producing oil, and news of northern Shaanxi oil production swept the whole China . In 1914, the then Beiyang (the Qing Dynasty name for the coastal provinces of Liaoning, Hebei and Shandong) Government signed a contract with the American Standard Oil

Company, organized geological investigation and drilled 7 wells in Huangling, Yan'an, Yanchang, Tongchuan counties . Oil reservoirs were found in each well, whereas the yield was extremely low . The American geologist M . L . Fuller wrote in his geological report that not even one well could be regarded as of any commercial value .

In later, experts including Wang Zhuquan, Pan Zhongxiang and Xie Jiarong (C .Y .Hsieh) were sent by the National Geological Survey of China respectively in 1923, 1931, 1932 and 1933 to those places for further investigation . Based upon the collected fossils information, they corrected the errors in stratigraphic classification by American Standard Oil Company, discovered apparent anticlinal structures in such areas as the southwest of Yongpingcun, surveyed and drew a 1 : 500 map of well locations in Yanchang region . Meanwhile, they wrote a paper, " Geology in northern Shaanxi oilfields ", published in *Geological Reports*, vol . 20, 1933 .

In 1934, the northern Shaanxi Oil Resources Department was established, and 7 wells were drilled in Yanchang and Yongping counties . Except in one well, oil was produced in all the other wells, two of which had an initial production of 1.5 t and 3 t per day . In 1935, the Chinese Red Army arrived to northern Shaanxi, and in 1940, the War Industry Bureau of Logistical Department, Military Commission of the Central Committee of the Communist Party of China, sent some people to the oil deposits in Yanchang for geological exploration . They concluded that the Yanchang area was a westward-dipping monocline, gentle in strata inclination, the dip angle generally being  $2^\circ \sim 3^\circ$  . Meanwhile, in Qilicun, an oil-filled nose-like anticline was found, with dip angle  $5^\circ \sim 8^\circ$ , and the first exploratory well yield crude oil flowing out at the depth of 80 m, hence the discovery of the Qilicun oilfield, which caused northern Shaanxi crude oil yield to be several times higher . The oil yield of 1943 equaled the total oil production of the previous 14 years, and the monthly volume of oil refinement increased from the original 2700 to 15000 pails, contributing substantially to the lighting in the border area of Shaanganning (Shaanxi-Gansu-Ningxia) .

Petroleum geological investigation in Sichuan Province was first carried out in 1915 by G . D . Loudorback in Qianwei, Leshan and Zigong counties . In 1929 and 1931, Zhao Yazeng, Huang Jiqing, Tan

The report was included in *Annals of Mineral Resources in China*, Weng Wenhao ed printed by Geologic Investigation Institute, Ministry of Agriculture and Commerce, 1919 .

Xichou and Li Chunyu *et al.* , from National Geological Survey of China, and geologists from geological departments of Zhongshan University and Central University conducted investigations in Ziliujing, Wutongqiao, Shiyougou, Penglaizhen and Daxian regions, and wrote corresponding geological reports .

Geological investigation brought new understandings of petroleum resources in Sichuan . Tan Xichou and Li Chunyu held that opinion:

A . Sichuan could be divided into 8 petroleum regions, i . e . , Fushun-Leshan, Zizhong-Renshou, Pengxi-Suining, Rongchang-Yongchuan, Baxian-Jiangjin, Daxian-Xuanhan, Lezhi-Jianyang and Chengdu-Qionglai;

B . Ziliujing and Gongjing are in a domal structure, Leshan and Baxian are anticlines, Rongchang-Yongchuan is excellent folds, Pengxi-Suining are gentle anticlinal structures, anticlinal structures in Lezhi-Jianyang are favorable for oil accumulation, and Zizhong-Renshou region with apparent in faults, with few folds, so that oil reservoir structures should be related with faults;

C . Oil-bearing zones in Sichuan could be subdivided into 6 units, starting from the Cretaceous Ziliujing Formation (now classified into the Jurassic) in the upper to the Triassic Jialingjiang Formation in the lower part, among which the Triassic limestone was the major oil-bearing unit .

During the Anti-Japanese War, more petroleum exploration was carried out in the Sichuan basin . Those engaged in the work included such experts as Huang Jiqing, Pan Zhongxiang and Chen Bingfan from National Geological Survey of China, Wang Jing and Shen Naiqing from Sichuan Petroleum Exploration Department, Xie Jiarong (C .Y .Hsieh) from the Bureau of Exploration for Mineral Resources and Chen Ben from Gansu Oil Resources Department .

At that time it was popularly held that Sichuan basin was most promising as a petroleum province, where oil might well have been generated in its Permian Qixia limestone, Leping coal measures, Triassic Jialingjiang limestone as well as the Jurassic and the Cretaceous . Since several wells that had been drilled did not produce much oil, it was inferred that the shallower layers were not rich in oil . On the other hand, drilling should be conducted into the Permian and the Triassic, which were of neritic facies and deep in buried depth . In October, 1938, Huang Jiqing put forward a suggestion to drill at the Choushuihe anticline in Weiyuan county . It turned out years later, however, that oil was not to be produced there .

In Sichuan basin, from the 1930 's to the end of

the 1940 's, exploratory wells were drilled in five regions, i . e . , Shiyougou and Feixianyan in Baxian county, Choushuihe in Weiyuan, Shengdengshan in Longchang and Haitangpu in Jiangyou, in which only the anticlinal structures in Shiyougou and Shengdengshan found commercial gas, the daily production was respectively  $1.4 \times 10^4 \text{ m}^3$  and  $14 \times 10^4 \text{ m}^3$  .

As to where to find petroleum in Sichuan, Xie Jiarong suggested that attention should be directed to the en echelon lower-relief anticlines, believing that such low anticlines between two major ones were most favorable for petroleum accumulation .

Petroleum geological investigation in Xinjiang region started between the end of the 19th and the beginning of the 20th centuries . Brief description of oil seepages there can be found in travel notes by Wang Shunan, Xie Bin, Wu Shaolin and Wu Aichen *et al.* . Oil was produced mainly in: Nanshan and Dushanzi in the southeast of Usu, Sulai, Heiyoushan (Karamay) to the southeast of Tacheng (Qoqek), Sudache —25 km in east and Sichagou —20 km in west of Dihua (Urumqi), north of Kuqa, northeast of Wensu, Hezierbo in Kashi (Kaxgar) and western Shachecheng (Yarkant) .

In 1905 and 1925, some Russian and American geologists went to Xinjiang for petroleum investigation in some local areas . From 1927 to 1935, the Chinese geologist Yuan Fuli joined the Sino-Swedish Northwest China Investigation Group, and found the marine Cretaceous and the Tertiary in southwestern Tarim, and bituminous veins in Turpan .

In 1942, Huang Jiqing, Yang Zhongjian (C .C . Young) and Weng Wenbo *et al.* , went to Xinjiang, making investigation in Dushanzi in Usu, Tongchang in Kuqa and Tuoklak in Wensu, and wrote the *Report on Geological Investigation in Xinjiang oilfield* in next year, regarding the non-marine Jurassic as the most important oil-generating formation . The best petroliferous geological conditions were found in the Dushanzi anticlinal structure, where the first well produced oil on January 14th, 1937 . And up to 1942, 23 wells had been drilled, the deepest being 1453 m, and the annual crude oil yield 6900 t . After 1945, production basically stopped, and merely indigenous methods were adopted for recovery .

Survey of petroleum geological investigation in Gansu and Qinghai provinces:

A . Yumen region of Gansu, where the first investigation was done by Xie Jiarong (1921) . Later came Zhang Renjian (1928), Hou Defeng and Sun Jianchu (1933), Gu Shaochuan and others (1937) . Zhang Renjian concluded that oil in Yumen region was of good