WORLD ATLAS OF OIL AND GAS BASINS

LI GUOYU

WILEY-BLACKWELL

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About the Author: Professor Li Guoyu

Li Guoyu was born in Lanzhou City, the capital of Gansu Province in northwest China on 17August 1930. He finished his higher education in the Russian Language Department of Lanzhou University in 1952, and furthered his studies at the Beijing Petroleum Geology School in the next year.

Li Guoyu's professional and academic career has been varied and multifaceted. He was the Vice Director of the Exploration Department of China's Ministry of Petroleum for many years and has also held the position of Director of the Oil and Gas Resources Bureau of Former China's Ministry of Energy. His career in the petroleum industry spans over 57 years, during which he was directly involved in the exploration, discovery and development of some of China's most significant oil and gas fields, including Daqing and Shengli.

Professor Li participated in the efforts of the Chinese authorities to promote international cooperation regarding resources in the world's continental shelf regions, which was a strategically important objective in an increasingly globalized environment.

One of his most significant achievements, which has become a new and radical school of thought in the petroleum geology field worldwide, is in the field of theoretical research concerning the development of sedimentary basins. A fundamental tenet of his views is the contention that any sedimentary basin must have potential to be oil and gas bearing.

Professor Li's written output has been prodigious. He has written 84 scholarly works, papers and theses, many of which have been published and have received professional and academic accolades and acknowledgement in countries such as the USA, Russia, UK and France. Professor Li is an Honorary Academician of the Russian Academy of Sciences, and has travelled to 47 countries in pursuit of this work.

A pioneering achievement is an Atlas compendium of the world's oil and gas basins and fields. This compendium is divided into two parts, the first covering Professor Li's home country of China and the second dealing with the rest of the world. These two parts were further subdivided into two series of colour Atlases, each comprised of four sections.

China: Vol. I: China Oil and Gas Basins Atlas
Vol. II: China Oil Fields Atlas (Part 1)
Vol. III: China Oil Fields Atlas (Part 2)
Vol. IV: China Gas Fields Atlas

World: Vol. V: World Atlas of Oil and Gas Basins
Vol. VI: World Atlas of Oil Fields (Part 1)
Vol. VII: World Atlas of Oil Fields (Part 2)
Vol. VIII: World Atlas of Gas Fields

Following this impressive effort, Professor Li created a further compendium, this time in the form of a collection of his major papers and thesis. This three-volume series comprise the following categories.

Vol. I: China Petroleum Geology
Vol. II: World Petroleum Geology
Vol. III: Collection of Inspection Reports on World Oil Regions and Areas

A third large-scale series is three volumes of a coloured Atlas.

Vol. I: Atlas of Oil and Gas Basins of China (Second edition)
Vol. II: New World Atlas of Oil and Gas Basins (Parts 1 and 2)
Vol. III: World Atlas of Oil and Gas Basins (English version)

Given his national and international academic stature, Professor Li has been invited as Visiting Professor at many of China's petroleum universities, as well as at the University of Texas in the USA and the West Siberian University of Russia. He continues to receive invitations to write and present papers on petroleum geology and on his views on sedimentary basin development at international conferences and forums, both in China and around the world.

Preface

When the manuscript of this English edition of *World Atlas of Oil and Gas Basins* was presented to me I was deeply impressed.

Data on the world's oil and gas resources do exist in the hands of oil and gas companies and academic institutions. But this is the first time that all the world's major basins – more than 500 – are presented to the general public in a succinct, reader-friendly format.

Oil and gas have played a critical role in fuelling human progress and will continue to do so in the 21st century. Through the colourful maps and detailed explanatory notes, Professor Li conveys a very important message: the world remains endowed with abundant oil and gas resources. His work shows, in detail, where these resources are located, in various geological structures across five continents and 190 countries.

Only a world-class expert with a long-term career in the oil industry could accomplish such a masterful job. I recently learned of Professor Li's 57 years of work as a geologist and that the Chinese edition of the book, published a few years ago, was widely acclaimed not only in China but elsewhere.

I know that Professor's Li's great wish is to share his work with the global community – hence this first translation of his Atlas into English. This is an admirable ambition, one for which Professor Li should be congratulated.

Lord Browne of Madingley
President, Royal Academy of Engineering
Managing Partner, Riverstone Europe LLP
London, 1st September 2009

Foreword

Professor Li Guoyu is a world famous petroleum geologist, whose many papers and theses have been published in different languages worldwide, including in countries such as the UK and Russia. Professor Li is a familiar and respected figure in the international community of petroleum geologists and oil and gas experts, and he has received justifiable praise for his vast scholarly and research work.

I am extremely pleased that Professor Li will soon publish another substantial work which will be a valuable addition to the world's store of written knowledge and expertise – the *World Atlas of Oil and Gas Basins*. This Atlas provides expert overviews and summaries of 507 petroliferous basins and 560 significant oil and gas fields in 190 countries and regions worldwide. In addition to geological and sedimentary data, the Atlas provides important information on the geography of the global oil and gas infrastructure, including major pipelines, refineries, terminals and port facilities.

There have been similar comprehensive works published in Russia in the past, such as the particularly noteworthy work of the Visotsky father and son team during the 1970s and 1980s (Visotsky, 1995; Visotsky *et al*., 1995). However, Professor Li's masterly publication with its wide array of maps, diagrams and explanatory notes ushers in a new and important historical phase in the further development of a global collection of integrated atlases.

I have no doubt that this new Atlas will be of critical importance and value to experts, scholars, investors and professional practitioners in the global oil and gas industry. Not only will it exert great influence on the continuing international study of the distribution laws and theories of oil and gas fields, it will also play a significant role in predicting trends in global oil and gas in the 21st century.

I am proud to be associated with this valuable and important publication and I wish my friend and colleague, Professor Li Guoyu future success, more vigorous creativity and good health and a long life of achievement.

A.E. Kontorovich
Academician, Russian Academy of Sciences
July 2009

Introduction

I drew the maps and wrote the various notes contained in this atlas in order to provide a summary of my views on the past, present and future of the world's oil and gas industry. The *World Atlas of Oil and Gas Basins* is a culmination of my research and studies on world oil and geology carried out over the past 57 years. The compilation of this atlas has evolved over many years (Li Gouyu, 1982a–c, 1988a,b, 1990a,b, 1991a–d, 1997, 2000, 2009; Kewan Gan *et al*., 1990; Yongxin Jiang and Yishan Dou, 2003). Although every effort has been made to update individual maps, this has not been possible in all cases. The reader is therefore urged to consult up-to-date international (such as the US Geological Survey World Energy Assessment – http://pubs.usgs.gov/dds/dds-060/) and local databases for more up-to-date information. I am pleased to say that I am optimistic, based on scientific research and theory, about the world's oil and gas resources for the future. The atlas covers an introduction to world petroleum geology, world oil and gas resources and the development of the global oil industry. This coverage includes the world's five continents, 190 countries and regions, 507 petroleum basins, as well as 560 large and significant oil and gas fields. The atlas provides what I consider to be a profound analysis and discussion of the past and present of the world oil and gas industry, and most importantly, its future.

Basic premise

According to my views on the development of sedimentary basins, which forms the basis of the atlas, any sedimentary basin must have the potential to be oil and gas bearing. However, each basin is distinct, particularly in respect of the commercial viability of developing and extracting the oil and gas within them. It is my scientific opinion that the world contains abundant oil and gas resources. There are one trillion tons of oil that are discoverable in the approximately 100 million km^2 of sedimentary rocks located on Earth. Approximately 70 million km^2 of which are distributed on continental landmasses, while the remainder are found under the oceans. In my view more and more large-scale oil and gas provinces will be discovered in the future and therefore the prospects of the industry for the 21st century are excellent. Furthermore, it is my belief that the industry will continue to play a key role in the global energy field well into the 22nd century.

The past

The history of the human race, particularly between 2000 BC and AD 1900, shows a remarkable transition from near-ignorance to a better appreciation of the Earth's resources and their functional value to human development. Three ancient civilizations – Egyptian, Babylonian and Indian – exploited oil asphalt from surface seepages for construction, lighting and rudimentary medicine production. It was only later that this rare fossil resource came to be exploited for oil production.

Total annual world production was merely 300 tons* in 1857, but then showed dramatic increases to 800,000 tons in 1870, 4 million tons in 1880, 10 million tons in 1890 and 20 million

* In the atlas SI units of measurement are used (e.g. ton, m, km), but units used for oil and gas reserves and production are often presented differently:
1 ton = 7.3 barrels of oil
1 barrel = 0.137 t
1 m^3 = 35.31 ft^3 (gas)
1 ft^3 = 0.02832 m^3

tons in 1900. As of 1900, 8.5 million tons of oil have been produced in the USA, representing 42% of world total. At the same time, Russia produced 10.68 million tons, 52% of the world total. The interesting fact is that these two countries remain the largest oil producers in the world and this reinforces the premise that there are still many large oil and gas provinces to be discovered.

The present

'The Present' refers to the whole of the 20th century, which represents a critical historical phase of the development of the global petroleum industry, particularly the 55 years after the end of Second World War. Consider the interesting statistic that worldwide production was a mere 20 million tons in 1900, but reached 3.36 billion tons by 2000, a staggering 164-fold increase over the course of the century. This spectacular growth rate clearly indicates the importance of oil and gas in developing a perspective for future analysis of the global energy industry.

There are five key features of the stages of the development of the global petroleum industry, which can be summarized as follows:

1 Oil and gas fossil fuels and their use in high-efficiency internal combustion engines were important drivers for the rapid human development during the early stages of the 20th century. By the year 2000, oil and gas accounted for 61% of the world's energy mix.

2 There were multiple significant discoveries of oil and gas provinces in the 20th century including:

Mexico	1901
Iran	1904
Venezuela	1922
Kuwait	1938
Saudi Arabia	1940
Baku (Second)	1948
Daqing (China)	1959
West Siberia (Russia)	1960
North Sea Oil	1969

These and other discoveries of oil and gas provinces have laid a solid basis for the development of the global oil industry both for the present and for the future.

3 Economic statistics clearly confirm that the level of a country's aggregate prosperity is directly proportional to national fuel consumption. Consider the following figures of fuel consumption in some of the world's major economies in 2000:

USA	890 million tons (mt)
Japan	250 mt
China	230 mt
Germany	129 mt
Russia	123 mt
France	94.9 mt
Italy	93.5 mt
Britain	78.9 mt

In all of these countries, the strong long-term industrial and agricultural bases and rapid sustained economic development were driven by abundant oil and gas resources.

4 Geopolitical competition for oil and gas resources continues unabated and indeed is intensifying. The USA, western Europe, Japan and China are four major oil consuming nations and regions. The competition among them for oil and gas is fierce, and in the case of the USA and western Europe, wars were waged in pursuit of access to these resources.

5 Oil exploration and extraction technologies have flourished. Geological conditions for oil and gas exploration and development are becoming more complicated, but humankind has tackled these challenges with vigorous advancement and enhancement of technologies such as geophysical techniques (e.g. three- and four-dimensional seismic mapping), horizontal drilling technologies and polymer flooding techniques, just to name a few.

The future

Here I refer to the third millennium, the period from the year 2001 to the year 3000. I must start by acknowledging that predicting oil and gas trends for a century is an extremely difficult task. Therefore, predictions for a millennium are unimaginably challenging. However, we may observe some trends from the analysis of oil reserves and production for this period, which are given in Table 1.

Table 1 demonstrates the production potential of the next millennium based on the best data available for reserves by the end of 2004. Based on scientific analysis of the trends of the global world industry I firmly believe the following:

- The quantity of global conventional and non-conventional oil resources that can be produced is in the range of 811.2 billion tons to 1112 billion tons. By the end of 2004, 129.9 billion tons had been produced cumulatively, representing between 12% and 16% of these reserves and resources. This suggests that 84% to 88% still remain unexplored and undeveloped.
- Seventy per cent of the Original Oil in Place (OOIP) figures excluded for 'recovery factor' reasons represent truly enormous reserves. The estimated recoverable oil reserves of 811.2 billion tons to 1112 billion tons mentioned above are calculated based on the 'recovery factor' basis, and merely represent 30% of global OOIP. This suggests that the excluded reserves are between 1622.4 billion tons and 2222.4 billion tons. I am not suggesting that all of this 70% can be produced. But we must not underestimate the ingenuity of humankind for further development of revolutionary oil and gas exploration, development and production technologies.

Table 1 World oil production forecast from 2001 to 3000

Period	Total number of years	Average oil production per annum (million)	Oil production of each period (billion)
2001–2100	100	3400	340
2101–2200	100	2000	200
2201–2300	100	1500	150
2301–2400	100	1000	100
2401–2500	100	500	50
2501–3000	500	300	150
Total			990

The conclusion is simple and definite: potential oil and gas reserves that are yet to be exploited are massive in scale.

I am indebted to the Chairman, Vice Chairmen and Members of the Editorial Board of the Atlas, as well as to the Advisors for their suggestions for the development of this important publication. I would also like to place on record my gratitude to all the editors and proofreaders. I am particularly grateful to Lord Browne and Dr A.E. Kontorovich for their willingness to write the Preface and Foreword to this Atlas. I wish also to express my appreciation to Mr Wang Junqiao, President of SJ Petroleum Machinery Co., Mr Wang Xun , President of Beijing Conspase Trading Co., Ltd for his strong support and to Mrs Li Wen for her warm help.

Professor Li Guoyu
1st October 2009

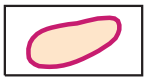
The Geological Time Scale

Era	Period	Epoch	Ma
Cenozoic (Cz)	Quaternary (Q)	Holocene (Q_2)	0.01
		Pleistocene (Q_1)	1.6
	Neogene* (N)	Pliocene (N_2)	5.3
		Miocene (N_1)	23.7
	Paleogene* (E)	Oligocene (E_3)	36.6
		Eocene (E_2)	57.8
		Paleocene (E_1)	66.4
Mesozoic (Mz)	Cretaceous (K)		144
	Jurassic (J)		208
	Triassic (T)		245
Palaeozoic (Pz)	Permian (P)		286
	Carboniferous (C)	Pennsylvanian (C_2)	320
		Mississippian (C_1)	360
	Devonian (D)		408
	Silurian (S)		438
	Ordovician (O)		505
	Cambrian (ε)		570
Precambrian (Pε)	Proterozic (Pt)		2500
	Archaean (Ar)		4600

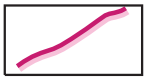
*Paleogene + Neogene = Tertiary (R). (Based on Tarbuck and Lutgens, 1991.)

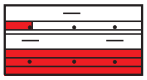
KEY TO MAPS

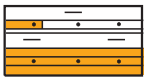

Sedimentary basin


Country


Neighbour countries


Basin boundary


Oil-bearing bed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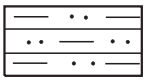
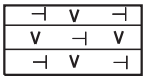

Silty mudstone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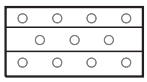
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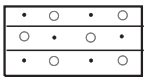
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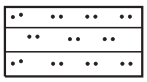
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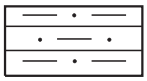
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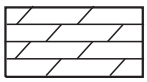
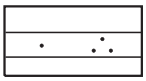
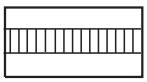

Dolomite


Guartzose sandstone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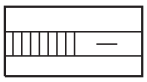
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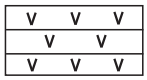
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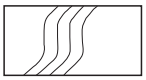
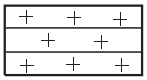
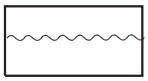
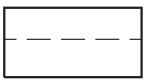
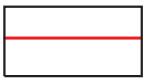
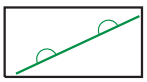

Metamorphic rock


Granite


Unconformity


Paraunconformity


Property uncertainty fault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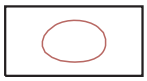
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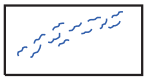
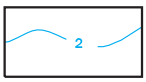
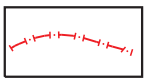
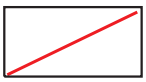
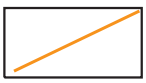

Coral Reefs



Seawater isobath (m)


Continental boundary


Oil pipe line


Gas pipe line


Refinery


Dock

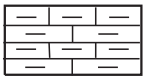
Oil field

Gas field

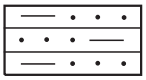
Oil and
gas shows

Asphalt,
oil sand, oil shale

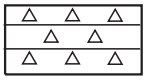
Coal bed



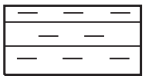
Argillaceous
limestone



Argillaceous
sandstone

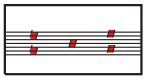


Breccia

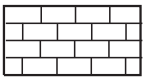


Mudstone clay

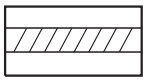
Shale



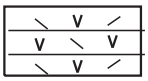
Oil shale



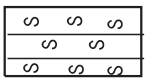
Limestone



Halite

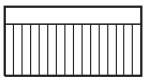


Dacite



Tuff

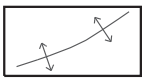
Basalt, basic
extrusive rocks



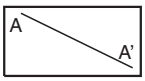
Stratigraphic
break

Denudation
line

Fault

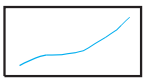


Structural
axial line



Profile line

Desert



River

Coast line

International
boundary

Undefined
international boundary

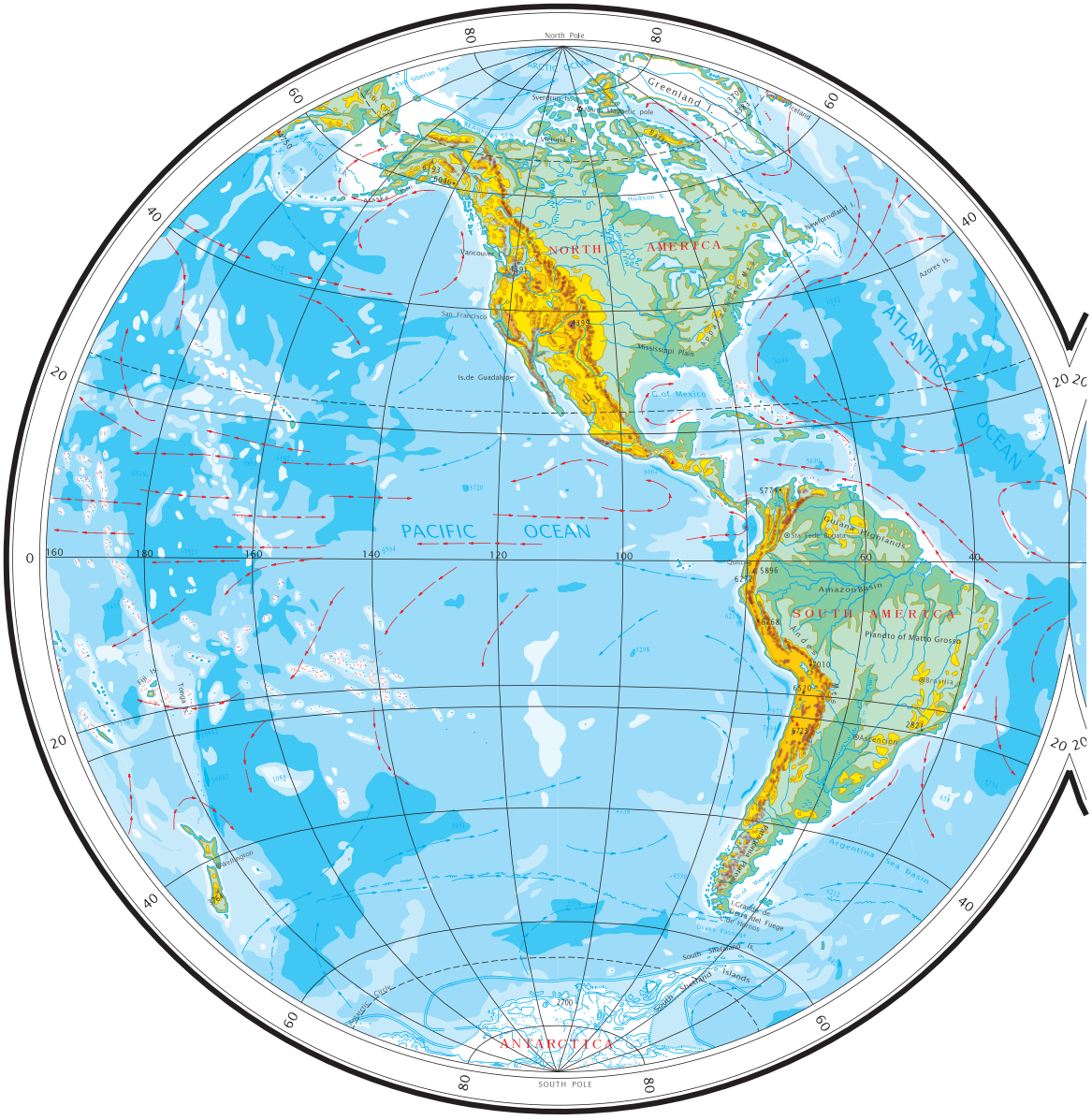
Capital

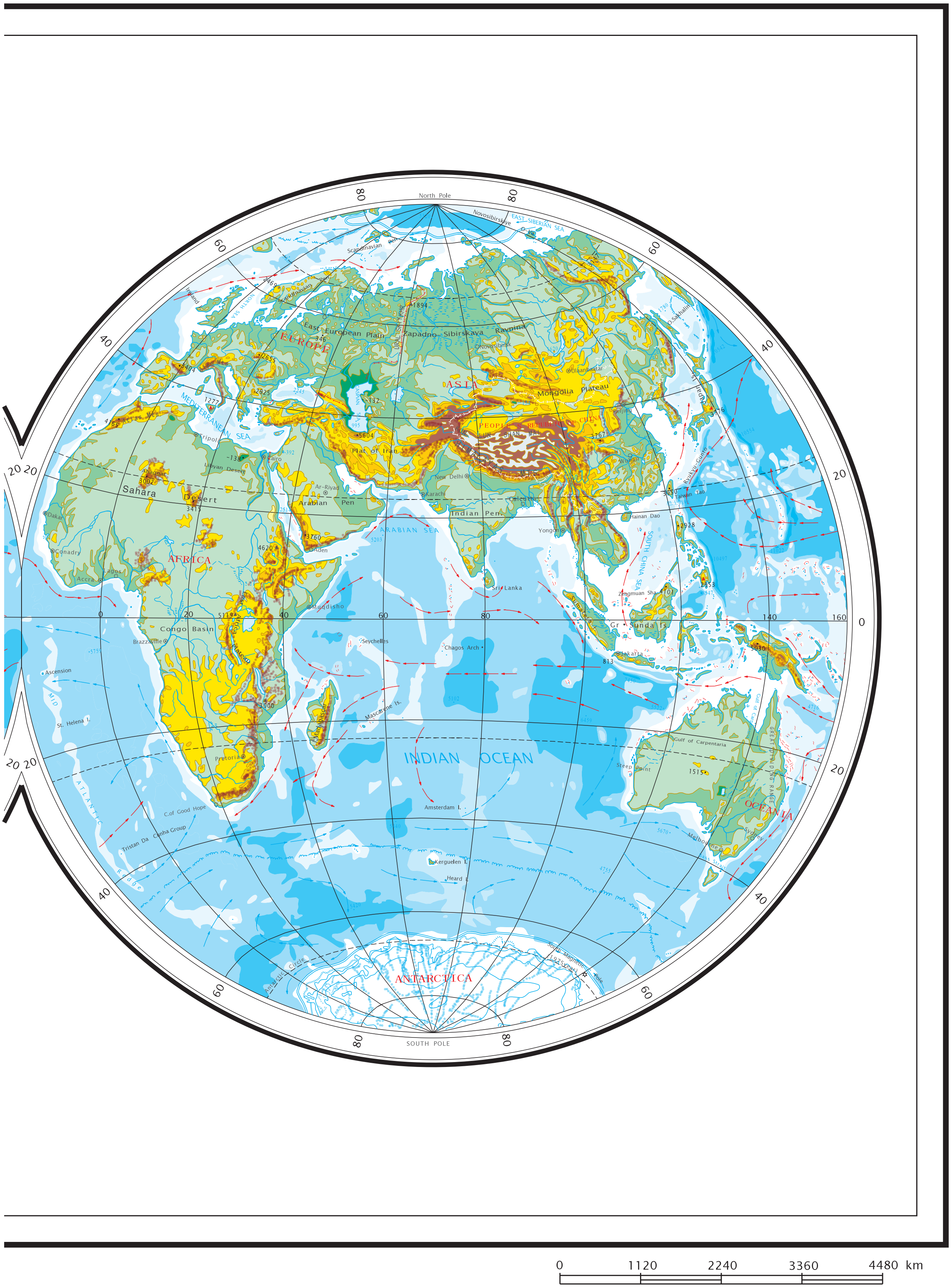
City

Part I

Overview

WORLD TOPOGRAPHY




North Pole
EUROPE
ASIA
AFRICA
OCEANIA
ANTARCTICA
INDIAN OCEAN
ARABIAN SEA
MEDITERRANEAN SEA
SOUTH CHINA SEA
East European Plain
Zapadno Sibirskaya Ravnina
Mongolia Plateau
Sahara Desert
Arabian Pen
Indian Pen
Plat of Iran
Congo Basin
Gulf of Carpentaria
GREAT DIVIDING RANGE
Seychelles
Chagos Arch
Mascarene Is.
Amsterdam I.
Kerguelen I.
Heard I.
St. Helena I.
Ascension
C.of Good Hope
Tristan Da Cunha Group
Gr Sunda Is.
Sri Lanka
New Delhi
Karachi
Aden
Cairo
Tripoli
Pretoria
Brazzaville
Lagos
Accra
Dakar
Conadry
Mogadisho
Jakarta
Yongon
Hainan Dao
Taiwan Dao
Melbourne
Sydney
SOUTH POLE
0 1120 2240 3360 4480 km

1 World Topography

Oceans and continents

Earth has an area of about 510 million km^2 (197 million square miles). Of this total, approximately 360 million km^2 (140 million square miles), or 71 per cent, are represented by oceans and marginal seas. The continents comprise the remaining 29 per cent, or 150 million km^2 (58 million square miles).

Land With an average altitude of about 875 m, land can be classified into continents, islands and peninsula. There are six mainland masses, namely: Eurasia, Africa, North America and South America, Antarctic, and Australia. Islands that are located near each other are called an archipelago.

Oceans Oceans refer to broad and continuous bodies of saline (salty) water on the Earth's surface. They are 3795 m deep on average. There are four oceans on Earth, namely, the Pacific, the Atlantic, the Indian and the Arctic. Seas are the smaller subdivisions of oceans. The largest sea in the world is the Coral Sea located off northeastern Australia with an area of 4.79 million km^2. Seas can be further divided into marginal seas, inland seas and intercontinental seas. Inland seas refer to those seas that extend onto mainland masses and which may connect with marginal seas or even with oceans by narrow waterways. The Bohai Sea and the Baltic Sea are illustrations of this type. A third common type of sea, the intercontinental, separates two or more continental land masses. The Mediterranean Sea is an example of this type.

Land and submarine topography

Land The surface of the Earth varies greatly in height and morphology. Using these two features as defining parameters, land presents itself in five forms: plains, mountains, plateaus, hills and basins.

A plain is a broad area of land with relatively low relief that has no cliffs at its edges. Plains are mostly less than 200 m in altitude and account for just under 35 per cent of the total land area. The largest plain in the world is the Amazon with an area of about 5.6 million km^2.

Mountains are often spectacular features that rise several hundred metres or more above the surrounding terrain. Mountainous areas have large altitudinal variations, steep slopes and great heights. Linearly extensive mountains are called mountain ranges. Adjacent mountain ranges that share similar genesis are called mountain systems. These ranges are mostly distributed in two main belts in the world. One belt comprises the south–north trending coastlines along both sides of the Pacific Ocean. It runs continuously from the tip of South America through Alaska, to ranges in Asia, the coastlines along Oceania as well as the Pacific Ocean, and islands outside marginal seas. The other is a belt that runs generally in an east–west direction, traversing Asia, southern Europe and northern Africa. This belt includes ranges in Java Island and Sumatra, the Himalayas, the Alps in southern Europe, and the Atlas in northwestern Africa.

World Atlas of Oil And Gas Basins, First Edition. Li Guoyu.

Ranges in the above-mentioned belts are typically grand in scope and possess high peaks of above 4000–5000 m. There are 14 peaks with altitude of above 8000 m, most of them are distributed in the Karakorum and the Himalayas Ranges in Asia. Among these peaks, the Qumolangma (Everest) in the Himalayas at an altitude of 8848 m is the highest point in the world.

Plateaus refer to areas with moderately high elevations and relatively flat surfaces and edged by steep cliffs. The world's highest plateau is China's Tibetan Plateau with an area of 2.2 million km^2 and an average altitude of 4500 m. The world largest plateau in area is the Brazil Plateau (Mato Grosso) in South America. Its area is about 5 million km^2.

A basin is a depression in the landscape, typically below the surrounding area, such as Sichuan Basin in China and the Congo Basin in Africa.

Submarine landforms The Earth's surface waters tend to obscure the true nature of submarine landforms. It is known that the submarine topography fluctuates as much as the visible landforms above sea level. Submarine topography can be described as consisting of the continental shelf, the continental slope and the ocean floor.

The continental shelf accounts for approximately 7.5 per cent of the Earth's total sea area. The continental slope is defined as the transitional belt between the continental shelf and the ocean floor. This type of slope is the world's largest. It has gentle inclines and relatively shallow water depths which would typically be no more than 200 m. There are, however, exceptions of up to 500–600 m. The difference in submarine elevation from the continental shelf to the base of the continental slope is about 3,000 m. The continental slope makes up about 12 per cent of the Earth's total sea area.

The ocean floor (also known as the seabed) typically refers to the extension of the continental slope and other continental margin features, such as the continental rise below sea level. the ocean floor is the main physical feature of the Earth's oceans, with depths of between 3000 m and 6000 m. In area, the ocean floor accounts for approximately 80 per cent of the Earth's total sea area.

Submarine topographical features vary greatly, with several different physical features such as ocean ridges, marine basins, ocean trenches, sea knolls, seamounts, and submarine plateaus, to name just a few.

WORLD POLITICAL MAP