Tianfeng Wan

The Tectonics of China

Data, Maps and Evolution

中国大地构造

——数据、地图与演化

高等教育出版社

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Preface

The theory of plate tectonics was introduced to China in the early 1970s. During the last thirty years, both Chinese and foreign geoscientists have undertaken many studies which contributed to our understanding of the tectonics of the Chinese continent, by systematically analysing and summarising considerable amount of data accumulated by regional geological surveys, and by improvements in the methods of research. These studies concerned not only the distribution and geometry of tectono-stratigraphic units and their deformation, but also the kinematics, dynamics and causes of rock deformation and movement of the lithospheric plates. As a result of these studies, many new and surprising phenomena have been discovered, and many new concepts have also been developed. Research has progressed from purely qualitative assessments of the amount of deformation, with the forces and rates of movement involved, to numerical calculations providing more quantitative estimates. Concepts have also evolved from the presumption that the Earth's crust is essentially stable to an appreciation that it is in constant movement. These aspects will be discussed in this book.

Tectonics is now an essential component of studies in Earth Sciences, providing the scientific basis for the discovery and exploitation of new mineral deposits and energy resources, the protection of the environment and the prediction and reduction of the effects of natural hazards. There is an urgent need to summarise systematically the abundant recently acquired tectonic data for scientific research, exploitation of mineral deposits and energy resources and the protection of the environment.

The factual and theoretical basis for studies in tectonics is provided by developments in: (1) Regional geological studies; (2) Tectonic models; (3) Methods of tectonic analysis; (4) Concepts of tectonic evolution.

Regional geological studies provide the foundation for the study of tectonics and have been conducted in China since 1930s. Regional geological maps at 1 : 1,000,000 scale were compiled for the main part of Chinese continental area during 1930s–1940s and at 1 : 200,000 scale from 1950s to 1980s (Published as provincial geological maps of China, 1984–1993). Based on these data, tectonic units have been identified, discussed and analysed carefully in each region (Huang JQ (1904–1995), also known as Huang TK, 1945, 1960, 1964, 1965, 1977, 1984, 1987; Group of Regional Geology, Beijing College of Geology, 1963; Ren JS et al., 1980, 1990, 1996, 2000; Yang and Yang, 1985; Cheng YQ, 1994; Che ZC et al., 2002). Local and regional tectonic characteristics are now well understood, but Chinese geoscientists recognized larger scale tectonic features and integrated the regional pictures into the tectonic development of the Chinese continent comparatively later than the geoscientists abroad as a whole. However, the use of fixed tectonic units does not provide an appropriate basis for the description of the tectonics of China, as during the course of geological evolution the effective tectonic units have changed throughout.

Tectonic models have provided important concepts for understanding tectonics. Li SG (1889–1971, also known as Lee JS, 1926, 1947, 1976) proposed a structural system based on a combination of the features of rock deformation and the different types of stress: $\in$ (epsilon) type; ξ (en echelon) type;

shear structural system; parallel structural system; longitudinal structural system; latitudinal structural system, etc. However, this classification will not be used in the following chapters.

Most recent monographs and textbooks on tectonics (e.g. Condie, 1982, 1997; Kearey and Vine, 1996; Van der Pluijm and Marshak, 1997; Oreskes, 2001; Erickson, 2001) used the same tectonic models: Convergent tectonics (subduction, collision, indentation and thrust belts); Divergent tectonics (oceanic ridges, rifts, extensional basins, detachments and metamorphic core complexes); Transform tectonics (transform and strike-slip faults); Inversion tectonics, acting on earlier tectonic systems. This theoretical system emphasizes the mechanisms and the geometry of each tectonic model, and is easy to be understood. However, this system does not place much emphasis on tectonic history. The system emphasizes the tectonic analysis of specific geological situations, but it is important to realize that geology or geosciences is essentially a historical science, and that many changes and many different tectonic events have affected the lithosphere for more than four billion years of Earth history.

It is really important for us to research the methods of tectonic analysis. However, only emphasizing the methods but never discussing the tectonic evolution in detail, as Ma WP (1992) did, has been proved ineffective.

Many monographs and papers emphasizing the historical aspects of the tectonics of China have been published by Huang JQ (1945, 1960, 1964, 1965, 1977, 1984, 1987), Li CY (1904–1988) (1982, 1984), Wang HZ (1982, 1985, 1990, 1994), Ren JS (1980, 1990, 2000) and Khain and Borhko (1996). These studies are concerned with "Historical Tectonics". On one hand, researchers engaged in historical tectonics pay more attention to stratigraphy and the characteristics of geological formations and their origins, and analyze their lithological and paleontological characteristics, their provenance, environments of formation and the origins of the sedimentary or igneous units, with emphasis on their historical evolution. On the other hand, tectonic modelers pay more attention to the transformation of rock bodies, i.e. rock deformation, structural geometry, kinematics and dynamics, with emphasis on the mechanisms of deformation. Although most researchers engaged in tectonics agree that both geological formation and transformation should be studied, and that historical and mechanical analyses should be combined, due to the differences in training, experience and the focus of their interests, these different approaches may produce different results. Zhang WY (1909–1984) et al. (1959, 1983) advocated that these approaches should be integrated in the study of the tectonics of China. The author considered that it is really important for us to follow these precepts in the present volume, though it is very difficult.

In this book, the author did his utmost to combine the studies of formation and transformation using the plate tectonic theory, together with historical and mechanical analyses. Abundant and recently acquired, geological, geochemical and geophysical research data are applied to describing and discussing the sequence of tectonic events which have affected the Chinese continental lithosphere from the Archean to the Recent. Until the present time, it is difficult to achieve this aim because of the scarcity of data on kinematics and dynamics.

In this volume, for understanding the tectonics of China, the author puts forward many new views: calculating the thickness of the continental crust of the Sino-Korean plate during the Archean and Paleoproterozoic; determining the periods during which the Supercontinent of Rodinia broke up and the continental blocks were amalgamated to form the Chinese continent; establishing the stages during the Neoproterozoic in which tillites were deposited on the Sino-Korean and Yangtze plates respectively; following the changes in the latitudinal and longitudinal distribution of the Chinese continental blocks during the Paleozoic. During the Late Paleozoic and Triassic, most of the continental blocks which constitute China collided and were amalgamated with the Eurasian Plate. Subsequently China continent was affected by intraplate deformation, with three periods of shortening in a near N-S orientation: Indosinian Period (260–200 Ma); Sichuanian Period (135–56 Ma); Himalayan Period (23–0.78 Ma); two periods of shortening with a near E-W orientation: Yanshanian Period (200–135 Ma); North Sinian Period (56–23 Ma). Since 0.78 Ma (Neotectonics Period), the state of stress among the plates which constitute the Chinese continent has been nearly in equilibrium.

In this volume, the characteristics of many collision zones in the Chinese continent are analysed in 3 dimensions and discussed in terms of the thickness of the crust and the lithosphere; a new hypothesis is proposed for the "thinning" of the lithosphere beneath the eastern China continent, which is possibly induced by the counterclockwise rotation of the continental crust extending across onto oceanic mantle; the control of the environment by tectonics is recognized; the influence of intraplate extension during the Mesozoic-Cenozoic on periods of major mineralization in China is made understood; finally, hypotheses about the dynamic mechanisms that control global tectonics are evaluated.

This book was originally written by the author in Chinese and published by the Geological Publishing House in Beijing in 2004. After incorporating many useful comments, the book was translated into English, with a reduction of local terms and the removal of discussions which were not necessary to the foreign readers. Throughout, the emphasis has been placed on large scale features and the major tectonic events which have affected the Chinese continent. Some errors in the initial version have been corrected following the suggestions of experts in specified fields. For the sake of the foreign readers, the latitudes and longitudes of critical localities have been inserted. Original data are recorded in Appendices, and a large number of references are cited, particularly from the Chinese literature, to facilitate further research in Chinese tectonics.

Tianfeng Wan
Beijing October 2010

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Although the preparation of this book is the responsibility of the author, it really represents the collective literary and scientific creation of many researchers, colleagues and friends. I would like to express my heartfelt gratitude for their invaluable help and guidance.

Contents

Chapter 1
Introduction

Tectonics is a comprehensive subject area involved in Earth Sciences concerning the historical development, evolution and origin of the Earth. The aims of this study are to determine the composition, the structure, the movement (including deformation and displacement) and the evolution of the outer sphere of the solid Earth, the lithosphere, and its relationship to activity in the interior, in the lower mantle and the core. This subject area is encompassed in the Theory of Plate Tectonics originating from the investigation of the ocean floors during 1960s, and combined with the theory of continental drift, which was until then not universally accepted, evolving into a comprehensive theory of global tectonics. Results

Fig. 1.1 The geography of China (http://www.sbsm.gov.cn, with permission of State Bureau of Surveying and Mapping, China).

from all branches of the geology, geophysics, and geochemistry, including isotope geochemistry, petrology, stratigraphical paleontology, paleoecology, paleoclimatology and paleogeography contribute to the

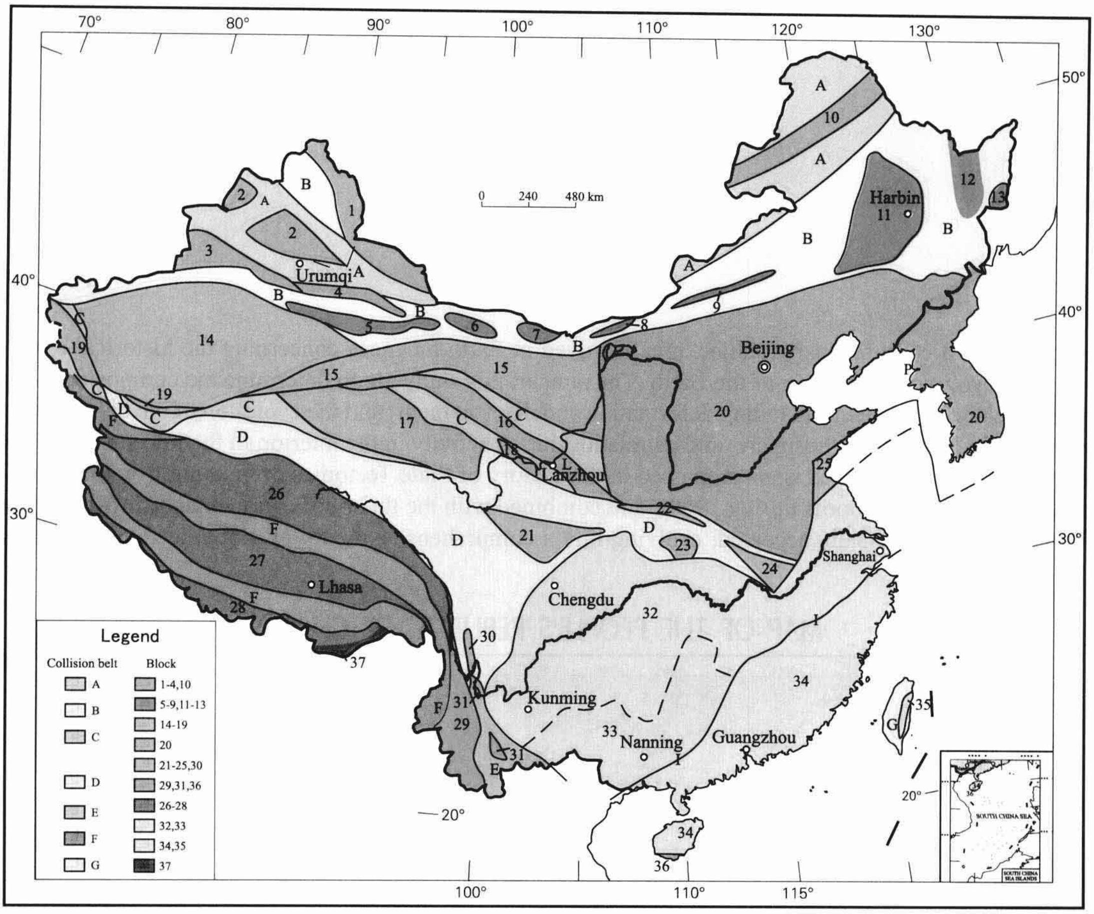

Fig. 1.2 Tectonic units of China during the Paleozoic.

Blocks in the Peri-Siberian Tectonic Domain: 1. Altay; 2. Junggar–East Kazakhstan; 3. Ili–Balchas; 4. Turpan–Xingxingxia; 5. Kuruktag; 6. Hongshishan; 7. Yagan; 8. North Bayannur; 9. Tuotuoshan–Xilinhot (Abagnar); 10. Ergun (close to Gondwana during the Neoproterozoic–Early Cambrian); 11. Harbin (Songhuajiang–Nenjiang); 12. Jiamusi–Bureinskiy (close to Gondwana during the Neoproterozoic–Early Cambrian); 13. Xingkai (i.e. Wandashan, close to Gondwana during Neoproterozoic–Early Cambrian).

Sino-Korean plate (20).

Blocks of the Yangtze Tectonic Domain: 32. North Yangtze Plate; 33. South Yangtze Plate; 21. Songpan–Garze (west Sichuan); 22. Middle Qinling; 23. Wudang; 24. Dabie; 25. Jiaonan (Sulu); 30. Zhongdian; 31. Lanping–Simao–Indosinian Plate; 34. Cathaysian Plate; 35. Taiwan (eastern Cathaysian Plate); 36. Sanya (northeast Indosinian Plate).

Blocks of the Xiyu Tectonic Domain (transition type): 14. Tarim Plate; 15. Altun–Dunhuang–Alxa; 16. Middle Qilian; 17. Qaidam; 18. Hualong; 19. central West Kunlun.

Blocks in the Peri-Gondwanan Tectonic Domain: 26. Qiangtang; 27. Gangdise (Lhasa); 28. Himalaya; 29. Baoshan–Sibumasu (Sino–Burma–Malay–Sumatra); 37. Indian Plate.

Collision Belts: A. Altay–Junggar–Ergun Early Paleozoic Collision Belt; B. Tianshan–South Hingganling Late Paleozoic Collision (eastern part of the Central Asian orogenic) Belt; C. Qilian–Altun Early Paleozoic collision belts in the Xiyu Plate; D. Shuanghu–Lancangjiang (Changning–Menglian), Lazhulong–Jinshajiang, and Qinling–Dabie–Jiaonan Triassic Collision Belt; E. Lanping–Simao Palaeogene Collision Belt; F. Bangong–Nujiang and Yarlung Zangbo River Cretaceous–Paleogene Collision Belt; G. West Pacific Palaeogene subduction zone (trench-arc zone). The Shaoxing–Shiwandashan Triassic Collision Belt is shown as a line between Yangtze Plate and Cathaysian Plate.

development of this subject area, encouraging cooperation of specialists engaged in all the geosciences disciplines in the construction of a comprehensive Earth Sciences system.

In this book, the tectonics of China (Figs. 1.1 and 1.2) is dealt with as a sequence of tectonic events through geological time. A comprehensive analysis of these events is based on the integration of records preserved in the rocks, which provides the evidence of the deformation produced by the movement of continental blocks during processes of the subduction, collision and intraplate compression and extension.

The tectonic systems developed during these events are described in terms of rates of movement, orientation of tectonic stresses, magnitudes of stress, and the timing and rate of deformation. These tectonic and structural aspects are integrated together with the paleo-sedimentary record, paleo-biogeography and tectonic reconstructions of the distribution of continental blocks at different geological periods, based on paleomagnetism, rock deformation and paleo-biogeographical data. As far as possible all these aspects are dealt with in a quantitative and a purely qualitative manner.

The Chinese continent is located in Eastern Asia (Fig. 1.1), composed of the Qinghai-Xizang (Tibet) Plateau, the Inner Mongolia-Ordos-Yunnan-Guizhou Plateau, the Tarim Basin and Junggar Basin and their surrounding mountains, and the eastern plains and hills. Tectonically, the Chinese continent consists of many continental nuclei and small blocks, which were gradually amalgamated to form the present Chinese continent. Until the Paleozoic, 37 tectonic blocks had been identified in the Chinese continent (Fig. 1.2) and classified into five tectonic domains, which will be discussed in detail in later chapters. The evolution of the Chinese continent was very different from the evolution of the North American, South American, Eurasian, African and Australian continental plates.

1.1 Tectonic Events

Concept: Before discussing tectonic events it is necessary to introduce the concept of the tectono-stratigraphic unit (структурный зтаж) first proposed by geologists of the Soviet Union in the 1940s, and introduced in the study of the tectonics of China by Zhang WY (1959). American geologists have also used a similar concept, the “tectonosynthem”, more recently (Muehlberger and Tauyers, 1989).

A tectono-stratigraphic unit encompasses all the tectono-stratigraphic features of a tectonic unit, distinguished by a particular type of deformation developed during a particular tectonic period. In terms of time, a tectono-stratigraphic unit represents a period in the tectonic evolution of the Earth; in space, it covers the area affected by a specific tectonic event (Fig. 1.3).

The boundary of a tectono-stratigraphic unit is taken at a break in sedimentation, marked by a regional angular unconformity which separates two tectono-stratigraphic units (Fig. 1.3). The tectono-stratigraphic unit lies between two angular regional unconformities. An angular regional unconformity is formed when an older rock unit deformed by either compression or extension is then uplifted, eroded and buried by younger rocks. The boundaries of tectono-stratigraphic unit should not be taken at “parallel” unconformities or disconformities, as these do not represent significant tectonic events.

Different tectono-stratigraphic units are characterized by different types, styles and degrees of rock deformation, with different intensity, resulting from different stress orientations in different tectonic environments (Fig. 1.3). The geological time occupied by a tectono-stratigraphic unit is a “tectonic period”. Each tectonic period can be divided into a stable (or “uniform”) period, which lasted for a relatively long period of time, and an active (or “catastrophic”) period which occupied a much shorter period of time at the end of the tectonic period (Table 1.1). Each tectonic period commences with a long, and stable period and ends with a short, and active period. Movement of plates, rock deformation and the related metamorphism and magmatism mainly constitute a tectonic event during the shorter and active tectonic period. By convention, these tectonic events are named after the area in which the tectonism was first recognized. However, if these events are named after their geological or isotopic age, to make

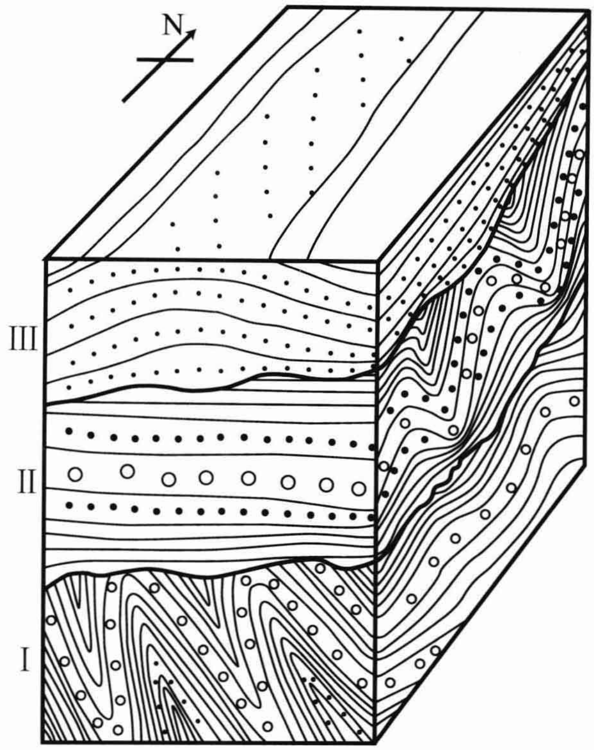

Fig. 1.3 Changes of folding styles and orientation of folding axis in different tectono-stratigraphic units.

Ⅰ. Holomorphic and linear type folds developed in the oldest tectono-stratigraphic unit, in a near north-south direction, slightly influenced by folding with an E-W orientation formed at a later period;

Ⅱ. Transition or Jura-type folds developed in intermediate tectono-stratigraphic unit, on E-W axes;

Ⅲ. Drape or Germano-type folds developed in the youngest tectono-stratigraphic unit, on N-S axes.

international comparison becomes easier. Conventional terms, derived from local tectonic periods or local events, are therefore used as little as possible in this book.

The degree and style of tectonism are different in the stable and active periods, but there is usually some connection and inheritance, for example, the orientation of tectonic stresses and the direction of plate movement may be the same in both periods. However, the styles and rates of rock deformation are very different, the magnitudes of the stresses are different and the types of magmatic activity and metamorphism are also very different (Table 1.1).

1.2 Universal Tectonic Events?

Stille (1876–1966) proposed that there was a rhythm in the tectonic evolution of the Earth and that geological history was punctuated periodically by "orogenic phases", which occurred at the same time in different parts of the world. In the 20th century this principle exerted a great influence on the development of tectonics, but has generated continual controversy since it was first put forward. By contrast, Soviet structural geologists in 1930s considered that rock deformation occurred continuously, with changes taking place over long periods of geological time (e.g. Vasilievsky, 1964), and some American geologists (e.g. Gilluly, 1949) not only disagreed with the concept of phases of universal orogeny, but

Table 1.1 Stable and active periods in Earth's evolution (in the period of several ten million years)

Type	Stable or uniformity period	Active or catastrophic period
Period of time	$\geqslant n \cdot 10^7$ years	$\leqslant n \cdot 10^4 - 10^6$ years
Atmosphere	Stable change of climatic zone and air temperature	Giant change of climate and climatic zone
Hydrosphere	Stable sea level, water quality and water temperature	Giant change of sea level, water quality and water temperature
Biosphere	Stable propagation and resuscitation	Bio-catastrophe
Paleomagnetism	Stable poles and minor motion	Pole reversal
Sedimentation and erosion	Continuous sedimentation, partial erosion	Partial sedimentation, hiatus, seismite, strong erosion
Strata boundary	Conformity or partial geographic conformity	Regional angular unconformity
Geothermal	Stable accumulation, weak geothermal action	Giant geothermal release and reactions
Magmatism	Magma gradually cooling, minor intrusion	Violent intrusion and volcanism
Metamorphism	Burial metamorphism, weak hydrothermal effects	Regional and dynamo-metamorphism, violent hydrothermal effects
Tectonic stress	Gradual accumulation and revision, small differential stress	Stress increase and release, giant differential stress
Vertical motion of plate	Stable depression and uplift, $\leqslant 0.1$ mm/yr	Strong depression and uplift, $\geqslant 1.0$ mm/yr
Horizontal motion of plate	Weak, $\leqslant n$ mm/yr	Strong, $\geqslant n$ cm/yr
Rock deformation	Slight or bending folds, small fracture	Strong, every type of fold and fault developed
Astronomy	Solar system deviate galaxy disk	Solar system just across the galaxy disk
Meteorite Impact	Small and weak impacts	Major impact

supposed that tectonism had occurred continuously throughout the whole evolution of the Earth (Wang HZ, 1990). In the 1970s–1980s, based on the recognition that sea-floor spreading was a continuous process, the appreciation that syn-sedimentary structures had developed over long periods of time, and the scarcity of unconformities in thrust zones or within orogenic belts, fewer geologists were willing to accept Stille's (1924) proposition. At present, the consensus view is that the Earth is a rheomorphic solid and is able to flow continuously under differential pressure, so that tectonism and orogeny have occurred uniformly, throughout geological time and that there has been no periodicity or rhythm during the tectonic evolution of the Earth (e.g. Gretener, 1981; Sengör, 1982; Hsu, 1989; Li JL, 1991; Zhu ZC, 1996).

Wang HZ (1982, 1985, 1990) advocated the concept of "mobilism" for the tectonic evolution of China, in which deformation had occurred during episodes of tectonic activity, periodically in different areas and at different time. From a comprehensive assessment of a large volume of tectonic data, Wan TF (1997) concluded that there is no evidence that important tectonic events occurred at the same time in different parts of the Earth. However, it is evident that tectonism has occurred over very large areas at approximately the same time in subduction zones, in collision zones and in areas of intraplate deformation. For example, Caledonian tectonic events occurred at almost the same time (429–425 Ma) in a zone extending all the way from the Appalachian Mountains in eastern America to Scotland and the western margins of the Scandinavia (Rogers and Dunning, 1991; Bally et al., 1989; Trewin, 2002). Similar extensive tectonic events have occurred in China, which will be detailed in the following chapters.

According to Hsu (1989) and Sengör (1982), if the Earth is a rheomorphic solid, periodicity would not appear in tectonic evolution on the scale of the Earth. According to the concept of mobilism, orogeny is a continuous and uniform process. When the plate tectonic theory was first proposed and data on sea-floor spreading was limited, this opinion seemed to be sustained. The original map showing the pattern of magnetic anomalies on the floors of the oceans implied that sea-floor spreading was a continuous process, in which the floors of the oceans expanded continuously in the same direction, only varying slightly in their velocity and direction of movement with time (Wilson, 1970; Le Pichon et al., 1973; Press and Siever, 1974). Given the relationship between the expansion of the oceans at mid-ocean ridges and their destruction in subduction zones along the margins of the oceans, it could easily be assumed that the processes of subduction and collision were also continuous processes. However, Hsu (1989) and Sengör's (1982) hypotheses contradicted many discovered tectonic facts before 1980s. When the much more detailed third edition of the magnetic anomaly map was published at the end of the 1980s (Cande et al., 1989; Cande and Kent, 1992; Ma ZJ et al., 1996), analysis showed that since the Middle Jurassic (156.6 Ma), the Pacific, Atlantic and Indian Oceans had all expanded during the same six periods, with movements in different directions and at different velocities (Table 1.2; Fig. 1.4). Sea-floor spreading at velocities of several cm/yr shows that the Earth has the properties of a rheologic solid, while the process shows some periodicity. It seems that both arguments are to some extent correct with general continuity, and a superimposed element of periodicity.

Evidence compiled in this volume shows that the tectonic evolution of the Earth has not become linear, with a uniform rate of change, but non-linear, with periodic variations in the rate of change. From our present evidence it appears that the processes continue over a period of time at a more or less constant rate, but are then interrupted by sudden and catastrophic changes. Such qualitative and quantitative changes are characteristic of all evolutionary processes. As Yu CW (2003) has explained, tectonism, like all other geological processes, should be considered in terms of non-linear dynamics in an unstable system. The evolution of the Earth systems should be studied using the complexity—"Chaos" theory.

In the past two hundred years, there has been a lively geological debate between proponents of uniformitarianism, who argue that geological processes have continued in much the same way and at the same rate throughout geological time (Hutton, 1785; Lyell, 1830–1833) and proponents of catastrophism, who argue that geological processes proceed by infrequent but catastrophic events (Cuvier et al. , 1817). At present, most Earth scientists agree that these concepts can be reconciled. It is recognized that there are stable periods (or periods of uniformity) lasting over a long time span, which alternate with active (or catastrophic) periods, occupying a much shorter time span (Tao SL et al., 1999); tectonic events represent this catastrophic period (Table 1.1).

Tectonic events are difficult to resolve, as their complete history is rarely preserved in the geological record. The evidence is never complete. Strong deformation, block displacement, violent magmatism and large-scale uplift of the Earth's surface have resulted in widespread erosion, forming unconformities, where the geological record has been destroyed. For this reason the study of tectonics did not advance very rapidly in many parts of the world. In many areas, facts are few, tectonic and geodynamic data are scarce; the geological literature demonstrates that these deficiencies do not deter geologists from engaging in much speculation and guesswork.

Table 1.2 Periods in the accretion of the ocean floor for the Pacific, Atlantic and Indian Oceans

0 Ma	6 stage
10 Ma	5 stage
37 Ma	4 stage
58 Ma	3 stage
97 Ma	2 stage
138 Ma	1 stage
156.6 Ma	

After Cande and Kent, 1992; Ma ZJ et al., 1996.