DEPARTMENT OF THE INTERIOR
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Notes on Sedimentary Basins in China --- Report of the American Sedimentary Basins Delegation to the People's Republic of China

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NOTICE

The views expressed in this report are those of the members of the Sedimentary Basins Delegation and are in no way the official views of the Committee on Scholarly Communication with the People's Republic of China or its sponsoring organizations -- the American Council of Learned Societies, the National Academy of Sciences, and the Social Science Research Council. The visit -- consisting of a bilateral workshop and field trip -- was part of the exchange program between the two countries and was supported by the National Academy of Sciences in the United States and the China Association for Science and Technology in China, with the Chinese Petroleum Society bearing special responsibilities as host. U.S. funding was provided by the National Science Foundation.

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SEDIMENTARY BASINS IN CHINA

Table of Contents

Page

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LIST OF FIGURES AND TABLES

LIST OF APPENDICES

SEDIMENTARY BASINS IN CHINA

1. Summary (AWB)

This report summarizes selected impressions obtained by the American Sedimentary Basins delegates during their visit to China in the late summer of 1985.

Sedimentary basins in China may be subdivided into extensional basins in Eastern China; basins associated with thin-skin decollement tectonics in Central China; and compressional basins associated with basement-involved thrust faulting and strike slip faulting in Western China. Other classifications are conceivable, but because basin classifications do not find hydrocarbons, we suggest that any concerns with classifications are less important than the careful analysis of all relevant data.

Superb seismic reflection profiles of the Chinese Petroleum Industry, which unfortunately are not published, reveal the details of the extensional history of Eastern China. Extension differs in age from basin to basin but starts in the early Mesozoic and ranges into the late Tertiary and Quaternary. We recommend that detailed kinematic studies and model studies be undertaken.

Basins associated with decollement tectonics (e.g., Sichuan and Ordos Basins) also require detailed kinematic studies that are based on reflection profiles, the application of balanced cross-sections, and model studies.

The delegation devoted much time to the compressional basins in Western China, in particular to the Qaidam Basin. These basins acquired their individual identity as a consequence of the India-Eurasia collision. They are characterized by late Paleogene to Neogene overthrusting and/or strike slip faulting. All of the basins have significant thicknesses of continental-lacustrine sediment of Mesozoic and Tertiary age, but the pre-Mesozoic history of these basins varies widely, e.g., marine Paleozoic in the Tarim Basin, mostly continental Paleozoic in the Junggar Basin, and strongly deformed Paleozoic folded belts in the Qaidam Basin. Here again we recommend that regional studies should be undertaken that reconcile the reflection seismic data with surface observations and geochemical data. Such studies should be supported by theoretical model studies.

We feel that the remaining hydrocarbon exploration potential of China is very large. This report contains a number of specific suggestions that may help to unlock that potential. Significant progress in understanding of the geology and the economic potential of the sedimentary basins in China will be achieved following integrated studies. We also recommend that an institute for advanced studies in sedimentary basins be set up in China. Progress in training could be achieved following a relaxation of the confidentiality rules that currently restrict access to geophysical data.

2. Introduction and acknowledgments (AWB & ABW)

The visit of the American Sedimentary Basins delegation to China was planned with the intent of bringing together Chinese and American scientists who were interested in the origin and evolution of sedimentary basins. Our main focus was on basic research as opposed to exploration for hydrocarbons. The latter, of course, is the subject of numerous visits and business discussions between Chinese and many Western petroleum companies. We felt that emphasis on some basic research aspects may help the long-range exploration efforts in China.

Our visit lasted from August 17 to September 8, 1985 and can be roughly subdivided in two segments: (1) Workshop, exhibit visit, and discussion under the auspices of the Chinese Petroleum Society and the Bureau of Geophysical Prospecting, Ministry of Petroleum Industry; (2) Discussions and field trip in Qaidam (Chaidamu) Basin under the auspices of the Petroleum Bureau of Qinghai Province. Most of the discussions there were held on two days in Dunhuang, Gansu Province, and during the field trip in Qinghai Province.

Professor Tian Zaiyi of the Chinese Petroleum Society spared no efforts to prepare for the visit and to organize the many meetings and field trips that were a vital part of this activity. The success of our visit is in large part due to his kind and generous efforts. Amy Wilson of the CSCPRC efficiently looked after all of the administrative arrangements for this activity on the American side. We all are most grateful for her friendly and patient understanding and for being a marvelous travel companion. Amy Wilson also helped us all with the editing of this report.

Appendices A-1 and A-2 list individuals whom we met in China and their affiliations. We are grateful for their interested and active participation during our meetings and during the field trip in the Qaidam Basin.

The American delegation was composed of a number of specialists as follows: Hans Eugster (deposition of source beds in evaporitic lacustrine environment), Tony Watts (basin modeling), I-Ming Chou (geochemistry and technical interpreter), Rob Clayton (seismic data processing and tomography), and Susan Kidwell (stratigraphy and taphonomy). The experience of these delegates has mostly been in academic research, while the balance of the delegation has had much direct experience in hydrocarbon exploration, i.e., Larry Meckel (exploration for stratigraphic traps and unconventional gas reservoirs), Bob Ryder (stratigraphy and exploration in Rocky Mountain Basins), and Bert Bally (general exploration, and particularly exploration of folded belts). Pete Vail (seismic stratigraphy) unfortunately had to cancel out of the visit at the last moment. Appendix B lists the members of the American delegation and their affiliations.

We wanted to share with our Chinese colleagues our views on how academic research can interact with exploration geology. All delegates submitted reprints and up-to-date information to our Chinese colleagues. These papers are listed in Appendix C and, in addition to other papers, will be referenced in this report. Our report is a joint effort, but occasionally we will emphasize specific areas of interest of the individual members of our delegation.

Our Chinese colleagues prepared a number of significant reports on specific topics. These are listed in Appendix D, whereas Appendix E indicates the conference program. We expect this material to be published in China, together with this report. To emphasize some points in this report, we selected a few illustrations offered to us by our Chinese colleagues.

Our report only highlights selected topics, and there is no intention to describe completely the sedimentary basins of China. Some topics pertain directly to Chinese geology; others are of a more central nature. The latter were included because we felt they pointed to future research directions in China. We assume that the reader of this report has some familiarity with the large geological literature available on the sedimentary basins of China. Our report also does not include any descriptions of Chinese petroleum or natural gas accumulations, even though some of the delegates are reasonably familiar with these accumulations.

We have added a number of illustrations to our report, but here again the reader is referred to the many publications on the geology of the sedimentary basins of China. Although all delegates contributed to many parts of the report, the initials of the main authors of the report are indicated in brackets with each chapter heading. (For a code see footnote of Table of Contents.) Thus any opinions expressed tend to be mainly those of the chapter authors.

We felt the need to make some recommendations. These are highlighted in bold type throughout the report so that they may be understood better within the proper context. Our hope is that this report - like our trip to China - will lead to greater cooperation between the sedimentary basin researchers of China and the United States.

We thank Amy Wilson for editing this report with unusual patience. We also thank Liu Chingju (Rice University) for drafting a number of our illustrations. Last, but certainly not least, we thank Bobbie Williams (Rice University) for typing this manuscript and for bearing with the many revisions of this report.

3. The classification and origin of sedimentary basins (AWB)

We were surprised to see the extraordinary interest of our Chinese colleagues in basin classification (Chen et al., 1985; Guo Lingzhi et al., 1985; Zhai Guangming et al., 1985). This interest was possibly due to the fact that one of us some years ago published a basin classification (Bally 1975; Bally and Snelson 1980; St. John, 1984). Note also that recently a more complex classification was published by Kingston et al., 1983.

In our view, basin classifications are of very limited utility. They serve mostly to provide general guidance regarding structural style and depositional cycles within a basin. Basin classifications at best serve as general background for potential reserve forecasts. On the other hand and more importantly, exploration priorities should not be set by basin classifications. Typically priorities are controlled by knowledge of the degree of past exploration in a basin, by basin analysis methods that incorporate all relevant information of the oil system (i.e., source bed, seal, reservoir, and trap), and by economic and political factors (see Kingston et al., 1983a,b). Basin classifications do not find oil!

In China it is nonetheless useful to group hydrocarbon exploration provinces in three main groups (see map Figure 1): (1) extensional basins, (2) thin-skinned foreland foldbelts and associated basins, and (3) basins associated with compressional basement uplifts. It is important to note that our Chinese colleagues are quite correctly conscious of the fact that each basin may have remnants of an ancestral history that preceded its individualization as a present-day basin, e.g., the Sinian-Paleozoic North China platform has preCambrian basement, but smaller extensional basins were later superimposed discordantly on the platform during various Tertiary stretching events. In contrast, the Songliao Basin with its giant Daqing oil field is initiated by a Jurassic-Lower Cretaceous extensional event that is mostly superimposed on a Paleozoic basement. In the Junggar Basin we recognize pre-Jurassic thrust faulting, early Mesozoic extension, and yet the present shape of the basin is due to Tertiary compression.

The main reason why basin classifications are so unsuccessful as predictors of hydrocarbon potential is that they are based mainly on structural and sedimentologic criteria. The richness of sedimentary basins, however, is mostly dependent on the presence or absence of various types of source beds. Whereas organic geochemical methodology has made giant progress during the last decades, published information regarding the distribution quality and maturation of source beds for most basins of the world is woefully lacking. In the absence of such published information it is unlikely that any worldwide basin classification will be of much use in predicting the overall hydrocarbon potential of the sedimentary basins of China.

Figure 1

Major sedimentary basins of China, after data from the Ministry of Petroleum Industry and Zhai Guangming et al., 1985

Three basic basin types are differentiated:

a) pull-apart (extensional) basins in Eastern China;

b) basins associated with thin-skin decollement tectonics in Central China;

c) compressional basins associated with basement-involved thrust faulting and strike slip faulting in Western China.

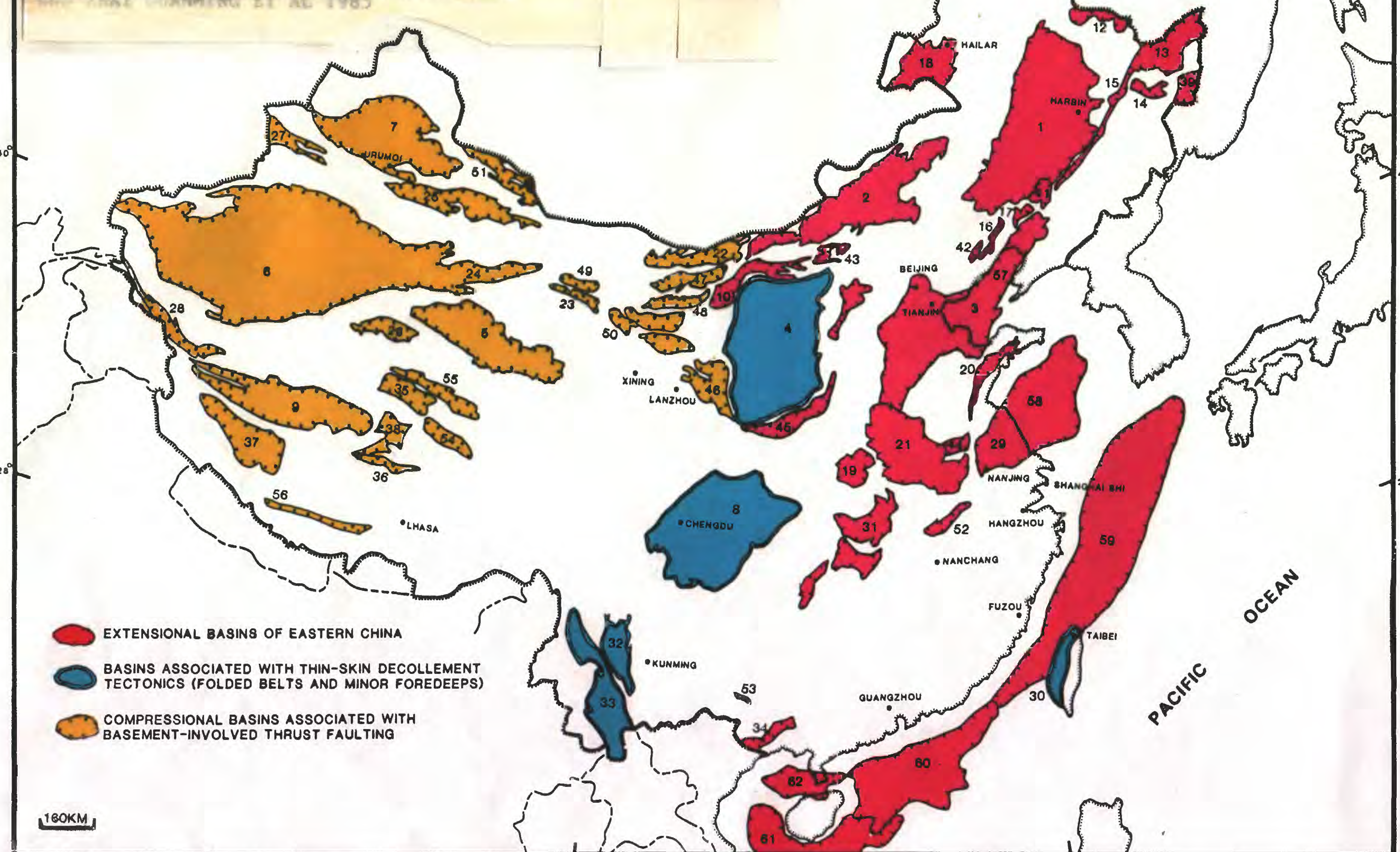
Legend: (Major Exploration Provinces of China)

BASINS:

1. Songliao
2. Erlian
3. Bohai Wan
4. Shaanganning (Ordos)
5. Qaidam
6. Tarim
7. Junggar
8. Sichuan
9. Qiangtang
10. Hetal
11. Mohe
12. Jiayin
13. Sanjiang
14. Boli
15. Yilan-Yitong
16. Jinlingsi-Yangshan
17. Zhongua-Heishan
18. Hailar
19. Nanyang
20. Jialai
21. Nanhuabei
22. Inggen
23. Jiusi
24. Dunhuang
25. Turpan
26. Kumkulig
27. Ili
28. Kunjirap
29. Subei
30. Taiwan
31. Jianghan
32. Chuxiong
33. Janping-Simao
34. Shiwan Dashan
35. Wulan Hu
36. Baingoin
37. Anglaren
38. Andel Hu
39. Hulin
41. Tieling-Changtu
42. Jianchang-Kazuo
43. Wulanhua
44. Guzhen
45. Wei He
46. Liupan Shan
47. Bayanmudu
48. Yarbulai
49. Huahai-Jinta
50. Minle
51. Santanghu
52. Wangjiang
53. Bose
54. Wenquan
55. Hoh Xil
56. Xigaze
57. Bohai
58. Nanhuang Hai
59. Dong Hai
60. Zhujiang Kou
61. Yinggehai
62. Beibu Wan

MAJOR EXPLORATION PROVINCES OF CHINA

MODIFIED AFTER DATA FROM THE MINISTRY OF LEUM



References*

Bally, A. W., 1975, A geodynamic scenario for hydrocarbon occurrences. 9th Petroleum Congress Proceedings v. 2, p. 33-44.

Bally, A. W. and S. Snelson, 1980, Realms of subsidence, in A. D. Miall (ed.), Facts and Principles of World Petroleum Occurrence. Can. Soc. Pet. Geol. Mem. G, p. 6-75.

Chen, H. J., Z. L. Sun, and Y. C. Zuang, 1985, Framework of Chinese Petroliferous Basins, Central Laboratory of Petroleum Geology, Ministry of Geology and Mineral Resources, Zhuoxian.

Guo Lingzhi, Shi Yangshen, Ma Ruishi, Lu Huafu, Dong Huogen, and Wu Baoquing, 1985, Dept. of Geology, Nanjing University, Scientific Conference Thesis of Sino-American Petroleum Sedimentary Basins, Zhuoxian.

Kingston, D. R., et al., 1983a, Global basins classification system, AAPG Bull., c. 67, No. 12, p. 2175-2193.

Kingston, D. R., et al., 1983b, Hydrocarbon plays and global basin classification, AAPG Bull., c. 67, No. 12, p. 2194-2198.

Klemme, H. D., 1975, Giant oil fields related to their geologic setting, Bull. Can. Soc. Pet. Geol., v. 23, p. 30-60.

Klemme, H. G., 1980, Petroleum Basins - Classifications and Characteristics, J. Petroleum Geology, v. 3, No. 2, p. 187-207.

St. John, B., 1984, Sedimentary Provinces of the World, AAPG Map Library.

Robertson Research International Ltd. and Bureau D'Etudes Industrielles et de Cooperation de L'Institut Francais du Petrole, 1979, The People's Republic of China, Its Petroleum Geology and Resources, Gwynedd, Wales.

Weng Wenbo, 1981, Evaluation of an oil and gas basin at its early stage of exploration, Acta Petrolei Sinica, v. 2, No. 1, p. 1-6.

Zhai Guangming, Wang Shenyang, and Li Gasheng, 1985, Characteristics of Sedimentary Basins in China and their Oil and Gas Distribution, in J. S. Mok, editor, Well Evaluation Conference of China, 1985, Schlumberger China.

Zhang Kai, Luo Zhili, Zhang Quing, Dai Jinxing, Yao Huijun, 1980, Classification of basins and potential hydrocarbon resources in China, Acta Petrolei Sinica, v. 1, No. 4, p. 1-18.

Zhang Wanxuan, 1981, On classification of petroleum pools and the types of petroleum pools in China, Acta Petrolei Sinica, v. 2, No. 3, p. 1-11.

*NOTE: This reference list includes titles that are not cited. It was felt the additional references may be useful for the reader.

4. <u>A discussion of extensional basins in China</u> (AWB, ABW)

Papers by Li Desheng (1980), Ma Xingyuan et al. (1982), Wang Hongzhen et al. (1982), Yan Dunshi et al. (1980), Zha Quanheng (1984), Zhai Guangming et al., (1982), and Zhang Wenyou et al. (1982) have provided good overviews. For our discussion of extensional basins we would like to list a few points that appear to us important.

(1) We were greatly impressed by the quality of the regional seismic reflection profiles displayed in the exhibit at Zhuoxian. There is little doubt that our Chinese colleagues have some of the best examples of half-graben tectonics and listric normal faults in the world. Such tectonics are now reported from many areas, e.g., North Sea, Suez basins, East African rifts, Atlantic-type continental margins, Rhine graben, offshore Newfoundland, Rio Grande rift, and the U.S. Basin and Range.

It is surprising in this regard that these kinds of features are not yet illustrated in the most modern textbooks of structural geology in the U.S. and that we lack adequately documented and published three-dimensional kinematic reconstructions of these important features. The reasons for the absence of adequate models are data confidentiality and the low priority that most oil companies place upon time-consuming kinematic studies.

Kinematic studies of half-graben systems are important for hydrocarbon exploration because such studies allow us to determine hydrocarbon migration paths through time. This kind of analysis is particularly important in basins that were subjected to later inversions.

The main unresolved problems in the exploration of extensional basins are:

-- The nature of displacement transfers particularly the direction of transfer faults that segment half-graben systems (see Figure 2);

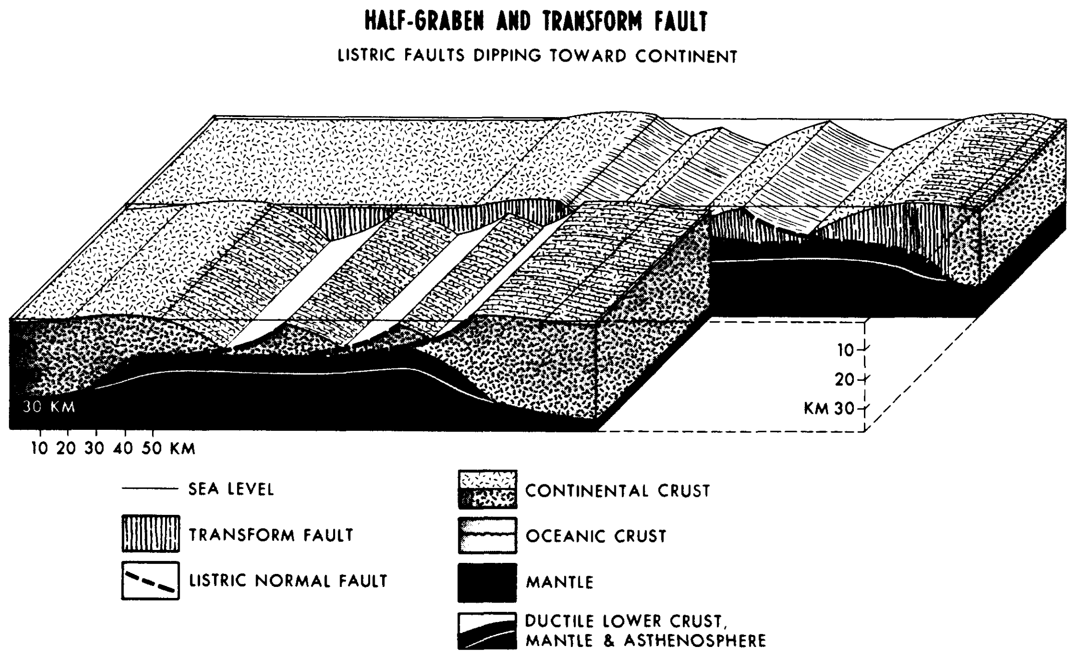
--Criteria that permit one to recognize dip-slip listric normal faults on seismic reflection sections, and to differentiate these from oblique and strike slip transfer faults;

--The relation of inversion structures to pre-existing extensional systems.

All these problems can best be resolved by a regional study of the entire extensional system based on a tight grid of seismic reflection profiles.

<u>Recommendation:</u> **It is recommended that the geologists and geophysicists of the Ministry of Petroleum Industry form a study team that undertakes a detailed regional kinematic structural study of Chinese extensional systems, with careful emphasis on transfer fault systems, dip-slip systems, and their evolution through geologic time. Emphasis should also be on the nature of inversion (see below).**

(2) A short comment on basin inversion may be in order. Inversions are defined as modification of originally extensional systems by later compressional forces (see Figure 3 and Bally, 1984; Lowell, 1985 p. 437-446). Such inversions profoundly modify hydrocarbon migration paths. Very little of substance has been published on inversions; however, the concept is quite familiar to petroleum geologists working in Northwest Europe (e.g., North Sea, Polish Trough, etc.), in Indonesia's back-arc basins (where inversions mark the initial phase of the



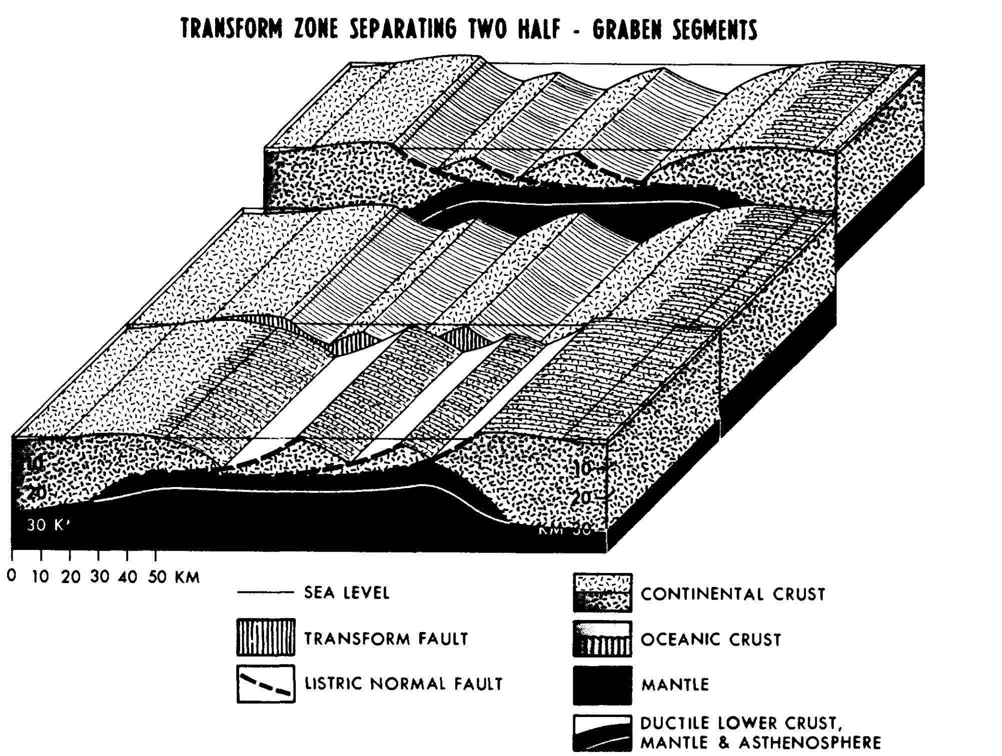


Figure 2

Transfer faults separating segments of half-grabens with changing vergence. In these block diagrams it is assumed that extension was at right angles to the strike of the half-grabens. More frequently the transfer faults have a strike that is oblique, say 20-35 degrees to the strike of the half-grabens.

Note also that there are a number of other possible relay systems that link half-grabens among each other (see Lowell 1985).

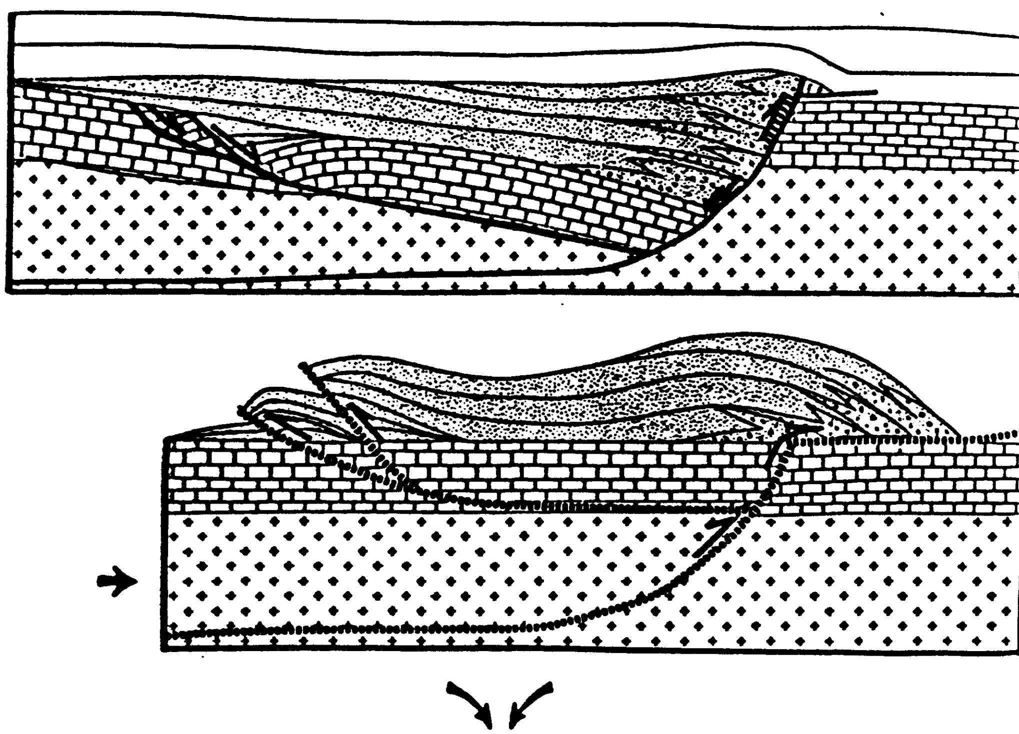


Figure 3

The top of the figure illustrates a mini-inversion of a half-graben. The sedimentary volumes have been balanced. The bottom of the section illustrates a complete inversion, which in effect restores the pre-rifting sequence to its original width. The figure is a simple geometric exercise to illustrate the volumetric problems associated with the inversion of a half-graben. In reality, the load of the inverted graben will lead to the formation of small foredeep-like depressions on both sides of the inverted wedge. The arrows on the bottom section illustrate two alternatives. The first alternative suggests subduction of the underlying crustal and mantle layer, which should lead to the formation of a root under the inverted half-graben (converging double arrows), and the second alternative illustrates inversion due to a distant "push" along an intracrustal coupling level. (Bally, 1984) collapse of the basin in a folded belt), in North Africa, and in other regions. Curiously, the concept of inversion has not yet reached the consciousness of geologists working on North American geology, although the Uinta Mountains of the U.S. and the Richardson Mountains of Northern Yukon provide fine examples. Many of the mountain systems of California appear to be inversions, and seismic reflection profiles of many basins in California show inversions.

On our visit to the geophysical exhibit in Zhuoxian we saw some splendid examples of inversion tectonics in China. The most important of these in terms of hydrocarbon production is the Daqing structure, but similar features are also indicated in the Western Bohai Basin and in a number of other extensional basins. Similar inversions occur in the Chinese offshore basins. A nice example of inversion tectonics is illustrated by Zha Quanheng (1984) under the name of compression torsional anticlines (Figure 10 of that paper). One gains the impression that most inversion tectonics in Eastern China are related to the far-reaching effect of the collision of India with China. But any such speculation would need to be documented in the study proposed by the previous recommendation.

(3) The regional timing of the opening of extensional basins: Li Desheng (1980) has outlined the polycyclic character of the Bohai Basin. Guo Lingzhi et al. in the paper submitted to the meeting at Zhuoxian quite correctly emphasized the back-arc type origin for many of the extensional basins in China. As a first illustration this concept could be easily shown by a simple map that indicates the age of inception of extension in each of the basins of Eastern China and relates that age to the radiometric and geologic ages of the acidic and basic island arc type intrusives of Eastern China.

Such a map would also show that other groups of extensional basins are due to the collision of India with Eurasia - for example, all of the half-graben system surrounding the Ordos Basin.

<u>Recommendation:</u> **Geologists from the Ministry of Petroleum Industry should combine efforts with geologists from the Ministry of Geology and the Academia Sinica (Chinese Academy of Sciences) to produce a map that shows 1.) the inception of extension as documented by seismic reflection profiles and wells and 2.) the age of ancient island-arc complexes as documented by radiometric and stratigraphic ages of acidic and basic intrusives and volcanics. Such a study would enable petroleum geologists to relate the timing of basin formation to the deposition of hydrocarbon source beds.**

(4) The relationship of source beds to extensional half-graben systems needs to be documented in specific detail. We will come back to source bed documentation in a later section of this report, but in the context of extensional tectonics a few important points should be made. There is a great need for cross sections based on seismic reflection profiles and E-Logs that show the specific location of source bed layers and their measured maturity (vitrinite reflectance, paraffin distribution, etc). A study of the sedimentary environment of each lacustrine source bed would also be important.

While it is assumed that most source beds in Eastern China derive from lacustrine basin fills, one wonders whether additional source beds may not be available from the platform sequences that underlie the extensional basins. In the area of the old North China platform, such a Paleozoic source - if not overmature - could be quite attractive. If such source beds have not yet been found, it may be worthwhile to make systematic stratigraphic studies to see whether in some areas such source beds may occur.

We will sum up our recommendations regarding source beds under a special chapter concerned with source bed studies. (See Chapter 12.)

(5) In the context of this discussion it is useful to point out the progress that has been made in recent years in basin modeling of extensional basins. Of particular note has been the development of models by Steckler and Watts (1981), Beaumont et al. (1982), Watts and Thorne (1984), Keen (1985), and others to explain the evolution of extensional basins in Atlantic-type continental margins. Although the individual features of these models vary, their main features may be summarized as follows:

a) tectonic subsidence (i.e., that part of the subsidence not caused by sediment and water loading) occurs by thermal contraction/uplift of the lithosphere during and following heating and thinning of the lithosphere at the time of rifting.

b) sediment and water loading causes flexure of the lithosphere.

c) the temperature structure of the lithosphere determines its flexural rigidity, so that as the lithosphere cools following a rifting event, its rigidity progressively increases with age.

Most models for extensional basins now incorporate the effects of lateral changes in the amount of extension across a basin, and some include the additional effects of sea-level changes, compaction, and erosion (e.g., Watts and Thorne 1984) and active heating because of dynamic processes in the lower part of the lithosphere or sub-lithosphere (e.g., Keen, 1985).

The appeal of the modeling of extensional basins to oil exploration is that models help to understand the maturation of source beds through time. Extensional basin models combine the effects of thermal contraction/uplift with sediment loading. It is therefore possible to use the models to compute the temperature in the sediments in a basin through time and hence the temperature history. The maturation of hydrocarbons depends on the temperature history of sediments. By superimposing contours of equal maturation on a stratigraphic cross-section of the basin, the basin model can be used to estimate where and at what depth in a basin a particular source bed would be mature. McKenzie et al., 1985, for example, have shown that there is good agreement between the predicted maturity based on basin models and observed values based on the kinetics of specific geochemical relations.

We recommend that the study of extensional basins in China be accompanied by the development of theoretical basin models. Such a project could be jointly undertaken by the Ministry of Petroleum Industry in conjunction with Chinese and U.S. university researchers. Although a number of Chinese extensional basins could be studied, the project should initially begin by focusing on one of the relatively straightforward offshore extensional basins. The following data sets would be required for the project:

1. **Geological maps of onshore regions;**
2. **Regional seismic reflection profiles;**
3. **Well data (sonic, porosity, depth to top of formations) from at least one point along each seismic reflection profile.**

References*

Bally, A. W., 1984, Tectogenese et Sismique Reflexion, Bull. Soc. Geol. de France, v. 26, p. 279-285.

Beaumont, C., C. E. Keen, and R. Boutilier, 1982. On the evolution of rifted continental margins: Comparison of models and observations for the Nova Scotian margin, Geophys. J. R. Astr. Soc., 667-715.

Chen Binghua, 1980, On the relation between the distribution of the buried hill oil fields and the evolution of paleostructures and paleogeomorphological features in middle Hebei, Acta Petrolei Sinica, v. 1, No. 4, p. 49-55.

Guo Lingzhi, Shi Yangshen, Ma Ruishi, Lu Huafu, Dong Huogen, and Wu Baoqing, 1985, Dept. of Geology, Nanjing University, Scientific Conference Thesis of Sino-American Petroleum Sedimentary Basins, Zhuoxian.

Keen, C. E., 1985. The dynamics of rifting: deformation of the lithosphere by active and passive driving forces, Geophys. J. R. Astr. Soc., 80, 95-120.

Li Desheng, 1980, Geology and structural characteristics of Bohai Bay, China, Acta Petrolei Sinica, v. 1, No. 1, p. 6-20.

Li Desheng, 1982, Tectonic types of oil and gas basins in China, Acta Petrolei Sinica, v. 3, No. 3, p. 1-12.

Lowell, J. D., 1985, Structural styles in petroleum exploration, Oil & Gas Consultants Int. Publications, Tulsa, 459 pp.

MacKenzie, A. S., C. Beaumont, R. Boutilier, and J. Rullkötter, 1985. The aromatization and isomerization of hydrocarbons and the thermal and subsidence history of the Nova Scotia margin, Phil. Trans. R. Soc. Lond., A315, 203-232.

Ma Xingyuan et al., 1982, Meso-Cenozoic taphrogeny and extensional tectonics in eastern China, in Symposium on Mesozoic and Cenozoic geology, in celebration of 60th anniversary: Geology Society of China, p. 67-68.

Steckler, M. S., 1985. Uplift and extension at the Gulf of Suez - Indications of induced mantle convection, Nature, 317, 135-139.

Steckler, M. S. and A. B. Watts, 1981. Subsidence history and tectonic evolution of Atlantic-type continental margins, Amer. Geophys. Union, Geodynamics Series 8, p. 184-196.

Tong Chongguan, 1980, Some characteristics of petroleum beology of the rift system in eastern China, Acta Petrolei Sinica, v. 1, No. 4, p. 19-26.

Wang Hongzhen et al., 1982, Mesozoic and Cenozoic basin formation in East China and adjacent regions and development of the continental margin, Symposium on Mesozoic and Cenozoic geology, in celebration of 60th anniversary: Geology Society of China, p. 157-159.

*NOTE: This reference list includes titles that are not cited. It was felt the additional references may be useful for the reader.

Watts, A. B., G. D. Karner, and M. S. Steckler, 1982. Lithospheric flexure and the evolution of sedimentary basins, in The Evolution of Sedimentary Basins, (eds.) P. Kent, M. H. P. Bott, D. P. McKenzie, and C. A. Williams, Phil. Trans. Roy. Soc. Lond., 305A, 249-281.

Watts, A. B. and J. Thorne, 1984. Tectonics, global changes in sea level and their relationship to stratigraphic sequences at the U. S. Atlantic continental margin, Marine and Petroleum Geology 1, 319-339.

Yan Dunshi, Wang Shangwen, and Tang Chi, 1980, Block faulting and formation of oil and gas fields associated with buried hills in Bohai basin: Acta Petrolei Sinica, v. 1, No. 2, p. 1-10.

Zha Quanheng, 1984, Jizhong Depression China - its geologic framework, evolutionary history and distribution of hydrocarbons. Am. Assoc. Pet. Geol. Bull. v. 68, p. 983-992.

Zhai Guangming and Zha Quanheng, 1982, Buried hill oil and gas pools in the North China basin, in The deliberate search for the subtle trap: AAPG Memoir 32, p. 317-335.

Zhang Wenyou et al., 1982, Mesozoic and Cenozoic geotectonic characteristics and dynamic model of the lithosphere in North China fault-block region, in Symposium on Mesozoic and Cenozoic geology, in celebration of 60th anniversary: Geological Society of China, p. 78-80.

*NOTE: This reference list includes titles that are not cited. It was felt the additional references may be useful for the reader.

5. Folded belt exploration in China (AWB)

In recent years the term "foreland folded belt" in the American oil industry has become synonymous with exploration in zones that are associated with thin-skinned decollement tectonics. The reason for singling out these exploration plays is that modern seismic techniques combined with the integration of surface geologic data and well information have led to great innovations in structural geology and a better understanding of the hydrocarbon habitat.

Historically, a number of decollement folded belts have already seen a great deal of more or less successful exploration. Successful oil exploration programs include the Polish and Rumanian Carpathians, the Baku area, and the Zagros folded belt of Iran and Iraq. Exploration in these regions was limited initially to the use of surface geology in areas where oil seeps were previously observed. Successful exploration for gas was also carried out in the Po Plain of Italy, which was only recently recognized as a buried folded belt as shown by modern regional seismic profiles.

The modern phase of folded belt exploration, which involves the extensive use of regional seismic profiles and structural interpretation techniques, was primarily successfully developed primarily in Canada (Bally et al., 1966; Dahlstrom, 1969 and 1970; and Jones, 1982; Price, 1981; Price and Mountjoy, 1970; Gordy et al., 1975) and in Wyoming (Royse et al., 1975). Similar techniques were attempted elsewhere with less exploration success (Roeder et al., 1978; Harris et al., 1981).

We feel that modern folded belt techniques have applications in a number of areas in China, particularly in folded belts of the Sichuan Basin, which in fact is a complex folded belt, and in the folded belt located to the west of the Shaanganning (Ordos) Basin. Similar techniques may be applicable to the Paleozoic folds of the Karamay area and to the northern Tarim Basin (i.e., the Keping faulted uplift area).

Before beginning the discussion of some the exploration aspects in folded belts let us attempt to clarify some questions of nomenclature, because folded belt nomenclature is complex and has not been updated in recent times. Many Chinese geologists insisted in telling us there is no A-subduction - that is subduction of sialic lithosphere - in China. It must be emphasized that the concept of A-subduction was introduced (Bally and Snelson, 1980) only to focus on a process that had long been recognized by Ampferer (1906). The term promised to be useful as a means of characterizing the setting of foreland basins (i.e., foredeeps). The term has been accepted by parts of the earth science community. But others feel that the term is unnecessary although the concept may be right. As far as Chinese Mesozoic geology is concerned, we agree that there has not been any major A-subduction in China. To circumscribe the Mesozoic - Cenozoic activity, we pointed out that an envelope around felsic intrusives of Triassic-Tertiary times replaces the A-subduction boundary in China. Therefore we all agree that there is no major A-subduction in China.

It is, however, important to point out that some areas of China - although on a global scale, quite small - show all the features of foreland decollement tectonics. Consequently these areas could legitimately be viewed as small A-subduction zones. Like the Canadian prototype these zones are associated with foredeeps which presumably were caused by the loading of a mountainward dipping basement monocline with overlying thrust sheets. Here again, the issues of basin classification and of nomenclature are not important as long as the structural phenomena are properly analyzed.

This report is not the place to write a long treatise on exploration of folded belts, so we will focus only on some aspects of folded belts that appear to us to be important for exploration in China.

First, let us distinguish sediment decollement tectonics (i.e., decoupling within stratigraphic sequences) from the decollement of thick slices of basement along decoupling zones within the continental crust and in some cases at the base of the continental crust. Recent crustal seismic reflection profiles have circumscribed intracrustal decoupling quite well, but as yet there are few papers published that describe the situation clearly (Cook et al., 1981, 1982, 1983). The problem is that traditional geological concepts view basement faults as sub-vertical and deep-seated. These concepts have been forcefully sustained by many European, American, and particularly Russian geologists. Chinese geologists hardly need to be reminded that until only recently all basement faults in China were considered to be sub-vertical, long-lasting, and deep-seated.

A number of geologists, particularly petroleum geologists in North America and in Europe, view things differently (see Lowell, 1985). Their concept is that the separation of sediment decollement tectonics from basement decollement tectonics is important but sometimes difficult to separate because both types of phenomena often occur in one and the same province and are linked together. Again, it is less important to worry about classification and more important to look at the evidence.

With this in mind let us turn to the Sichuan Basin. In Zhuoxian we were given a very instructive paper by Bao Ci et al. (1985), and much of what follows is based on that paper and on the opportunity we had to see a number of seismic reflection profiles across the Sichuan Basin.

Let us consider the Yangzi (or South China) platform in a plate tectonic context as a small microcontinent that, based upon its Cathasian floras, was quite separated from Eurasia during Paleozoic times. The platform is characterized by an old (pre-Sinian) basement, overlain by Sinian sediments and over 3000 m of Ordovician-Silurian age platform carbonates.

The first important Paleozoic tectonic event was the collision of the platform with the mid-Paleozoic Cathasian folded belt. In other words, a thick lower Paleozoic geosyncline with a passive margin record (i.e., miogeosynclinal sediments) in excess of 6000 m was deformed by overthrusting from the present-day southwest by the Cathasian fold belt. The process generated a Devonian foredeep clastic wedge that is now only partially preserved. Only thin upper Paleozoic carbonates and shales were then deposited on the Yangzi platform. A Permian extensional event in the southwest is suggested by the presence of widespread basaltic flows. The reader should remember that during the Permian this platform was quite distant from present-day Eurasia (Lin Jin-Lu et al., 1985). Some authors place the Yangzi platform near Australia during the Cambrian age.

Isopach maps suggest significant thickening of Triassic isopachs along the northwestern (Long Men Mountain) margin of the Sichuan Basin (Luo Zhili, 1985). To some of us this thickening would indicate that the Yangzi platform had arrived and joined the Indosinian fold belt by upper Triassic time. The suggestion is that this collision brought about the formation of Triassic age foreland fold belts, and this load caused the thickening of the isopachs. The erosion at the giant Luzhu-Kaijang uplift could perhaps be explained as due to the peripheral bulge associated with that collision.

Here we must remember that the late Tertiary collision of India with Eurasia (Molnar and Tapponnier, 1975) caused much of the present-day Yangzi platform to move from a former position much farther to the west to its present-day position. In other words, if we assume that the present-day Qaidam Basin was located well over 500 km farther west, in a reconstruction then we must also assume the Yangzi platform would also have to slip westward along complex Neogene strike slip faults approximately into the area that now is occupied by the Tibetan Plateau. (See also Lin Jin-Lu et al., 1985) All of this is, of course, poorly substantiated speculation. We mention these possibilities simply to suggest that the history of the Sichuan Basin cannot be treated in a static manner, but instead it should be treated in a plate tectonic context.

Let us go back to the Mesozoic and Cenozoic evolution of the Sichuan Basin. A shift of the isopach during Jurassic times towards the northeast suggests loading by thrust sheets located in the Dabashan area. Consequently, it appears that another collision is responsible for the formation of northwest trend folds in that part of the Sichuan Basin.

Finally, and most importantly, all the decollement tectonics responsible for the southwest striking folds of the present-day Sichuan Basin occurred in Tertiary times. From the seismic reflection profiles it is clear that the major decollement level is near the base of the Cambrian, but additional subsidiary decollement levels may involve Permian shales and Triassic evaporites. It is not clear that these decollement tectonics are entirely associated with the India-Eurasia collision; perhaps some older decollement phases may still be preserved at the edges of the Sichuan Basin.

Let us accept for a moment this somewhat speculative synthesis of the information presented to us and contemplate the consequences for petroleum geology.

(1) It would be very important to find out what source beds if any occur within the marine Paleozoic series.

(2) If our view of the Sichuan Basin has any merit for future exploration, then it would be very important to use seismic stratigraphic studies, combined with conventional subsurface studies, to define clearly the position and definition of major unconformities within the Sichuan Basin. The sequences between these unconformities represent different plate tectonic and sedimentologic regimes that, in turn, will control different regional hydrocarbon migrations paths.

(3) Any stratigraphic and migration-path studies would have to be done simultaneously with detailed structural studies involving the construction and restoration of regional profiles based on seismic evidence (balanced cross sections).

(4) Note that the internal structure in decollement anticlines is quite complex. Different levels have different closures. These often are not vertically superposed.

Recommendation: We recommend that the Ministry of Petroleum Industry sponsor a major integrated study of the evolution of the Sichuan Basin. It would be desirable if such a study would be performed primarily by Chinese scientists from different organizations. U.S. scientists would be pleased to help as advisors and perhaps to work on selected aspects of the study. The important thing is that the study be a complete integration of stratigraphic work (i.e., reservoir seal and stratigraphic traps), structural studies (i.e., structural traps), and source bed studies, (i.e., hydrocarbons). Structural studies should be based on reflection seismic profiles. It is also important that these petroleum industry-sponsored studies be combined with structural studies in the adjacent mountain ranges that could well be carried out by colleagues from the Ministry of Geology and by academic researchers.

Typically, folded belt studies for hydrocarbon exploration involve the following steps:

(A) Structural studies

(1) Regional tectonic maps. Such maps are very important. They should simplify the surface geology by grouping various tectono-stratigraphic sequences, intrusives, extrusives, and, particularly, the nature of various faults (i.e., strike slip, normal, overthrust-reverse, and unknown). A good scale for such overview maps is 1:250,000. It is important that such a map be updated as new information comes in.

(2) The construction of regional geological profiles across the whole basin and the adjacent mountains. Reasonable scales for such sections are 1:100,000 or in special cases 1:50,000. The following steps are important:

--Good regional seismic reflection profiles should be available wherever possible. The geologist should be working with the migrated and the non-migrated version of seismic reflection profiles. Automatic depth conversions are desirable, but they can also quickly be done manually. Note that all migration processing should not only attempt to provide the best image of the structure, but should also preserve the correct image of the underlying decollement level.

--The geologist should tabulate all velocity information available from acoustic logs and other sources (e.g., refraction) to be able to make an adequate depth conversion.

--The depth-converted information has to be projected on the regional structural section that is oriented in the presumed path of transport. In the Sichuan Basin four to six cross-sections across the basin and the adjacent mountains in a NW-SE direction and two sections in a SE-NW direction would be adequate.

--The regional cross-sections, assuming that flexural-slip tectonic principles are honored, should be balanced (see Dahlstrom, 1969; Boyer and Elliott, 1982; Suppe, 1980a, 1980b, 1983; Woodward et al., 1985). The essence of balanced cross-sections is that they are internally consistent and geometrically correct. Whereas such sections still may offer many alternative interpretations, they are the only way by which exploration problems can be defined.

There are numerous rules used in construction of balanced cross-sections (see the papers cited above), but it is our experience from many folded belts that balanced cross-sections that are based on seismic profiles are mostly the product of a time-consuming trial and error process. Thus the techniques cannot be easily programmed for a computer; instead people actually have to be trained by doing the work. In our experience initial training can take several months.

--Note that the scale of balanced cross-sections is regional. It is often difficult to reconcile details observed in the outcrops and in wells with features that are visible on a much larger scale. Thus special studies of structures on the surface and in the subsurface have to be undertaken to reconcile regional observations with local observations.

--If there are considerable amounts of considerable overthrusting in a given area, it will be important to make palinspastic base maps that will serve as the basis for stratigraphic studies. In our judgment this step may not be required initially in the Sichuan area, but it certainly would be required in the West Ordos folded belt.

(B) Stratigraphic studies

In many folded belts stratigraphic studies should be undertaken concurrently with structural studies. We would like to suggest the following:

1) Regional stratigraphic studies should be documented with detailed correlation sections that include information from wells and reservoir information that emphasizes the continuity of regional seals and clearly indicates the nature of the paleontologic control. If possible, such sections should be along the same transects as the structural profiles.

2) Concurrent with conventional surface and subsurface stratigraphic studies, it will be most important in areas such as the Sichuan Basin to attempt detailed seismic stratigraphic studies. These studies should indicate which seismic stratigraphic sequences can be mapped and how they are calibrated by well logs. Such studies are a most important step because they will permit the transfer of subsurface information onto a regional seismic scale. In this manner the petroleum geologist will be able to focus on the specific interval that will become of interest in the exploration of stratigraphic traps. Note again that seismic stratigraphic interpretations require considerable training that is best done by actually interpreting profiles with the help of expert instructors.

(C) Source bed studies

Here again, as emphasized in a number of places in this report, specific source bed intervals, which have at least an organic matter content in excess of 1 - 1.5% organic matter, should be identified and documented. Such source beds should also be plotted on seismic profiles, stratigraphic correlation sections, and structural profiles (see Chapter 12).

The preceding structural and stratigraphic studies should form the basis of regional basin reconstructions that are best done initially on the regional sections but can be transferred in three dimensions and time using isopach maps. The combination of these maps will permit the interpreter to chart oil migration paths through geologic time. This procedure, in turn, will help to rank subtle stratigraphic traps according to exploration priorities.

The preceding headings, (A), (B), and (C), list some of the important steps that will be involved in the project that we recommend. Let us now turn our attention to some specific problems that we noted. One of the profiles across the Sichuan Basin showed a feature that reminded us of a classical triangle problem (Jones, 1982; Teal, 1983). The seismic section suggested a situation that has been interpreted by our Chinese colleagues as an angular unconformity. Instead we propose the presence of a basinward dipping thrust fault. We would like to note that this situation turns out to be very common in the Canadian Rocky Mountains and that drilling and surface geology in those cases led to quite a different solution, i.e., a thrust fault that has a direction toward the mountain range. Thus the structure is not a paleostructure but is simply another expression of disharmonic flexural slip folding. The implication for exploration is obvious. A paleostructure would be a more attractive target, and the disharmonic structural complex is more difficult to explore. We would like to emphasize that this situation is now being recognized in many other folded belts of the world.

Some words regarding the Western Ordos fold belt may be in order. In the exhibit in Zhuoxian we saw some seismic profiles across that fold belt. This fold belt has limited extent and, as pointed out to us by Professor Tian, it has some similarities with the Rocky Mountain folded belt of Canada and the U.S. Of course, the West Ordos folds are very local and are probably another expression of the India-Eurasia collision. Note that on seismic profiles some segments of that folded belt have a vergence (i.e., direction of thrusting) to the east, while other segments have a vergence to the west. Although this fact may be surprising, similar situations occur in other folded belts, and conjugate sets of thrust faults do not pose a significant mechanical or geometric problem. An alternative concept may be a strike-slip related flower structure. (Lowell, 1985, p. 45-126).

<u>Recommendation:</u> **Of special interest is the kinematic relationship of the younger half-graben systems to the west of the folded belt and on the northern side of the Ordos Basin. While we cannot express any judgment on the basis of seeing the data only for a very short time, it would seem to us that a comprehensive regional structural study of the structural evolution of the folded belt and half-graben surrounding the Ordos Basin will be most important for the rational continuation of exploration efforts in that area. We therefore recommend that such a study be undertaken.**

References*

Ampferer, O., 1906, Über das Bewegungbild von Faltengebirgen, Austria, Jahrb. geol. Bundesanst, 56, 539-622.

Bally, A. W., Gordy, P. L., and Stewart, G. A., 1966, Structure, seismic data, and orogenic evolution of southern Canada Rocky Canadian Rocky Mountains: Bull. Can. Pet. Geol., v. 14, p. 337-381.

Bally, A. W. and Snelson, S., 1980, Realms of subsidence: in A. D. Miall (ed.), Facts and Principles of World Petroleum Occurrence: Realms of Subsidence: Can. Soc. Petr. Geol., Mem. 6, p. 9-94.

Bao Ci, Yang Xianjie, and Li Dengxiang, 1985, Regional structure features and structural mode of Sichuan Basin, Sichuan Petroleum Admin., Presented at Zhuoxian.

Boyer, S. E. and Elliott, D., 1982, Thrust systems: Amer. Assoc. Petrol. Geol. Bull., v. 66, no. 9, p. 1196-1230.

Cook, F. A., Albaugh, D., Brown, L., Kaufman, S., Oliver, J., and Petersen, T., 1982, The COCORP seismic reflection traverse across the southern Appalachians: Amer. Assoc. Petrol. Geol., Studies in Geol. no. 14, 61 pp.

Cook, F. A., Brown, L., Kaufman, S., Oliver, J., and Petersen, T., 1981, COCORP seismic profiling of the Appalachian orogen beneath the coastal plain of Georgia: Geol. Soc. Amer. Bull., v. 92, p. 738-748.

Cook, F. A., Brown, L. D., Kaufman, S., and Oliver, J. E., 1983, The COCORP southern Appalachian traverse: in A. W. Bally (ed.), Seismic Expression of Structural Styles - A Picture and Work Atlas: Amer. Assoc. Petrol. Geol., Studies in Geol. #15.

Dahlstrom, C.D.A., 1969, Balanced cross-sections: Can. J. Earth Sci., v. 6, p. 743-757.

Dahlstrom, C.D.A., 1970, Structural geology in the eastern margin of the Canadian Rocky Mountains: Bull. Can. Pet. Geol., v. 18, p. 332-406.

Dorr, J. A., Jr., Spearing, D. R., and Steidtmann, J. R., 1975, The tectonic and synorogenic depositional history of the Hoback Basin: Rocky Mtn. Assoc. Geol. Symp. Deep Drilling Frontiers in Central Rocky Mountains, p. 549-561.

Fox, F. G., 1969, Some principles governing the interpretation of structure in the Rocky Mountain orogenic belt: in Kent, P. E. et al. (Eds.), Time and Place in Orogeny, Geol. Soc. Lond. Spec. Pub. 3, p. 23-42.

Fox, F. G., Panarctic Oils, 1983, Structure sections across the Parry Islands Fold Belt and the Vesey Hamilton Salt Wall, Arctic Archipelago, Canada: in A. W. Bally (ed.), Seismic Expression of Structural Styles - A Picture and Work Atlas, Amer. Assoc. Petrol. Geol., Studies in Geol. #15.

*NOTE: This reference list includes titles that are not cited. It was felt the additional references may be useful for the reader.

Gordy, P. F., Frey, F. R., and Ollerenshaw, N. C., 1975, Structural geology of the foothills between Savanna Creek and Panther River, SW Alberta, Canada: Guidebook, Can. Soc. Petrol. Geol., Can. Soc. Explor. Geophys., Explor. Update 1975, Calgary.

Harris, L. D., Harris, A. G., De Witt, W., Jr., and Bayer, K. C., 1981, Evaluation of southern eastern overthrust belt beneath Blue Ridge-Piedmont Thrust: Am. Assoc. Petrol. Geol. Bull., v. 65, p. 2497-2505.

Jones, P. B., 1982, Oil and gas beneath east-dipping underthrust faults in the Alberta foothills: Rocky Mtn. Assoc. of Geologists Symp., p. 61-74.

Laroche, P. J., 1983, Appalachians of southern Quebec seen through seismic line no. 2001: in A. W. Bally (ed.), Seismic Expression of Structural Styles - A

Laubscher, H. P., 1965, Ein kinematisches Modell der Jurafaltung: Ecl. Geol. Helv., v. 58, p. 232-318.

Laubscher, H. P., 1976, Fold development in the Jura, Tectonophysics, v. 36, p. 337-365.

Lin Jin-Lu, Fuller, M., and Zhang Wen-You 1985, Preliminary Phanerozoic polar wander paths for the north and south China blocks, Nature, v. 31B, p. 444-449.

Lowell, J. D., 1985, Structural Styles in Petroleum Exploration, Oil & Gas Consultants International, Inc., Tulsa, 459 pp.

Luo Zhili, 1985, On mechanism of the thrust belt of the Long Men Mountain and its influence of the formation of the Qinghai-Xizang (Tibet) Plateau and accumulation of hydrocarbon. Chengdu College of Geology, 15 pp.

Molnar, P. and Tapponnier, P., 1975, Cenozoic tectonics of Asia: Effects of a continental collision, Science, v. 189, No. 4201, p. 419-426.

Pieri, M., 1983, Three Seismic Profiles through the Po Plain: in Seismic Expression of Structural Styles, AAPG Studies in Geology Series 15, v. 3, p. 3.4.1.8-26.

Pieri, M. and Groppi, G., 1981, Subsurface Geological Structure of the Po Plain, Italy: Pub. 414, del Progetto finalizzato Geodinamica (CNR), 13 pp.

Price, R. A., 1981, The Canadian foreland thrust and fold belt in the southern Canadian Rocky Mountains: in K. McClay and N. J. Price (eds.), Thrust and Nappe Tectonics: Geol. Soc. London, Spec. Pap. no. 9, p. 427-448.

Price, R. A. and Mountjoy, 1970, Geologic structure of the Canadian Rocky Mountains: in J. O. Wheeler (ed.), Structure of the southern Canadian Cordillera, Spec. Pap. Geol. Assoc. Can., v. 6, p. 7-25.

Roeder, D., Warner, M. A., and Witherspoon, W. D., 1978, Evolution and macroscopic structure of Valley and Ridge thrust belt, Tennessee and Virginia: Univ. of Tenn. Geol. Sci., Studies in Geol., Knoxville, v. 2, 25 pp.

***NOTE: This reference list includes titles that are not cited. It was felt the additional references may be useful for the reader.**

Royse, F., Jr., Warner, M. A., and Reese, D. C., 1975, Thrust belt structural geometry and related stratigraphic problems, Wyoming-Idaho-Northern Utah: Rocky Mtn. Assoc. Geol. Symp. Deep Drilling Frontiers in Central Rocky Mtns., p. 41-45.

Suppe, J., 1980a, A Retrodeformable Cross Section of Northern Taiwan: Proc. Geol. Soc. China, no. 23, p. 46-55.

Suppe, J., 1980b, Imbricated Structure of Western Foothills Belt, Southcentral Taiwan: Petroleum Geol. Taiwan, no. 17, p. 1-16.

Suppe, J., 1983, Geometry and Kinematics of Fault Fend Folding: Am. Jour. Sci., v. 283, p. 684-721.

Suppe, J. and Chang, Y. L., 1983, Kink method applied to structural interpretation of seismic sections, western Taiwan: Petroleum Geology of Taiwan, no. 19, p. 29-49.

Suppe, J. and Wittke, J. H., 1977, Abnormal Pore-Fluid Pressure in Relation to Stratigraphy and Structure in the Active Fold-and-Thrust Belt of Northwestern Taiwan: Petroleum Geol. Taiwan, no. 14, p. 11-26.

Suppe, J. and Namson, J., 1979, Fault-bend Origin of Frontal Folds of the Western Taiwan Fold-and-Thrust Belt: Petroleum Geol. Taiwan, no. 16, p. 1-18.

Teal, P. Rae, Shell Canada Res. Lmtd., 1983, The triangle zone at Cabin Creek, Alberta: in A. W. Bally (ed.), Seismic Expression of Structural Styles - A Picture and Work Atlas, Amer. Assoc. Petrol. Geol., Studies in Geol. #15.

Woodward, N. B., Boyer, S. E., and Suppe, J., 1985, An outline of balanced cross-sections, Univ. of Tennessee, Dept. of Geol. Sci., Studies in Geology 11, 2nd edition.

***NOTE: This reference list includes titles that are not cited. It was felt the additional references may be useful for the reader.**

6. <u>Basins of compressional origin in Western China</u> (AWB)

In discussing the compressional basins of Western China it is useful to differentiate their early development during Paleozoic and Mesozoic times from their later development during late Paleogene and Neogene times. The point is that the early development is quite different for various basins, but in contrast it can be fairly stated that the basins of Western China acquired their present individuality as a consequence of the India-Eurasia collision during Paleogene-Neogene times.

Our Chinese colleagues are accustomed to viewing basins as permanent features, sometimes of polyphase origin. It is therefore often very difficult to recognize that the early development of a basin and its basement is shared over larger regions. It should also be emphasized that the Tertiary collision has separated basins and mountain ranges in such a manner that the continuity of earlier stages of development has been disrupted.

It may be best to visualize the position of the Tertiary basins by a tectonic sketch map (Figure 4) that emphasizes the following aspects:

1) Major strike slip fault systems dissect the mountain ranges of Western China. While the Altun Shan fault system is quite obvious, other systems appear to be less well documented.

2) Associated with strike systems are mountain ranges that are characterized by Paleozoic basement cores that were overthrust over the adjacent basins during the Tertiary collision as follows:

- The Tian Shan has a double vergence towards the north over the Junggar Basin and towards the south over the Tarim Basin.

- The Western Kunlun Range is overthrust toward the northeast in the western Tarim Basin.

- The Eastern Kunlun is separated by some 500 km from the Western Kunlun by the Altun Shan strike slip system, and is overthrust towards the east along the southwest side of the Qaidam Basin.

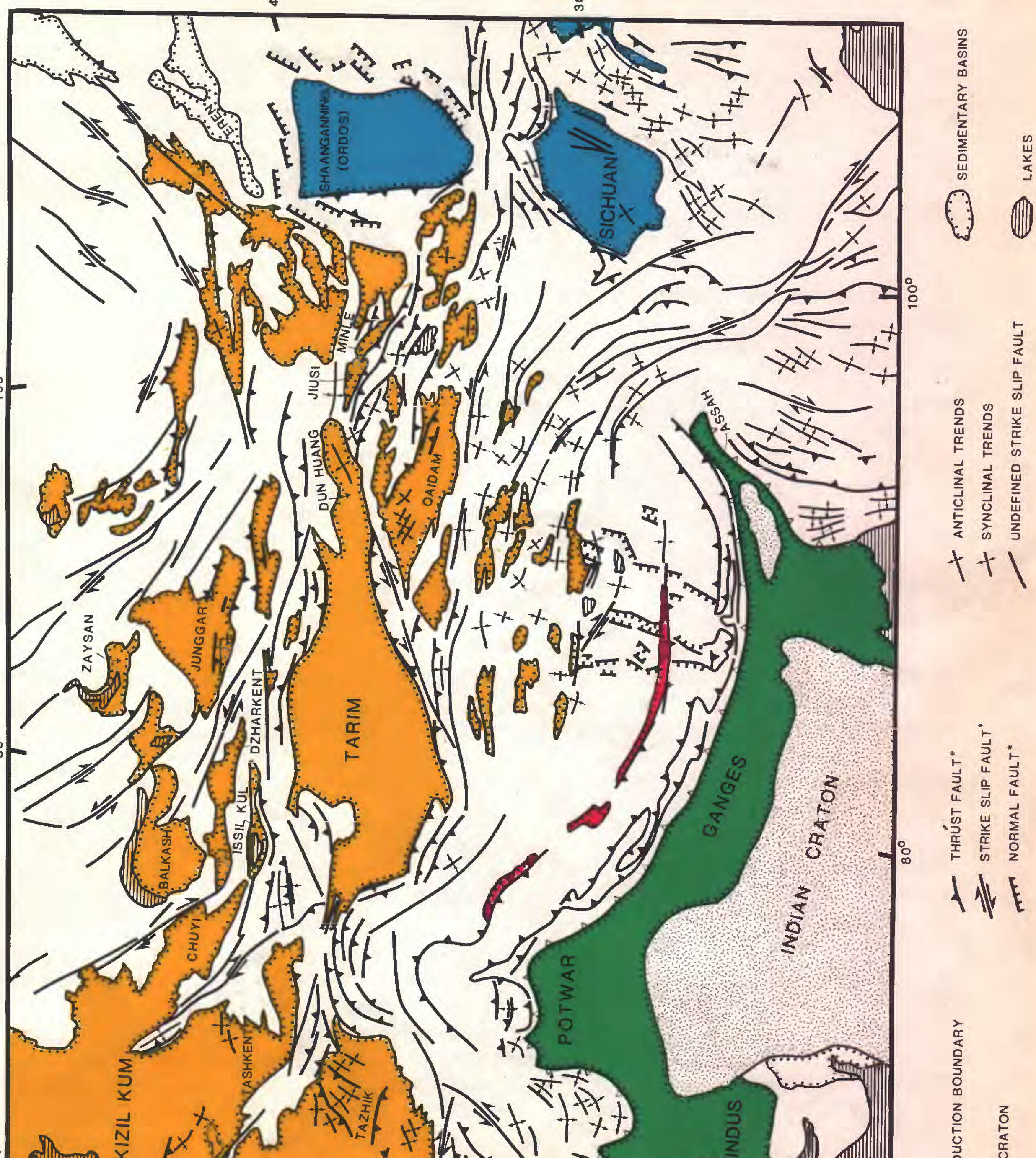
- The Qilian Shan Range has a dual vergence, i.e., it is overthrust towards the south over the northern Qaidam Basin and overthrust toward the north along the edges of the Gansu Corridor.

Each of these basement-involved overthrust systems forms a substantial lithospheric load that will cause Tertiary isopachs to thicken towards the adjacent overthrust mountain. To geologists familiar with North American geology the structural styles are somewhat comparable to the basement-involved deformation of the Colorado-Wyoming Rockies and the Paleozoic foreland deformation of Oklahoma, West Texas, and the ancestral Rocky Mountains. We would like to remind the reader, however, that in the Rocky Mountains the tectonic-stratigraphic evolution of the Paleozoic platform sequence and Mesozoic foredeep sequence is very different from what we see in China. The Tertiary deformation of the Colorado-Wyoming Rocky Mountains and the formation of lacustrine (Green River-type) basins are broadly comparable to the basins of Western China. A Cretaceous foredeep sequence is, however, absent in Western China!

Figure 4

Tectonic setting of compressional basins in Western China. Most of the structural features shown on this map were formed as a consequence of the India-Eurasia collision. To the south in the foreland of the Himalayas is the A-subduction related peri-Himalayan foredeep (Indus, Ganges, and Assam Basins). The basin associated with ophiolites of the Yarlung Zangbo suture is the folded remnant of a pre-collisional forearc basin. Elongated Tertiary basins and synclinoria, which have been drawn using the 1:1,500,000 geologic map of Qinghai-Xizang, suggest intensive Tertiary deformation of the Tibetan Plateau that involves the pre-Tertiary basement. The Tarim, Qaidam, Turpan, Junggar, and Gansu Corridor Basins are all bounded by Tertiary reverse faults and/or strike slip faults. The same may be said for the basins of the Soviet Union. It is concluded that all these basins acquired their present identity during and that they are a product of the Tertiary India-Eurasia collision. Tertiary folds and overthrusts within and surrounding the Sichuan Basin and to the west of the Shaanganning (Ordos) Basin reveal thin-skinned decollement tectonics also associated with the India-Eurasia collision.

Note that strike slip fault systems associated with the Kunlun Shan, the Altun Shan, and the Tian Shan suggest extensive post-Tertiary lateral displacement (according to Lin Jiu-Lu et al. 1985, as much as 4000 km with respect to Siberia for the Sichuan Basin!). We can therefore safely conclude that the pre-Tertiary development of the basins of Central China has no significant relation to the Tertiary individualization of these basins. The relative position of the pre-Tertiary Junggar, Tarim, Qaidam, Gansu Corridor, and Sichuan Basins is still very obscure. **Additional comparative stratigraphic and paleomagnetic studies are urgently needed.**



KIZIL KUM
TURKMEN
TAZHIK
ASHKENT
CHUYI
BALKASH
ISSIL KUL
DZHARKENT
ZAYSAN
JUNGGAR
TARIM
DUN HUANG
JIUSI
MINLE
QAIDAM
EREN
SHAANGANNING (ORDOS)
SICHUAN
ASSAH
POTWAR
INDUS
GANGES
INDIAN CRATON
60°
80°
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30°
A-SUBDUCTION BOUNDARY
INDIAN CRATON
THRUST FAULT*
STRIKE SLIP FAULT*
NORMAL FAULT*
* FAULT TYPE OFTEN INFERRED
ANTICLINAL TRENDS
SYNCLINAL TRENDS
UNDEFINED STRIKE SLIP FAULT
NEOGENE GRABEN SYSTEM
SEDIMENTARY BASINS
LAKES

Obviously, the combination of strike slip faults and overthrusts tempts the "flower-structure"-minded geologists to interpret much of Western China according to the model prescribed by our colleagues from Exxon (Harding, 1973, 1974; Harding and Lowell, 1979). This analysis has recently been undertaken by Liu Hefu (1984). At least one of us (AWB) has serious questions regarding the flower structure model in China, however, because the widespread evidence for basement decollement suggests an alternative explanation that views both the overthrusts and the strike slip faults as decoupled along mid-crustal decoupling levels (see also Figure 12 in this report). On the other hand Hirn et al. (1984b) have offered compelling refraction and wide-angle reflection evidence supporting deep-seated strike-slip fault systems that offset the Moho and reach into the mantle.

With this brief introduction, let us now discuss two basins: the Junggar and the Tarim Basins. During our meeting in Zhuoxian we were given two excellent papers by our Chinese colleagues (Peng Xilin et al., 1985) and we had an opportunity to see a number of seismic reflection profiles across these basins with these same colleagues. The following chapter will provide more detailed material on the Qaidam Basin.

First, the Junggar Basin. Recent summaries in English of this basin are given by Ulmishek (1984) and by Lee (1985a). In Zhuoxian we were given another summary by Peng Xilin et al. of the Xinjiang Petroleum Administration Bureau.

The Junggar Basin is surrounded by outcrops of mid-Paleozoic fold belts, and it can therefore be safely assumed that the economic basement underlying the whole basin is of mid-Paleozoic Variscan age. Overlying the basement is a generally flat-lying sequence of terrestrial coal bearing Upper Carboniferous and thick continental Permian. There are reports of marine Upper Carboniferous and early Permian in the region of the Karamay field (Ulmishek, 1984). There is considerable evidence on seismic reflection profiles of an upper Hercynian (i.e., Permian to probably lower Triassic) extensional event (see Figure 6). Such events are quite common following the mid-Hercynian orogeny (e.g., Central France and large areas of West Siberian Basin). An obvious question is whether these extensional half-graben systems should be considered as separate exploration targets. Permian and Triassic isopachs, therefore, are probably influenced by this stretching event and subsequent cooling.

An interesting structural situation is associated with the west side of the Junggar Basin and can be observed in the area of the Karamay (see Figure 5). Some fascinating and detailed seismic reflection profiles clearly show a compressional structure that involves Carboniferous and Permian sediments. A major pre-Triassic unconformity that seals the major compressional phase and is followed by minor compressional reactivations in pre-middle Jurassic times and pre-Upper Jurassic times. All of these structures have all the characteristics of decollement structures. A modern kinematic analysis of these structures could help in the evaluation of the petroleum potential of the Karamay area. Note that similar but more gentle compressional structures underlie large areas of the Tarim Basin.

While the Triassic has an overall typical thickness of about 1 km, the Jurassic thickens in a southward direction. Over most of the basin Mesozoic sediments are relatively undisturbed, and some seismic profiles show an impressive monocline

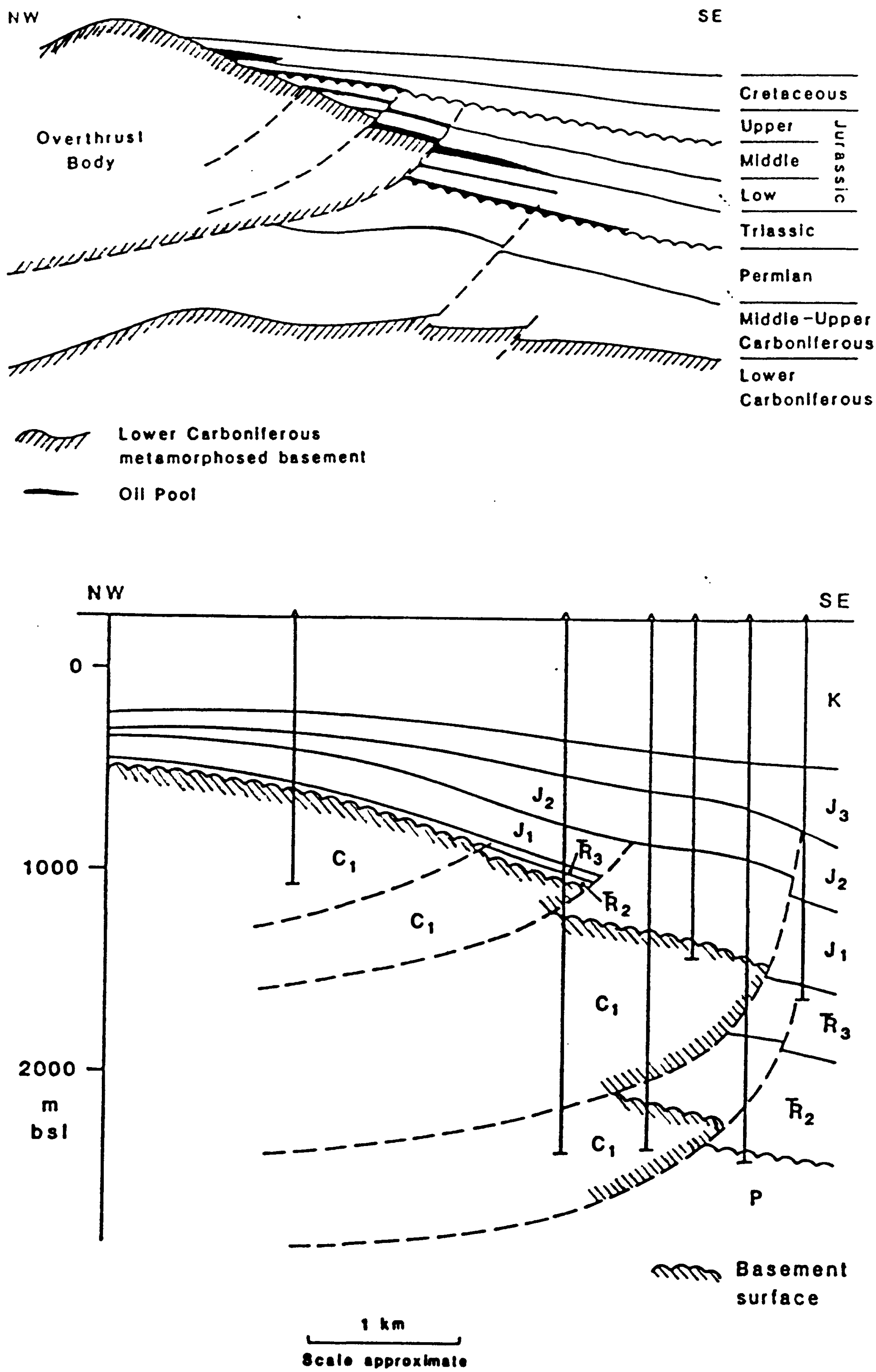
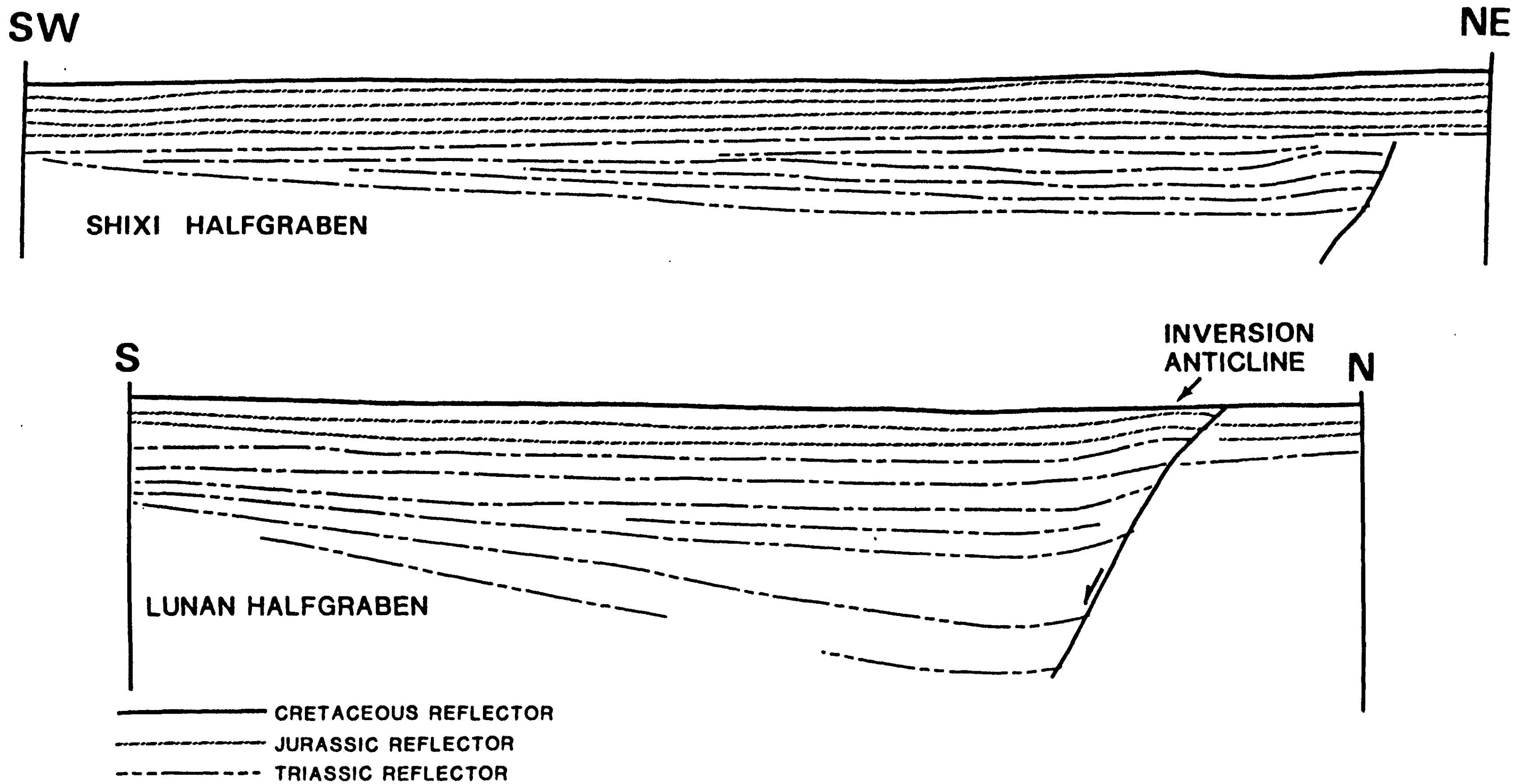


Fig. 5

TOP: Schematic section across the Karamay structure showing hydrocarbon trapping domains.

BOTTOM: Section across Karamay oil field, both sections redrawn by Ulmishek, 1984, after Lin Longdong, 1984.

Note southward verging overthrusts that were emplaced during the latest Paleozoic and Triassic.



JUNGGAR BASIN SKETCH OF SEGMENT OF REFLECTION SEISMIC PROFILE

NO TIME SCALE
NO HORIZONTAL SCALE

Figure 6

Line drawings of seismic profiles (no vertical and horizontal scales) across the Shixi half-graben (top) and the Lunan half-graben (bottom). Both features are located in the northern half of the Junggar Basin. Note the formation of Triassic half-grabens in that area, and also the text book type inversion structure (see also Figure 3 of this report) on the lower section. The timing of the inversion is not clear: according to Peng Xilin et al., 1985, we are dealing with a pre-Cretaceous inversion. In a regional context, however, a Tertiary inversion would be more plausible.

dipping toward and under the Tian Shan. No doubt much of the tilt of the Junggar Basin monocline is associated with thickening in the Tertiary continental formations, which is related in turn to loading by the Tian Shan overthrusts.

There remains a significant question: was the Junggar Basin during the Mesozoic directly connected with the Tarim Basin and other adjacent basins in the Soviet Union to form a much larger basin that was disrupted by Tertiary strike-slip and reverse faulting? Or, alternatively, was the Junggar Basin formed as an individual entity and totally separated from other basins by Jurassic times? The latter is the commonly accepted view, but that view is preconditioned by the traditional concept that most basins in China were individualized as basins quite early during their evolution. To us it seems more likely that the Junggar was isolated as a separate basin much later as a consequence of the India-Eurasia collision.

Which of the two above-mentioned alternatives is correct can only be decided by stratigraphic studies. Detailed stratigraphic correlations that go across and connect all basins of Western China would be particularly useful for late Paleozoic, Mesozoic, and Tertiary formations. Such correlations should be combined with sedimentologic studies that document the origin of clastic depocenters as they may or may not relate to adjacent present-day mountain ranges.

During our meetings there was little discussion concerning the exploration aspects of the basins. These are summarized in Ulmishek (1984). Two medium-size fields (i.e., about 200-300 million barrels each) are associated with the paleostructures on the northwest side of the Junggar Basin (Karamay area), and several small fields were found within the Tertiary folded belt that is associated with the north-verging Tian Shan overthrust.

At first glance, the Tertiary folded belt of the Southern Junggar Basin looks rather unpromising, but we did not see any seismic data across that area. We cannot escape a general impression that most structures in that area will be so complex that they will require considerable structural geologic expertise for an appropriate evaluation.

We now turn to the Tarim Basin. Professor Tian and his colleagues from the Research Institute for Petroleum Exploration and Development of the Ministry of Petroleum Industry and the associated Bureau of Geophysical Prospecting gave us a very fine introduction to the geology of the Tarim Basin. Combined with the opportunity to see a number of regional reflection profiles across the Tarim Basin, we can summarize the geology of the Tarim Basin as follows:

The Tarim Basin differs from the other basins of Western China because its basement is Precambrian in age. Thus the Precambrian Tarim platform (microcontinent) is today surrounded by Paleozoic belts of mostly Variscan age. The relation of these Paleozoic folded belts to the Tarim Basin itself is obscured by Tertiary tectonics that are related to the India-Eurasia collision. Thus the Tarim Basin was individualized as a basin during late Paleogene-Neogene times. Its northern margin is marked by southward verging basement overthrusts of the Tian Shan. Its southwestern margin is dominated by northeast verging overthrusts of the Kunlun Shan, and its southeastern border is dominated by strike slip tectonics associated with the Altun Shan fault system.

Sinian and Paleozoic (Figures 8A and 8B) platform sequences overlie the basement and are particularly thick in the northeastern depression of that basin. Post-upper Paleozoic folding is quite evident on the regional seismic reflection profiles and clearly control the thickness distribution of the upper Paleozoic formations (Figure 7B).

Continental Triassic and Jurassic (Figure 9A) sequences unconformably overlie the Hercynian (probably basement-controlled) folds analogous to the Karamay area in the Junggar Basin. Thicknesses in excess of 5000 m of continental sequences are reported in the northeast Tarim.

Of special interest are relatively thin Upper Cretaceous and Paleocene marine intervals in the western part of the Tarim Basin. That sequence connects the marine realm of the Ferghana depression of the Soviet Union and the relatively undisturbed upper Cretaceous marine formations of the Tibetan Plateau. Thus a paleogeographic picture emerges that indicates that much the Tibetan Plateau during the Upper Cretaceous and possibly the Paleocene was a shallow water sea that to the south was bounded by the Gandese (Trans-Himalayan) island arc.

Here again we caution that paleomagnetic studies suggest that the pre-Tertiary distribution of the major tectonic elements surrounding the Tarim Basin may differ substantially from today's distribution.

Finally, the Tertiary isopachs clearly suggest loading by basement overthrusting to the north side and the southwest side of the Tarim Basin. (See Figure 9B)

Note that regional cross-sections presented by Tian et al., 1985 (Figure 7B) differ from previously published cross-sections across the Tarim Basin. We had a chance to see regional seismic reflection profiles and on this basis have little doubt that, even in its simplified form, the section by Tian et al. is much more accurate than any of the previously published cross sections.

The following comment may apply to all the basins in Western China, including the Jiuquan Basin and other basins in the Gansu Corridor and the Qaidam Basin that we will discuss in the next chapter. The material we were shown greatly amplified our understanding of the basins of Western China. However, with the exception of the Qaidam Basin, we did not have any indepth conversations concerning the hydrocarbon habitat of most basins. Previous reports (e.g., Robertson Research, 1979, and Ulmishek, 1984) provided some familiarity with the types of hydrocarbon fields discovered in some of these basins and with the general nature of the source bed and reservoir distribution. Given that background, we were struck by the absence of any integrated geological, geophysical, and geochemical studies that would permit an indepth basin analysis of any individual basins in Western China in a style comparable to basin studies conducted in North America.

Figure 7

Tarim Basin: major tectonic units (top) and schematic structural cross section, after Tian Zaiyi et al., 1985. The structure section (below) shows large upper Paleozoic structures that are characterized by basement-involved reverse faulting. The Mesozoic sequence is onlapping on these old structures. The indicated Jurassic thickness increase toward the Tian Shan needs more documentation and verification. The Tertiary fill, however, is related to loading overthrusts in the north (Tian Shan) and in the south (Kunlun Shan) of the Tarim Basin.

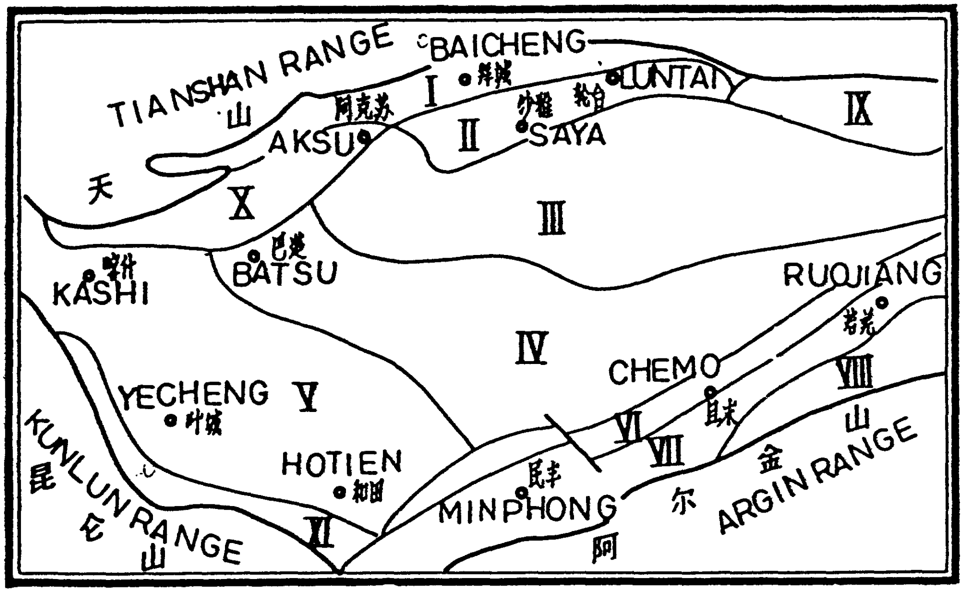


FIG. 7A 塔里木盆地构造单元划分图

TECTONIC UNITS IN THE TARIM BASIN

Ⅰ拜城坳陷 Ⅱ塔北隆起 Ⅲ北部坳陷 Ⅳ中央隆起 Ⅴ西南坳陷
Ⅵ且末—若羌断隆 Ⅶ东南坳陷 Ⅷ阿尔金断隆 Ⅸ库鲁克塔格断隆
Ⅹ柯坪断隆 Ⅺ铁克里克断隆

IBUICHENG DEPRESSION ⅡTABEI UPLIFT
ⅢNORTHERN DEPRSSION ⅣCONTRAL DEPRESSION
ⅤS-W DEPRESSION ⅥCHEMO-RUOJIANG FAULTED UPLIFT
ⅦS-E DEPRESSION ⅧARGIN FAULTED UPLIFT
ⅨKULUKETAG FAULTED DEPRESSION ⅩKEPING FAULTED UPLIFT
ⅪTIKELIKE FAULTED DEPRESSION

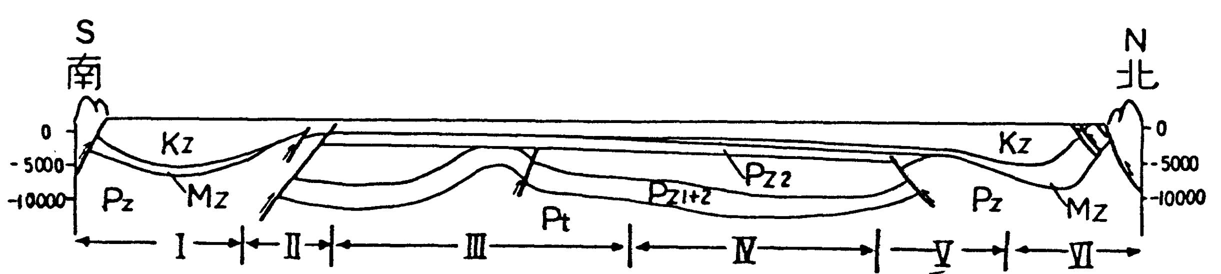


FIG. 7B 民丰—拜城地质剖面示意图

SCHEMATIC CROSS SECTION OF MINPHONG—BAICHENG STRUCTURE

Ⅰ东南坳陷 Ⅱ且末—若羌断隆 Ⅲ中央隆起 Ⅳ北部坳陷 Ⅴ塔北隆起
Ⅵ拜城坳陷

Ⅰ S-E DEPRESSION Ⅱ CHEMO—RUOJIANG FAULTED UPLIFT
Ⅲ CENTRAL UPLIFT Ⅳ NORTNERN DEPRESSION
Ⅴ TABEI UPLIFT Ⅵ BAICHENG DEPRSSION

Figures 8A and 8B

Tarim Basin: Lower Paleozoic isopachs (top) and Upper Paleozoic isopachs (below), after Tian Zaiyi et al., 1985. It is not clear what is the cause for the drastic thickness changes shown by the isopachs. Possible unconformities have been postulated at the base of the Cambrian, at mid-Paleozoic levels ("Caledonian"), and within and/or at the top of the Paleozoic. How these unconformities influence the isopachs is not clear. The answer to the question is obviously of great importance for the exploration for stratigraphic traps.

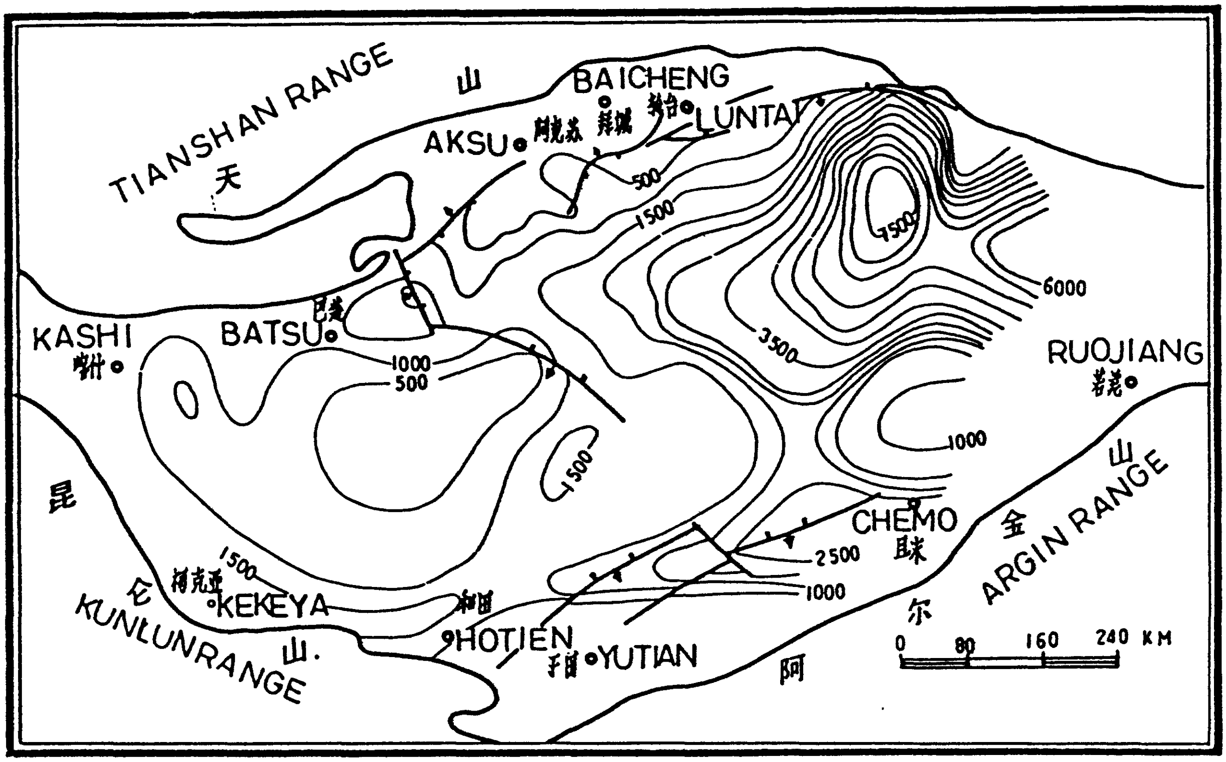


FIG. 8A 塔里木盆地下古生界等厚图

LOWER PALEOZOIC ISOPACHMAP OF TARIM BASIN

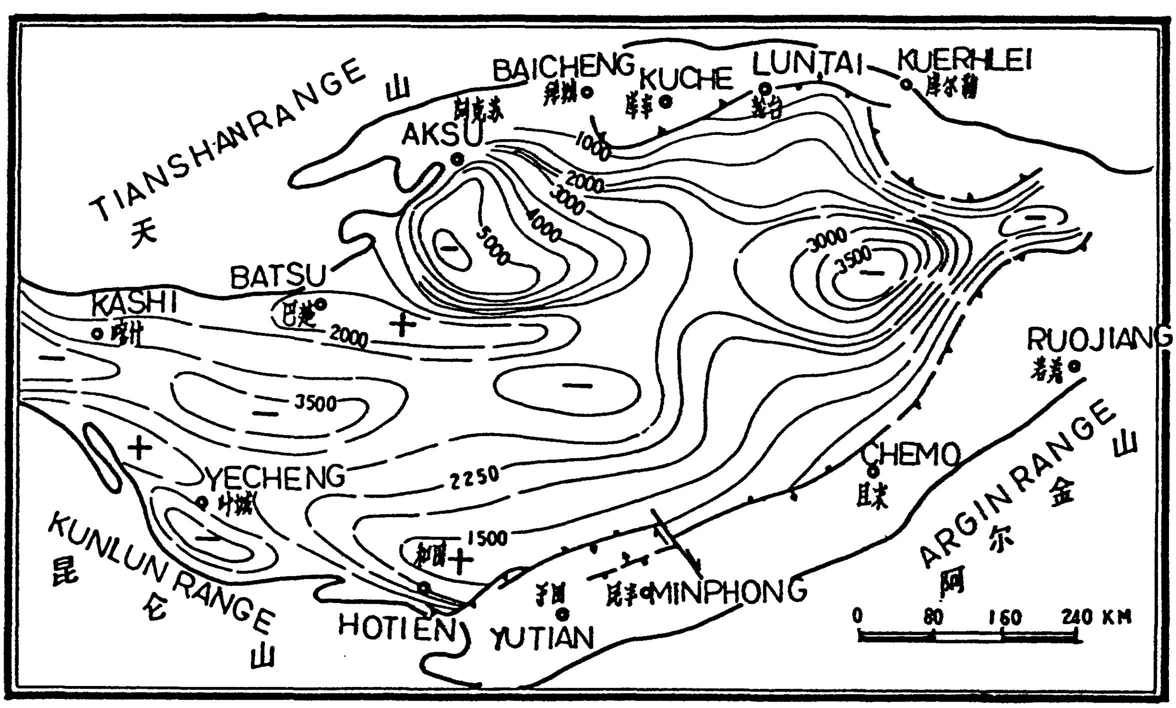


FIG. 8B 塔里木盆地上古生界等厚图

UPPER PALEOZOIC ISOPACH MAP OF TARIM BASIN

Figures 9A and 9B

Tarim Basin: Jurassic-Triassic isopachs (top) and Tertiary isopachs, after Tian Zaiyi et al. 1985. Thickness changes of the Jurassic-Triassic isopachs, particularly the thick pocket of sediments to the south of the Tian Shan, are not clearly understood. Thickening of the Tertiary is related to the formation of the Tertiary Tian Shan and Kunlun Shan. Both mountain ranges were formed as a consequence of the India-Eurasia collision, and basement thrust sheets of the mountain ranges formed the load that was responsible for the Tertiary subsidence of the north and southwest parts of the Tarim Basin.

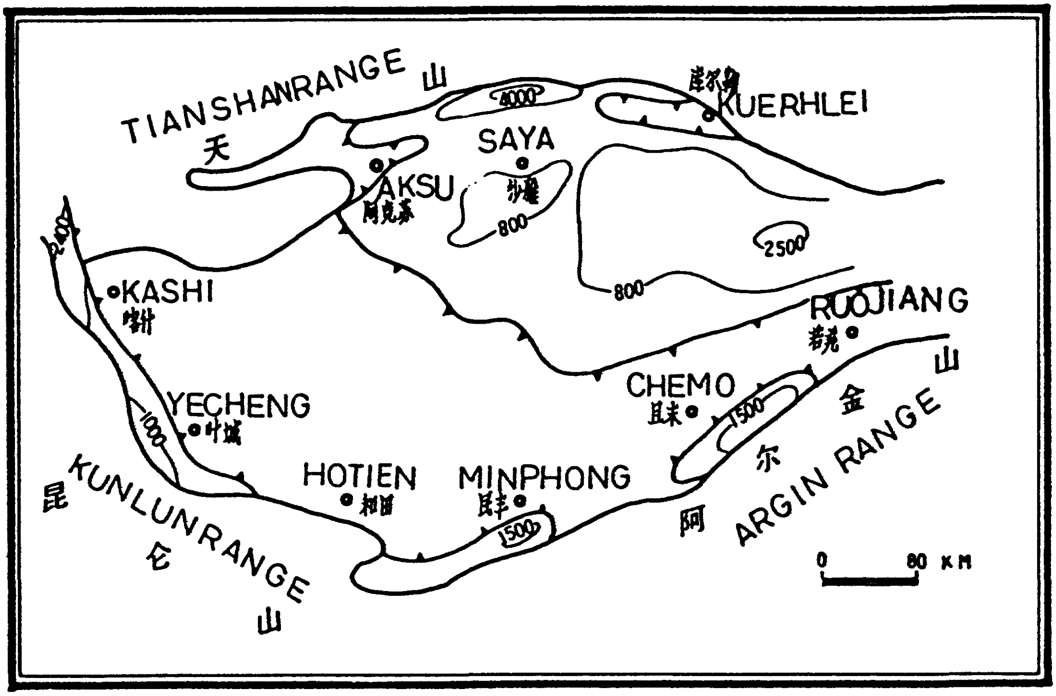


FIG. 9A 塔里木盆地三迭—侏罗系等厚图

JURASSIC—TRIASSIC ISOPACH MAP OF TARIM BASIN

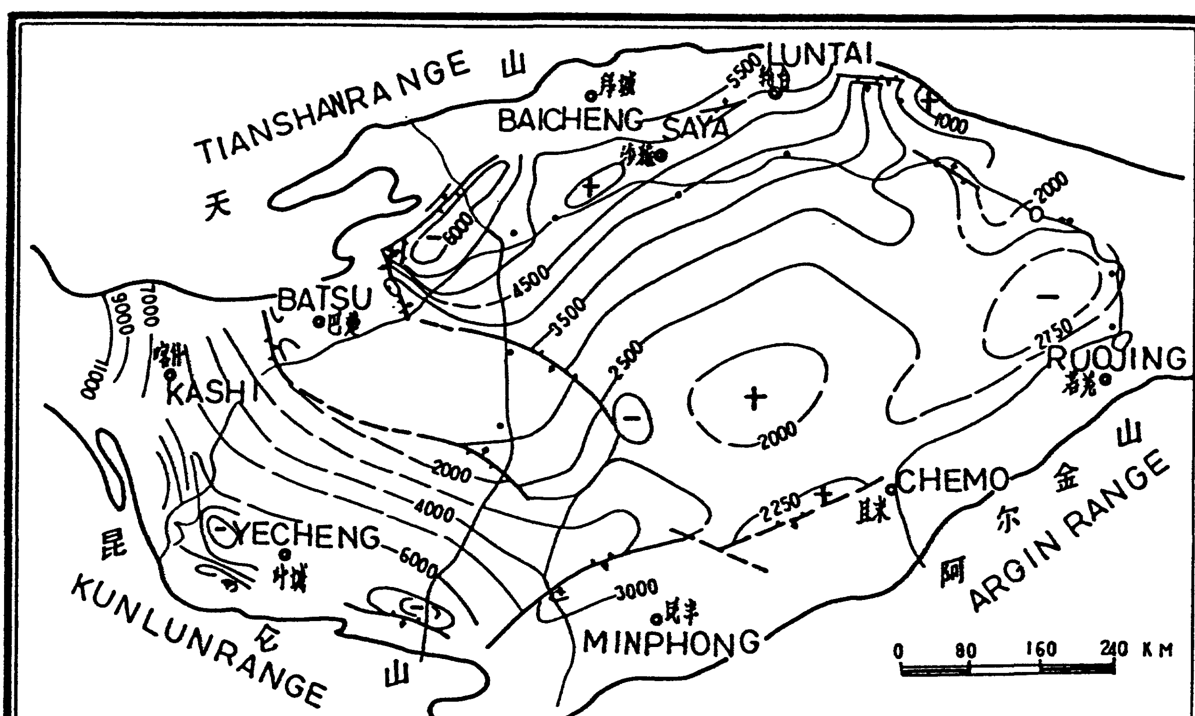


FIG. 9B 塔里木盆地第三系等厚图

TERTIARY ISOPACH MAP OF TARIM BASIN

References

Chang Chengfa and Pan Yushen, 1981, A brief discussion on the tectonic evolution of Qinghai-Xizang Plateau, geological and ecological studies of Qinghai-Xizang Plateau, Vol. 1, Science Press, Beijing, China, p. 1-18.

Chang Chiyi, 1981, Alluvial-Fan Coarse Clastic Reservoirs in Karamay, Petroleum Geology in China, J. F. Mason, (ed.), PennWell Publishing Co., Tulsa, Okla., p. 154-170.

Chen Shaozhou, Gao Xinchen and Qiu Dongzhou, 1982, A preliminary study of China's Eogene transitional facies, Oil and Gas Geology, v. 3, No. 4, p. 343-350. (in Chinese)

Fan Pu et al., 1980, Formation and migration of continental oil and gas in China, Scientia Sinica, v. 23, Nos. 10 and 11, p. 1286-1292 and 1417-1427.

Harding, T. P., 1973, Newport Inglewood trend, California - An Example of Wrenching style of deformation. Amer. Assoc. Pet. Geol. Bull. Vol. 75, p. 97-116.

Harding, T. P., 1974, Petroleum traps associated with wrench faults, Amer. Assoc. Pet. Geol. Bull. Vol. 57, p. 97-116.

Harding, T. P. and Lowell, J. D., 1979, Structural styles and their plate tectonic habitats.

Hirn, A., Lepine, J., Jobert, G., Sapin, M., Wittlinger, G., Xu Zhong Xin, Gao En Yuan, Wang Xiang Jing, Teng Ji Wen, Xiong Shao Bai, Paudey, M. R., and Tater, J. M., 1984a, Crustal structure and variability of the Himalayan border of Tibet, Nature, Vol. 307, p. 23-25.

Hirn, A., Nercessian, A., Sapin, M., Jobert, G., Xu Zhong Xin, Gao En Yuan, Lu De Yuan, and Teng Ji Wen, 1984b, Lhasa block and bordering sutures - a continuation of a 500-km Moho traverse through Tibet, Nature, v. 307, p. 25-27.

Hu Bing et al., 1969, Problems of the Paleozoic of Tarim Platform, International Geology Review, v. 11, No. 6, p. 650-665.

Hu Boliang, 1981, On the organic geochemical characteristics and oil-source correlations in the Tarim Basin, Oil and Gas Geology, v. 2, No. 4, p. 360-368 (in Chinese).

Huang Difan, Li Jinchao, and Zhou Zhuhong, 1981, Evolutionary characteristics of soluble organic matter in Quaternary to Pliocene of the Tsaidam Basin, Acta Petrolei Sinica, Special Issue, v. 2, No. 4, p. 100-112.

Huang Ti-fan, Ch en K o-tsao, Hsu Yung-ch ang, Pan P u, and Liang Ti-kang, 1968, Formation of asphalt in quaternary sediments of Tsinghai Lake (Koko Nor) and problems on continental-origin petroleum, International Geology Review, v. 10, No. 10, p. 1189-1211.

*NOTE: This reference list includes titles that are not cited. It was felt the additional references may be useful for the reader.

Kang Yuzhu, 1981, Characteristics of petroleum geology of the Tarim Basin, Oil and Gas Geology, v. 2, No. 4, p. 329-340 (in Chinese).

Lee, K. Y., 1984, Geology of the Chaidamu Basin, Qinghai Province, Northwest China, U. S. Geological Survey Open-File Report 84-413, 46 pp.

Lee, K. Y., 1985a, Geology of the petroleum and coal deposits in the Zhungaer Basin, Xinjiang Province, Northwest China, U. S. Geological Survey Open-File Report 85-230, 53 pp.

Lee, K. Y., 1985b, Geology of the Tarim (Talimu) Basin, Xinjiang Province, Northwest China, with Special Emphasis on petroleum deposits, U. S. Geological Survey Open-File Report 85-616, 54 pp.

Li Desheng, 1983, Tectonic types of oil and gas basins in China, Scientific Research Institute of Petroleum Exploration and Development, Beijing, China.

Lin Jiu-Lu, Fuller, M., and Zhang Wen-You, 1985, Preliminary phanerozoic polar wander paths for the north and south China blocks, Nature, Vol. 313, p. 444-449.

Lin Longdong, 1984, The discovery of nappe-screened oil pool and the prospects of the Karamay Oil Field, Oil and Gas Geology, v. 5, No. 1, p. 1-10 (in Chinese).

Liu Hefu, 1984, Structural styles of Mesozoic-Cenozoic petroliferous basins of China, Trans. Third Circum-Pacific Energy and Mineral Resources Conf., S.T. Watson, (ed.), American Assoc. of Petrol. Geol., Tulsa, Okla., p. 173-179.

Lu Minggang, 1981, Source for oil in the western part of the Tarim Basin, Acta Petrolei Sinica, v. 2, No. 3, p. 31-36 (in Chinese).

Min Yu, 1981, Hydrocarbon accumulations in sedimentary basins of nonmarine facies in China, Petroleum Geology in China, J. F. Mason, (ed.), PennWell Publishing Co., Tulsa, Okla., p. 1-4.

Molnar, P. and Tapponnier, P., 1975, Cenozoic tectonics of Asia: Effects of a continental collision, Science, v. 189, No. 4201, p. 419-426.

Peng Xilin, Li Lichen, Zhou Demin, Wu Zhixuan, Wu Qingfu, Liu Zhaorong and Yuan Wenxian, 1985, Evolution features and tectonic types of the Junggar Basin, Xinjiang Petroleum Administration Bureau, presented at Zhuoxian.

Pitman, J. K., Fouch, T. D., and Goldhaber, M. B., 1982, Depositional setting and diagenetic evolution of some Tertiary unconventional reservoir rocks, Uinta Basin, Utah, American Association of Petroleum Geologists Bulletin, v. 66, No. 10, p. 1581-1596.

Powell, C. McA. and Conaghan, P. J., 1975, Tectonic models of the Tibetan Plateau, Geology, v. 3, No. 12, p. 727-731.

Robertson Research International Ltd. and Bureau D'Etudes Industrielles et de Cooperation de L'Institut Francais du Petrole, 1979, The People's Republic of China, Its Petroleum Geology and Resources, Gwynedd, Wales.

*NOTE: This reference list includes titles that are not cited. It was felt the additional references may be useful for the reader.

Shang Huiyun and Li Jinchao, 1981, Abundance and types of organic matter in source rocks of continental facies, Acta Petrolei Sinica, Special Issue, v. 2, No.2, p. 8-16 (in Chinese).

Shao Hung-Shuen and Huang Ti-fan, 1969, Paleolimnetic salinity of Dzungar and Ordos Basins, International Geology Review, v. 11, No. 4, p. 461-470.

Song Jianguo and Liao Jian, 1982, Structural characteritics and petroliferous regions in the Chaidamu (Tsaidam) Basin, Acta Petrolei Sinica, Special Issue, p. 14-23 (in Chinese).

Tian Zaiyi, Chai Guilin, and Lin Liang, 1985, Formation and evolution of Tarim Basin, Petroleum Exploration and Development Institute of MPI and Bureau of Geophysical Prospecting of MPI, presented at Zhuoxian.

Tapponnier, P., et al., 1981, The Tibetan Side of the India-Eurasia Collision, Nature, v. 294, p. 405-410.

Ulmishek, G., 1984, Geology and petroleum reserves of basins in western China, Argonne National Laboratory ANL/ES-146, 131 pp.

Wang Shangwen et al., 1983, Petroleum geology of China, Petroleum Industry Press, Beijing, China (in Chinese).

Wang Yichung and Tan Shidian, 1981, The evolution and hydrocarbon-bearing prospects of the Tarim Plate Structure, Petroleum Exploration and Development, v. 3, p. 1-9.

Wang Youxiao et al., 1983, Geochemical characteristics of crude oils from Qaidam Basin, Oil and Gas Geology, v. 4, No. 1, p. 121-127 (in Chinese).

Wang Zuzhi, 1981, The Distribution of Mesozoic sediments in the northern part of the Chaidamu Basin, Petroleum Exploration and Development, v. 2, p. 20-26 (in Chinese).

Wen Shixuan et al., 1981, Sedimentary development and formation of stratigraphic regions in Xizang, Geological and Ecological Studies of the Qinghai-Xizang Plateau, Vol. 1, Science Press, Beijing, China, p. 119-130.

Xie Gongjian, 1981, Occurrence of the oil pool in the metamorphosed basement in Yaerxia in the western part of the Jiuquan Basin, Acta Petrolei Sinica, v. 2, No. 3, p. 214-30 (in Chinese).

Xu Zhengyu, 1980, The Tertiary and its petroleum potential in the Lunpola Basin, Tibet, Oil and Gas Geology, v. 1, No. 2, p. 153-158 (in Chinese).

Yan Yugui et al., 1983, Some problems concerning petroleum geology of the Tarim Basin, Scientia Sinica, Ser. B, v. 26, No. 11, p. 1201-1215.

Yi Ronglong and Jiang Shengbang, 1980, The oil and gas potential in the Paleozoic of Tarim Basin, Oil and Gas Geology, v. 1, No. 1, p. 26-36 (in Chinese).

*NOTE: This reference list includes titles that are not cited. It was felt the additional references may be useful for the reader.

Zhang Yongxia, 1982, The characteristics of regional geological structure of the Tarim Basin, Acta Geophysica Sinica, v. 25, No. 3, p. 243-251 (in Chinese).

Zhao Bai, 1982, Prospects of petroleum exploration of Permo-Carboniferous in Junggar Basin, Oil and Gas Geology, v. 3, No. 1, p. 75-80 (in Chinese).

*NOTE: This reference list includes titles that are not cited. It was felt the additional references may be useful for the reader.

7. Comments on the geology of the Qaidam Basin

A. Introduction and structural setting (AWB)

Papers by Xie Mingqian et al. (1985) and by the Geological Exploration Research Institute of the Qinghai Petroleum Administration (1985) were given to us during our trip. There are plans for these papers to be published in China. Additional publications on the Qaidam Basin include Di Hengshu (1984), Song Jianguo and Liao Jian (1982), and the English-written compilations of K. Y. Lee (1984) and Ulmishek (1984).

As with all our comments we will not attempt here to provide a complete review of all the material; instead we will focus on a few specific aspects that appeared important to us.

The basement of the Qaidam Basin is Precambrian and Paleozoic in age with radiometric ages of 1500 m.y. (K/Ar) for a gneiss and 460 m.y. (Rb/Str) for an ultrabasic rock from the Altun Shan; 1700 m.y. (K/Ar) and 300-400 m.y. (K/Ar) for granitic-gneissic rock from the Qilian Shan; and 200-300 m.y. (K/Ar) for felsic rocks to the south of the Qaidam Basin. We conclude that the basement is pre-Mesozoic in age and there are no simple Paleozoic exploration objectives in the Qaidam Basin because the thick Proterozoic and Paleozoic sediments reported from the margins of the basins have been severely deformed during the Precambrian and Paleozoic orogenies.

Little is known about the Triassic underlying the Qaidam Basin. Triassic sediments are developed at the eastern end of the basin where marine sediments have been reported. Farther to the west, red coal-bearing clastics are reported.

The continental-lacustrine Jurassic-Cretaceous red sandstones, mudstones, and conglomerates also contain source beds with total organic matter contents in excess of 1.5 ranging to 4.2 (middle Jurassic). Jurassic thicknesses in excess of 3 km have been reported along the northeastern margin of the Qaidam Basin. We failed to recognize such large thicknesses on seismic profiles and therefore are unable to explain the reason for the great thickness reported. Possible explanations are: thickness increases due to structural repetition, or else due to the formation of local grabens. It is, however, unlikely that the reported thickness increase towards the Qilian Mountains has much to do with the formation of these mountains, which occurred much later during the Tertiary.

The Paleogene of the Qaidam Basin consists of lacustrine and continental brownish-red mudstones, sandstones, and some conglomerates. Source beds reported have typically less than 1% total organic carbon. These source beds are in the upper Oligocene at the northwestern end of the basin. Isopachs thin towards the Altun Shan and pinch out along a southwest-northeast trend near Golmud. The greatest isopach thickness in excess of 2000 m - like the source beds - is located in the northwestern part of the basins.

Miocene and Pliocene formations consist of continental to lacustrine brown, yellow, and gray mudstone and sandstones. Source beds are located in the northwestern deep portions of the basin, again showing fairly low contents of total organic carbon (below .8%). The Miocene and Pliocene reach thicknesses in excess of 8000 m in the northwestern center of the basin.

During the Quaternary as the Qaidam Basin gets filled up, the isopachs more closely coincide with the present-day center of the basin. Gas source beds with low content of total organic matter occur in the center of the basin.

We were particularly pleased to have the opportunity to see a large number of high-quality regional reflection profiles in the Qaidam Basin. Combined with the maps and sections offered to us by our Chinese colleagues at Dunhuang, we came up with a structural interpretation that is illustrated on Figures 10-14.

A generalized tectonic map was drawn using a map that was provided to us by the Exploration Research Institute of the Qinghai Petroleum Administration. We combined that map with the 1,500,000 map of the Qinghai-Xizang Plateau. The result (Figure 11) shows all documented or presumed Tertiary deformation in the area. In that perspective, the Qaidam Basin is essentially a Tertiary synclinorium that was formed as a consequence of the India-Eurasia collision. The collision began sometimes during the Eocene and is still continuing today.

The Qilian Mountains to the north of the Qaidam Basin have a dominant vergence toward the northeast forming the load that may be responsible for the subsidence of the basins in the Gansu Corridor. On the northeast flank of the Qaidam Basin, however, we see southwest-verging thrust faults forming the main margin of the Qaidam Basin. The Altun Shan left-lateral strike-slip system forms the northwestern boundary of the basin, and the northwest-verging overthrusts of the Kunlun Shan form the southern margin of the basin.

Seismic reflection profiles permit an interesting kinematic resolution of the formation of the Qaidam Basin. A SE-NW striking reflection profile near the Altun Mountains (Figure 14) shows growth (i.e., updip convergence of beds on anticlines) during an interval starting from the Eocene and ending at the base of the middle Pliocene. Convergence and growth are then resumed during the late Pliocene and Quaternary.

Similar Paleogene and early Neogene growth is not observed on the Qilian Shan and Kunlun Shan flanks of the basin. From this observation, one may tentatively conclude that an earlier Paleogene to early Neogene Qaidam Basin formed at the inception of the Altun Shan strike-slip system. The axis of that early Qaidam Basin was subparallel to the Altun Mountain strike-slip system, as is also suggested by the Paleogene isopachs. Subsidence in the northwest part of the basin was probably due to loading by thrust sheets associated with the Paleogene strike-slip system.

On the Kunlun side of the Qaidam Basin the timing of the deformation is much later. Anticlines exhibit virtually no convergence prior to the Pliocene, implying that the margin of the basin was farther west. On the other hand, anticlines associated with the Kunlun system show vigorous growth (i.e., updip stratal convergence during the Pliocene and Pleistocene). (Figure 14)

On the northeast side growth on structures is limited to late Pliocene and Pleistocene strata. Most, if not all, of the anticlines appear to be of Plio-Pleistocene age, and they do not reveal any obvious early growth history. Note also that based on what we see on the reflection seismic profiles, most structures involve the pre-Mesozoic basement.

Looking at a larger scale (Figure 11 and 12), the Qaidam Basin forms part of a collisional tectonic belt that includes the Tibetan Plateau and the Qilian

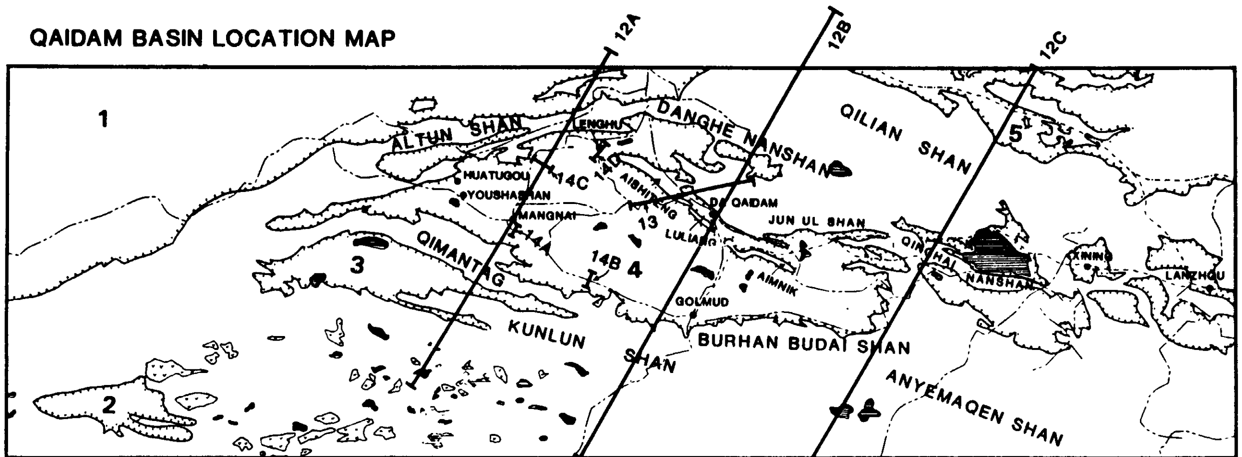
Mountains to the north. Widespread evidence for compressional and strike-slip faulting suggests to us the presence of a mid-crustal decollement level because it is difficult to visualize a widespread series of regional synclinoria not being connected by some sort of a relay system. Of course, our hypothesis needs proof that could come only from a crustal reflection seismic profile across the Qilian Mountains, the Qaidam Basin, and the Tibetan Plateau to the south.

By way of additional information, we would like to point out that there is a consensus that the Tibetan Plateau is underlain by an unusually deep Moho. We are not aware of any map that would provide detailed documentation for depth of the Moho in various locations on the Tibetan Plateau. Xie Mingqian et al. (1985) indicate that the Moho is at 52 km in the central part of the Qaidam Basin, 56 to 62 km in the Golmud area and on the south side of the basin, and 60 to 58 km on the northside of the basin in the Da Qaidam and Delingha areas.

Geothermal gradients are 30 - 50 c/km at the north side of the Qaidam Basin and 50 - 60 c/km at the northwest edge of the basin. Temperature gradients are 30 - 50 c/km in the west and 30 - 50 c in the east.

Farther south in Tibet Hirn et al., (1984) have published refraction studies that show major strike-slip fault systems offsetting the Moho and reaching into the underlying mantle. This suggests a segmentation into lithospheric blocks.

QAIDAM BASIN LOCATION MAP



BASIN OUTLINE
1 TARIM BASIN
2 QINGTANG BASIN
3 KUMKULIG BASIN
4 QAIDAM BASIN
5 MINLE BASIN
LAKE
ROADS
RAILROAD
PLIO-PLEISTOCENE VOLCANICS

FIG. 10

TECTONIC SKETCH MAP OF NE-QINGHAI PLATEAU AND QAIDAM BASIN BASED ON PETROLEUM BUREAU OF QINGHAI AND GEOL. INST. OF QINGHAI-XIZANG PLATEAU

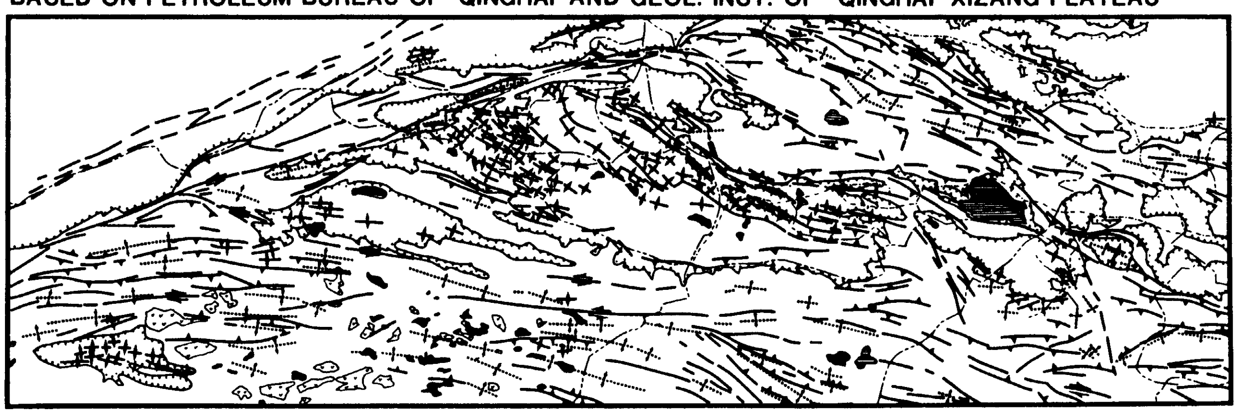


FIG.11

BASIN OUTLINE
THRUST FAULT
STRIKE SLIP FAULT
ANTICLINE
SYNCLINE
PLIO-PLEISTOCENE VOLCANICS

Figure 10

Location map of the Qaidam Basin. Location on cross-sections on Figure 12 are also indicated. (A. Bally)

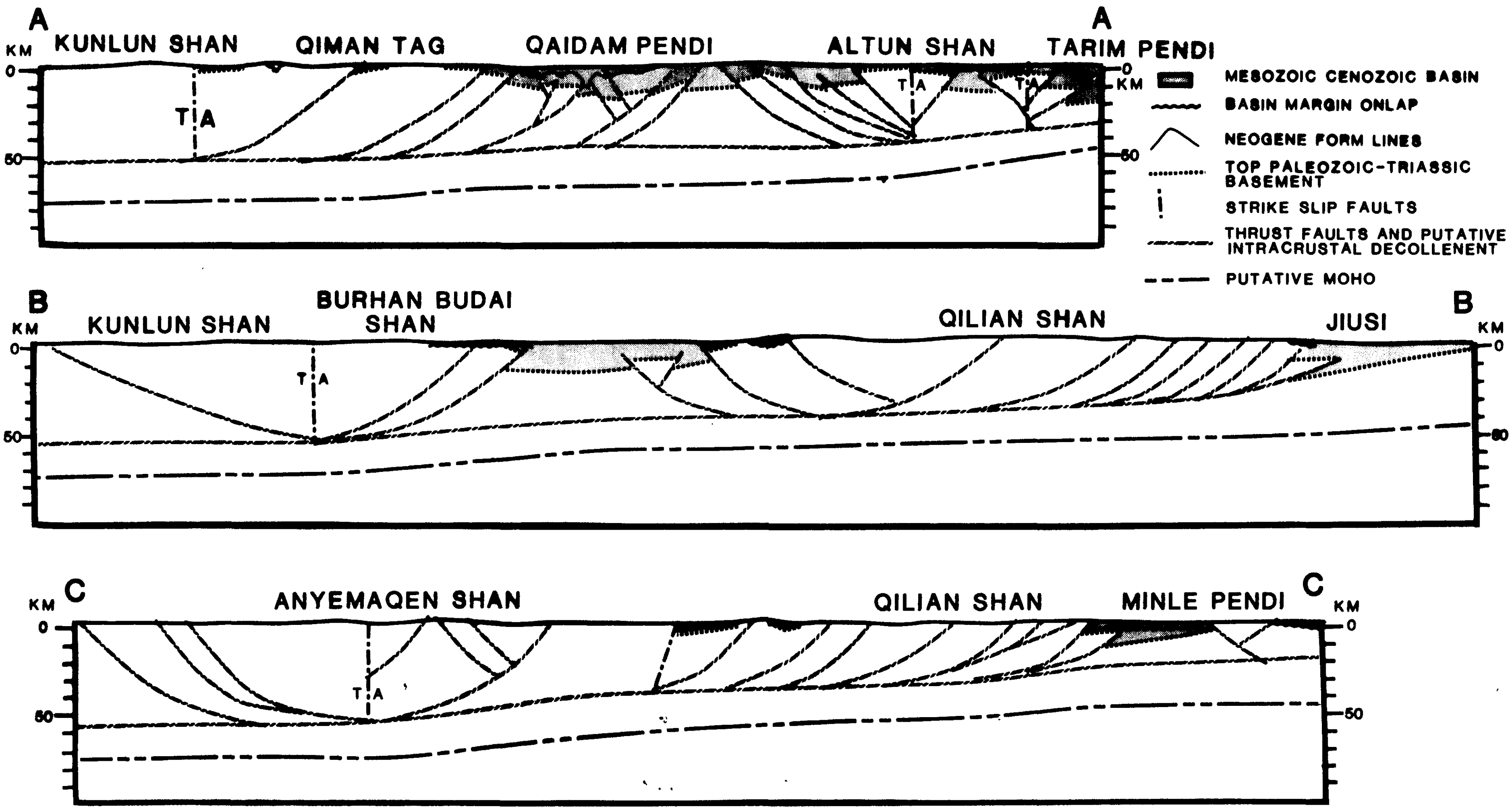
Figure 11

This tectonic sketch map of the Qaidam Basin and parts of the adjacent NE-Qinghai Plateau is based on a map provided by the Petroleum Bureau of Qinghai that was combined with information derived from the geologic map of the Qinghai-Xizang (Tibet) Plateau (Geological Institute of Qinghai-Xizang Plateau, Chinese Academy of Geological Sciences, 1980).

All structural features shown are either documented or inferred to be of Tertiary age. The vergence of the many small thrust faults in the Qaidam Basin was verified by inspection of a grid of reflection seismic profiles.

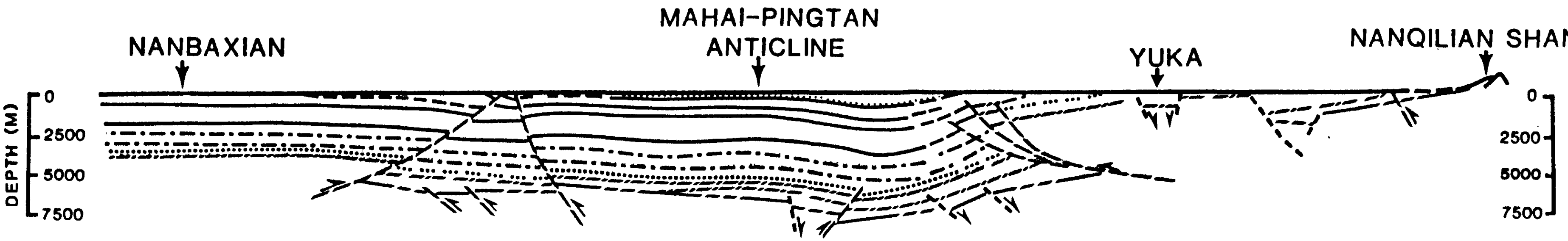
Note that the Tibetan Plateau appears to be characterized by pervasive Tertiary compressional structures. The map emphasizes synclinoria. The compressional nature of these features needs to be further verified in the field. Note also that the small Kumkulig Basin to the southwest of the Qaidam Basin replicates the general outline of the Qaidam Basin.

It may be concluded that the Qaidam Basin is in essence a Tertiary synclinorium and that is bounded by a strike-slip system which is associated with the Altun Shan (see also Wang Ningguo, 1982). To the north the Qaidam is overthrust by southwest-verging thrust fault, and to the south the basin is overthrust by northward verging thrust fault. (AWB)



SCHEMATIC STRUCTURE SECTIONS ACROSS QAIDAM BASIN (QINGHAI PROV.) — A.W.BALLY

Figure 12: Schematic structural sections across the Qaidam Basin and its surrounding mountain ranges. For location, see Index map, Figure No. 10. These simple sections illustrate the concept that the Qaidam Basin, the Qilian Shan to its north, and the Kunlun Shan of the northern Tibetan Plateau form part of a major crustal decoupling system with associated strike-slip faults and thrust faults with conjugate vergences. The depth of the decoupling level is hypothetical and presumed to be somewhere in the middle crust. This hypothesis could be tested by deep crustal reflection seismic profiles. Note that this concept also postulates that the whole Tibetan Plateau is underlain by an intracrustal decoupling level, which will ultimately merge into the south-verging Himalayan thrusts. (AWB)
An alternative concept would have the Moho offset by strike-slip fault and accommodate the overthrust in huge flower-structures (see Hirn et al., 1984).



LEGEND:

QUATERNARY (Q)
UPPER PLIOCENE (N_2^3)
MIDDLE PLIOCENE (N_2^2)
LOWER PLIOCENE (N_2^1)
MIOCENE (N_1)
OLIGOCENE (E_3)
PALEOCENE-EOCENE (E_1-E_2)
CRETACEOUS (K)
JURASSIC (J)
JURASSIC (J_1-J_3)
BASEMENT

GEOLOGIC CROSS SECTION OF SEISMIC LINE 1001

ACROSS NANBAXIAN-- MAHAI-PINGTAN-- YUKA AREAS

Figure 13

Geologic cross-section across northeast margin of Qaidam Basin (after Di Hengshu, 1984). This section reproduces a SE-NW seismic reflection profile across the central part of the Qaidam Basin.

Note the southwest verging thrust fault system that forms the northern boundary of the basin.

Note also that there is no significant convergence towards the basin margin. This observation suggests an original basin margin that would be located farther to the northeast and that has been eroded subsequently. The Jurassic extensional features suggest one possible interpretation of the seismic profile. However, obvious normal faulting affecting Jurassic strata was not observed on the seismic profiles that we saw.

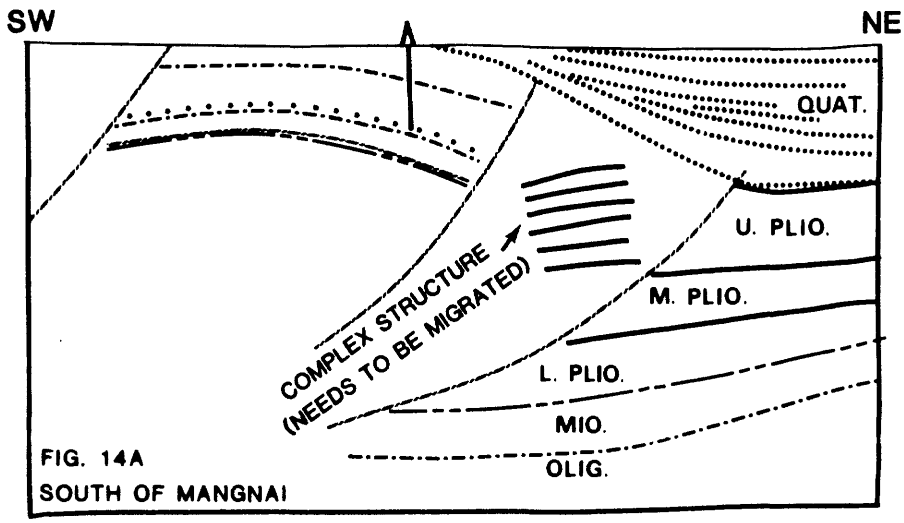


Figure 14a.

Sketch of reflection profile south of Mangnai area (Western Qaidam Basin). Note post - Upper Pliocene structure and updip convergence of Quaternary beds, indicating Quaternary growth.

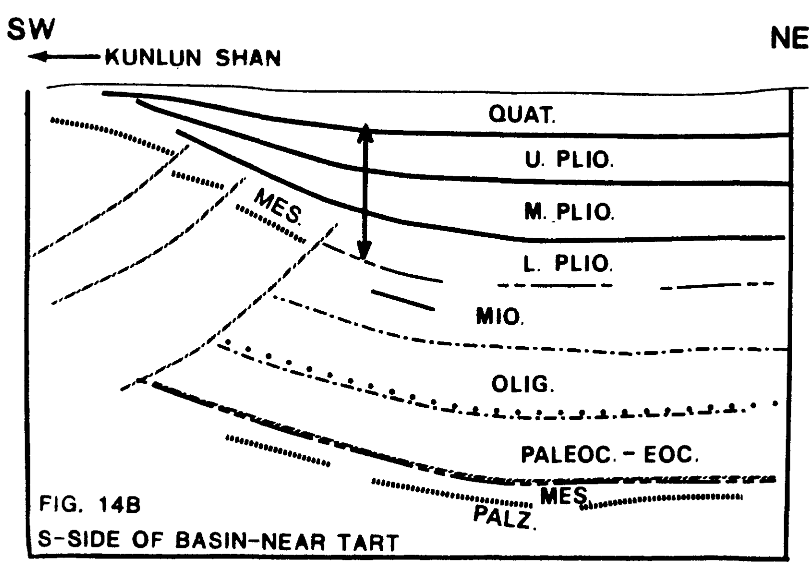


Figure 14b.

Sketch of typical reflection profile on the SW-flank of Qaidam Basin. Note updip convergence of mid-Pliocene to Quaternary strata indicating late Neogene formation of southwest side of Qaidam Basin.

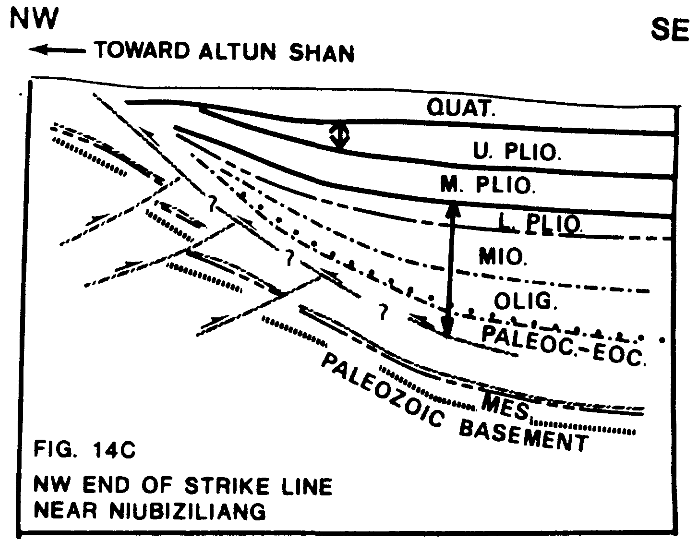


Figure 14c.

Sketch of reflection profile across NW end of Qaidam Basin. Contrast the early growth from late Paleogene to mid-Pliocene suggesting a late Paleogene inception of the Altun Shan strike slip fault system in response to the beginning India-Eurasia collision.

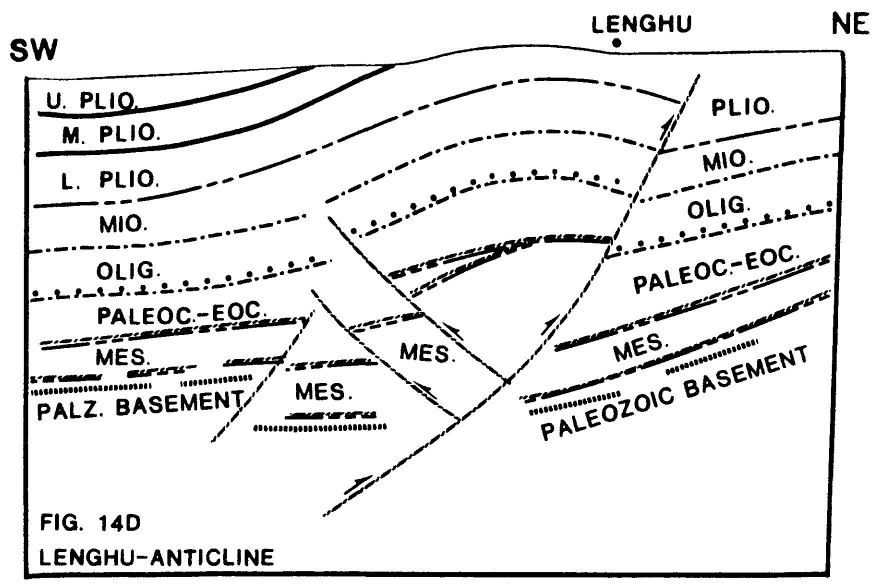


Figure 14d.

Sketch from seismic profile across Lenghu anticline. Contrast vergence toward northeast, with the southwest vergence of the section shown on Figure 13. Note also post-Upper Pliocene formation of the basement-involved Lenghu anticline.

B. Stratigraphy and sedimentation (RR)

The sedimentary fill in the Qaidam Basin is Jurassic through Holocene in age and attains a thickness as much as 15 km. The terrigenous clastics derived from the adjacent Altun, Kunlun, and Qilian Mountains that surround the basin and the subordinate carbonate and evaporite rocks are all nonmarine, closed-basin deposits. In general, the rocks grade basinward from 1) conglomerate, conglomeratic sandstone, sandstone, and red shale of alluvial fan and alluvial plain origin to 2) interbedded medium-to-fine grained sandstone, green to gray shale, and carbonate mudstone and grainstone of nearshore lacustrine origin to 3) gray to brown shale and siltstone and intercalated evaporite beds of offshore lacustrine origin. The generalized geologic cross section from the Qilian Mountains to the Han No. 2 drill hole (Figure 15) is an example of how Chinese geologists and geophysicists view the distribution of rocks of alluvial plain and lacustrine origin in the Qaidam Basin. This section was constructed from drill hole and seismic data. Additional geologic cross-sections that emphasize the lithofacies and depositional environments of the Tertiary sequence in the Qaidam Basin are presented in Qian Kai et al. (1985).

Correlation of major stratigraphic units: Chinese geologists studying the Qaidam Basin have the same problems that other geologists have with rock- and time-stratigraphic correlations in thick nonmarine sequences. Typically, the sedimentary rocks in the Qaidam Basin are characterized by abrupt facies changes, few laterally continuous marker beds, and sparse fossil assemblages dominated by ostracodes and charophytes. However, excellent outcrop data in combination with nearby well and seismic data have enabled the Chinese to establish reasonably good correlations throughout the basin.

Correlations might be further refined through the use of tuff beds as recognized in middle (N_2^2) and upper (N_2^3) Pliocene beds that crop out along the southwest limb of the Dafengshan anticline. These beds are very thin, but detailed stratigraphic studies may find them over widespread areas of the basin. Moreover, radiometric age dates might be obtained from biotite in the tuffs.

Ostracode grainstones and ostracode-bearing carbonate mudstones as recognized in the lower Oligocene and Miocene sequence in the core of the Shizigou anticline may extend 5 to 10 km along the outcrop belt and into the adjacent subsurface. These beds are good marker beds on a local scale and possibly on a basinwide scale if extensive overlap between the beds can be demonstrated.

Palynomorph zones have been established for the Tertiary, Cretaceous, and Jurassic Periods throughout much of the world and are particularly valuable for determining the age relationships among nonmarine rocks. **The rocks of the Qaidam Basin should be sampled and analyzed for palynomorphs for the purpose of possibly refining the stratigraphic correlations in the basin.**

At many localities along the margin of the Qaidam Basin (e.g., Lulehedonggou and Shizigou anticlines) many of the systemic and series boundaries are marked by unconformities. Commonly, these unconformities are confined to anticlines that were growing at the time of sedimentation. However, in some cases the unconformities associated with the anticlinal structures may be more widespread. Knowledge concerning the lateral extent and stratigraphic position of the major unconformities in the basin not only might improve the quality of stratigraphic

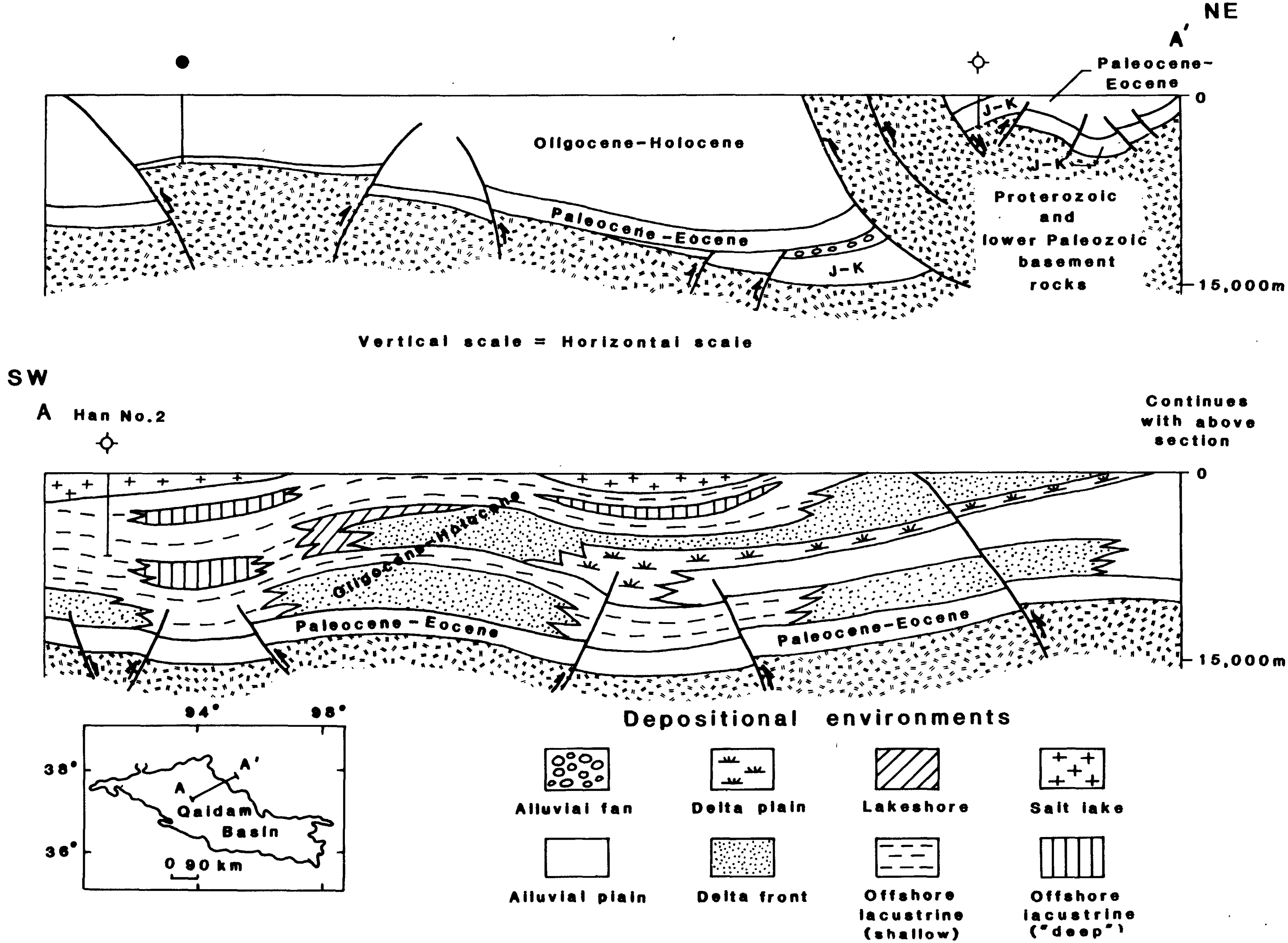


Figure 15

Sketch of generalized geologic section through the northern part of the Qaidam Basin emphasizing major depositional environments as interpreted by geologists and geophysicists of the Qinghai Petroleum Bureau.

correlations but also might help define stratigraphic traps and pathways of oil migration.

Finally, the importance of having excellent outcrops very close to wells and seismic lines should be reemphasized. Wherever possible, outcrops data should be tied to adjacent wells that are in turn tied to seismic data by synthetic seismograms or vertical seismic profiles. The established stratigraphic correlations should be continually tested as new outcrop and subsurface data are acquired.

Lithofacies and depositional environments: Six major lithofacies were observed during the one-week field trip. A brief description and an interpretation of the depositional setting of each lithofacies are presented in the following text. Most examples are drawn from the Tertiary sequence.

Cobble- to pebble-sized conglomerate, conglomeratic sandstone, red shale, and mudstone derived from nearby tectonic uplands represent the deposits of an alluvial fan system. Commonly, the major lithologic units are arranged in upward-coarsening and upward-thickening sequences from 3 to 10 m thick (Figure 16a). Red shale and mudstone appear at the base of the sequence, followed by conglomeratic sandstone and coarse-grained sandstone, which in turn are followed by cobble-and pebble-sized conglomerate. Commonly, 1-to 10-cm thick, well-indurated beds of caliche (calcium-carbonate cemented gravel, sand, silt, and clay) cap the conglomerate beds (Figure 16a). The conglomerate units are massive to crudely stratified beds with local scour features at their base; crudely stratified units are thickly to very thickly bedded with planar beds being the dominant sedimentary structure. The clasts are sub-angular to sub-rounded, locally imbricated, set in a coarse-grained sandstone matrix, and supported predominantly by adjacent clasts. The conglomeratic sandstone and sandstone units are thin to average bedded with planar beds being the dominant sedimentary structure. Channel-form beds and medium-scale cross-beds are rare. Ostracode- and charophyte-bearing calcareous terrigenous mudstone and argillaceous carbonate mudstone beds up to 3 m thick of probable lacustrine origin are locally intercalated with the red shale and mudstone units. This lithofacies is best exposed in outcrops of early and late Oligocene age ($E_3{}^1$ and $E_3{}^2$) in the Shizigou anticline.

Sandstone bodies up to about 50 m thick and at least 2 km wide, composed of numerous composite channel-form units, were deposited in a well-integrated perennial braided channel system. This channel system probably was incised into the original alluvial fan system and initiated a second-generation alluvial fan that may have been larger than any single fan of the first system. The headwaters of the braided stream system extended far beyond the origin of the relatively short braided channels that fed the first-generation alluvial fan (Figure 16b). The base of the individual channel-form units is marked by low-relief scour surfaces, filled locally with pebble-and granule-sized clay rip-up clasts. Shale, mudstone, and siltstone deposits and channel-form sandstone units with high-relief scour surfaces are uncommon. Individual channel-form sandstone units are coarse- to medium-grained and thickly to average bedded with planar beds and low-angle cross-beds being the dominant sedimentary structures. This lithofacies is best exposed in outcrops of late Pliocene ($N_2{}^3$) age between the Shizigou anticline and the town of Huatougou.

Thinly to very thinly bedded red shale, red mudstone, and fine- to very fine-grained sandstone with interbeds of thick- to averaged-bedded, medium- to

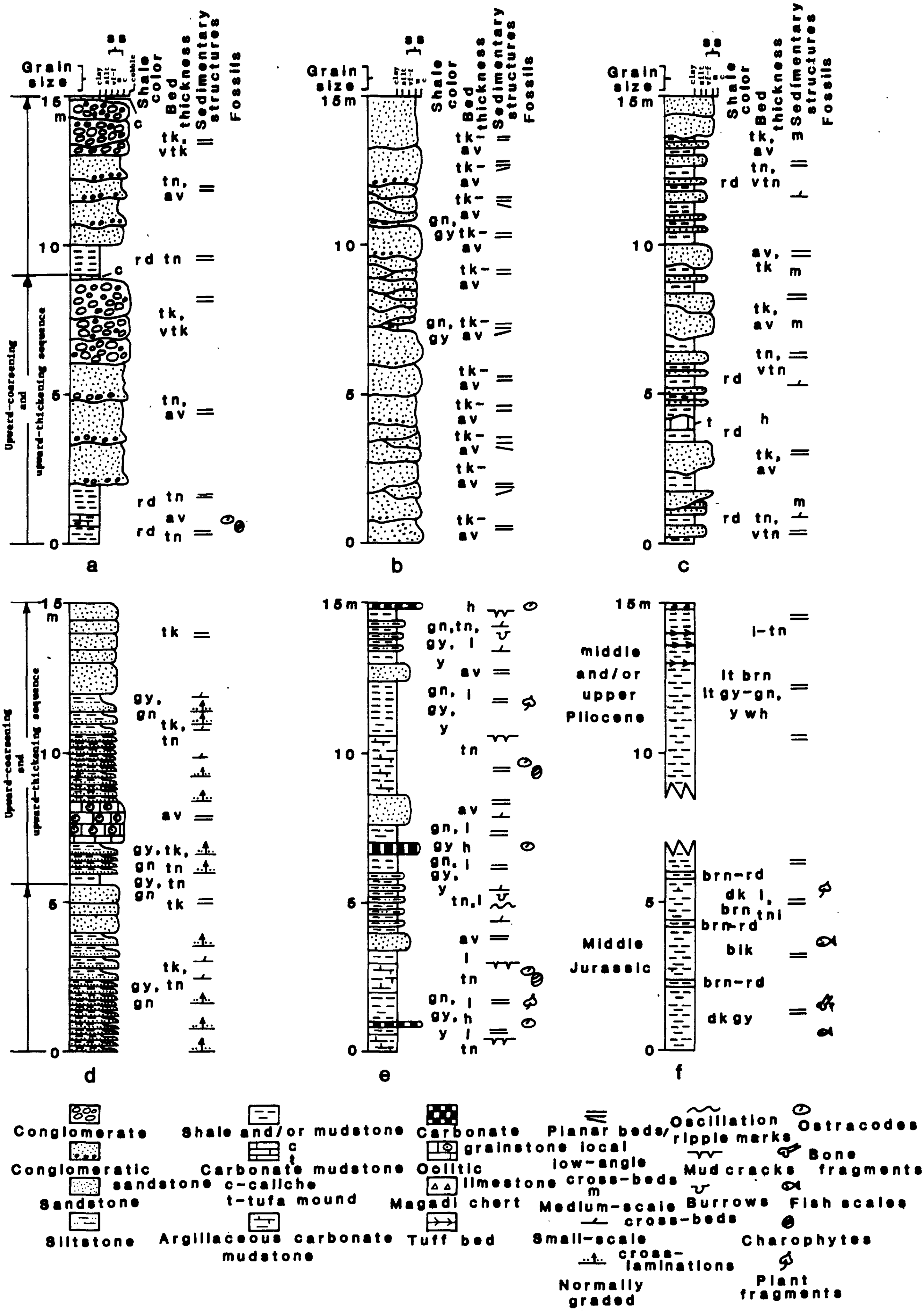


Figure 16

Typical sedimentary sequences exposed along northern margin of the Qaidam Basin.

fine-grained channel-form sandstone probably were deposited in an alluvial plain system downslope from the first-generation alluvial fan system (Figure 16c). The channel-form sandstone units are as much as 3 m thick and exhibit low-relief scour surfaces at their base. Planar beds are the dominant sedimentary structure in the channel-form units, but medium-scale cross-beds are common. Sedimentary structures of the thinner-bedded and finer-grained sandstone units are characterized by planar beds and local small-scale cross-laminations. Laterally persistent tufa mounds as much as 3 m thick are locally intercalated with the red shale and sandstone sequence suggesting that at times the alluvial plain was inundated by lacustrine water and that nearby springs discharged carbonate-rich groundwater into the lake. These springs may also have been an important source of water for eroding many of the channels in the alluvial plain system. This lithofacies is well exposed in outcrops of the Youshashan formation of early Pliocene age ($N_2{}^1$) in the Youshashan and Shizigou anticlines.

Normally graded and planar bedded sandstone units with intercalated green to gray mudstone and siltstone and local oolitic limestone represent the deposits of a sandstone-dominated lacustrine shoreline system (Figure 16d). Commonly, the sandstone units are arranged in upward coarsening and upward-thickening sequences from 3 to 15 m thick comprised of thin-to thick-bedded normally graded sandstone units in the lower two-thirds of the sequence and planar-bedded sandstone units as much as 3 m thick in the upper third of the sequence (Figure 16d). The normally graded sandstone beds grade upward from coarse-grained sandstone with granules and local scour features at the base to fine-grained sandstone at the top. Green to gray, 2 to 5 cm-thick shale and mudstone beds, intercalated with small-scale cross-laminated siltstone, cap many of the normally graded sandstone beds. The graded sandstone beds possibly formed on the offshore part of a lacustrine fan delta, whereas the planar-bedded units at the top of the sequence possibly formed on the nearshore, shallower water part of a lacustrine fan delta. Sheetfloods interacting with tranquil lacustrine water may have been the dominant depositional process. The oolites in the oolitic limestone units consist of well rounded, fine- to medium-sized quartz grains enclosed by several layers of white chalk-like calcite. The oolitic limestone was probably formed along the shoreline of a sulfate or carbonate-rich lake during expanding or stable phases of the lake. The lithofacies shown in Figure 16d is well exposed in outcrops of late Pliocene age ($N_2{}^3$) along the northeast flank of the Mangya anticline.

Interbedded units of light green, yellow, and light gray mudstone, silty mudstone, shale, fine-grained sandstone and siltstone, partly fossiliferous (ostracodes, charophytes, plant fragments) carbonate mudstone, and ostracode grainstone formed along a carbonate-dominated lacustrine shoreline system (Figure 16e). The majority of these strata are thin bedded to laminated and commonly contain burrows, tracks and trails, and desiccation cracks. The desiccation cracks range from a few centimeters to approximately 1 m in length and in plane view have a rectilinear pattern. These desiccation cracks indicate that the lacustrine shoreline deposits were commonly exposed to subaerial conditions. Many of the sandstone and siltstone units show planar laminations, small-scale cross-laminations, flaser beds, load casts, and oscillation ripple marks. This lithofacies is well exposed in lower ($N_1{}^1$) and upper ($N_1{}^2$) Miocene rocks of the Shizigou anticline.

Sequences dominated by light gray-green, light brown, and yellow white, thinly bedded to thinly laminated calcareous mudstone with local thin beds of tuff, magadi chert, and anhydrite nodules were probably deposited in an offshore lacustrine system (Figure 16f, upper part). Magadi chert and anhydrite nodules originate from brines having vastly different chemical properties and thus do not coexist at a single locality (see discussion by Eugster in Part C of this chapter). Outcrops of offshore lacustrine mudstone, containing tuff beds and magadi chert, are located in middle (N_2^2) and/or upper (N_2^3) Pliocene rocks along the southwest limb of the Dafengshan anticline. Dark gray, dark brown, and black, thinly laminated calcareous shale of Middle Jurassic (J_2^7) age, exposed 10 to 15 km southeast of the Yuka anticline, had the highest concentration of organic matter of the offshore lacustrine deposits we visited (see discussion by Bally in Part A of this chapter). Fish scales, plant fragments, bone (?) fragments, and small mica flanks are commonly scattered along bedding surfaces (Figure 16f, lower part). The total thickness of the dark-colored shale at this locality, including local interbeds of 15 to 25 cm-thick, brick-red shale, is about 100 m.

The generalized diagram on Figure 17 is an attempt to synthesize the previously discussed lithofacies into a single depositional model. An eolian dune system is included in the model because eolian dunes are common features in the present-day Qaidam Basin. Probably this conceptual model is oversimplified because it is based largely on outcrop data and because all the cited lithofacies may not have coexisted at a given time. Continual changes in lake chemistry, provenance (related to tectonic history), and climate commonly dictate which lithofacies will be predominant at a given time as well as their geometry and distribution. As new data become available, the model can be modified and refined, or abandoned. Many of the environments cited in the depositional model (Figure 17) probably can be found in the present-day Qaidam Basin. Therefore, a detailed study of recent depositional environments of the basin would be an important step toward understanding the ancient sedimentary rocks of the basin and their facies relations, particularly those of Pliocene age. The addition of an eolian dune system to the depositional model (Figure 17) without supporting outcrop evidence shows the importance we place on modern analogues for aiding in the interpretation of ancient depositional environments in the Qaidam Basin. That similar studies of depositional environments are important has been shown by Qiu Yinan et al. (1980) for the Daqing oil field.

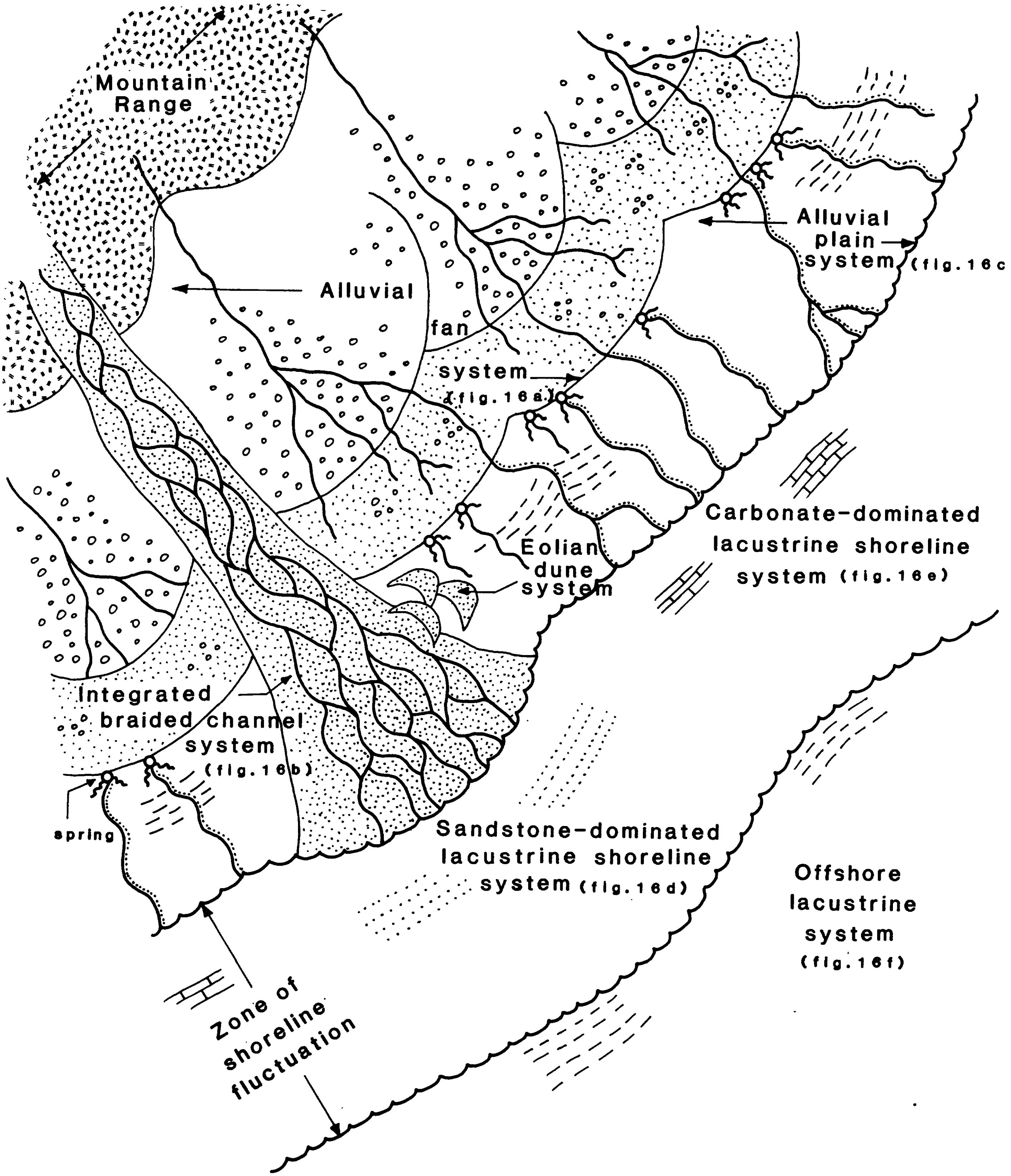


Figure 17

Depositional model for sedimentary sequence of the Qaidam Basin. Shoreline in model is approximately 100 km in length. Note the terminology used in this model differs slightly from the terminology used by Eugster in Part C of this chapter.

C. Source beds (HPE)

During our trip to the Qaidam Basin we were shown only one source bed that was reasonably rich in TOC (total organic carbon): bed J_2^7 of the Jurassic. We were, however, able to make some interesting observations relating to the geochemistry of the Tertiary paleolakes that occurred in the Qaidam Basin. These observations tie in nicely with the structural evolution of the basin deduced by A. W. Bally from the seismic reflection profiles. Furthermore, we know that the present Charhan salt lake contains unusual amounts of potassium represented by the mineral carnallite ($KMgCl_3.6H_2O$). It should be pointed out that such potassium concentrations can form only by evaporation of a very large body of open water. If circulation had been largely subsurface, most of the K would have been absorbed by the clay and volcanic glass surfaces. This problem has been discussed in detail by Eugster and Jones (1979).

Qaidam source beds must be lacustrine, and such source beds differ significantly from marine source beds. Nearly all published accounts deal with marine source beds. Lacustrine source beds are formed under the following conditions:

1) Large lake, protected from clastic silicates

2) High organic productivity, because of high nutrient levels (P, N, K).

3) Anoxic sediment-water interface, preserving some of the phytoplankton-derived TOC, no infauna

4) Small authigenic carbonate input, protecting TOC's from dilution

5) Rapid lateral and vertical facies changes in response to tectonic and climatic events

6) Concentric facies patterns

7) Source beds are dominated by inorganic carbonates (calcite and dolomite)

8) Water chemistry may be $Na\text{-}CO_3$ or $Ca\text{-}SO_4$ dominated, depending on water source

Some of these aspects have been discussed in Eugster and Kelts (1983) and Eugster (1985). The sedimentology of closed basins was investigated by Hardie et al. (1978) and by Smoot (1983), whereas the mechanics of carbonate production was studied by Smoot (1978). From basin edge to basin center, the following lithofacies were observed: Alluvial fans - sand flats - dry mud flats - saline mud flats - perennial lake (or salt pan). Siliciclastics reach out to the dry and saline mud flats. In the saline mud flats, groundwater is close enough to the surface for evaporative concentration. The first mineral to precipitate in the muds or on the surface by this process is calcite, $CaCO_3$, regardless of water chemistry. During calcite precipitation, the Mg/Ca ratio in the water increases, eventually causing protodolomite to replace calcite. Upon continued evaporation, saline minerals may form within the muds, such as gypsum ($CaSO_4.2H_2O$) or halite (NaCl).

In the perennial lake environment, only mud-size inorganic material is present, either washed in by sheet floods from the mud flats, transported by wind or formed in situ. Allochthonous material is either siliciclastic or carbonate (calcite or dolomite), whereas the authigenic material is largely $CaCO_3$ precipitated in response to algal blooms, which remove CO_2 and raise the pH. Such blooms are most frequent in spring-summer, leading to the formation of a carbonate-rich summer lamina. In the fall, algae die and accumulate as a dark, TOC-rich lamina. Such a laminated kerogen-rich limestone is the principal source rock of the Green River Formation in the U.S. ("oil shale").

The size of the perennial lake is not constant. It may expand and become fresher and more oxygenated. This change destroys most of the TOC and does not lead to a good source rock, or the lake may shrink and form a small central salt lake, also terminating source bed formation. In other words, good conditions for source bed formation depend on a delicate balance between carbonate precipitation and kerogen accumulation. Optimal conditions for total organic carbon accumulation and preservation exist during the regressive phase, when salinity is raised, nutrients are concentrated, and there still is enough water for extensive algal blooms.

Finally, it should be remembered that in closed basins, braided streams may reach far out into the basins, carrying porous sands to the vicinity of the source beds.

We now must consider the effect of water chemistry on the nature of the chemical sediments deposited. For the Qaidam Basin we need to consider only two types:

a) dominated by $Na\text{-}CO_3$

b) dominated by $Ca\text{-}SO_4$

The first type (a) is that typical of the Green River Formation (Bradley and Eugster, 1969). It is formed by weathering of most igneous and metamorphic rocks and leads to high pH brines (Eugster and Hardie, 1978). It can be recognized by the presence of flinty bedded chert known as "Magadi-type" chert (Eugster, 1969; 1980; Surdam et al., 1972) formed when the silica-rich brines of the lake are flooded by less saline water. The presence of brines can also be recognized by the presence of zeolites in volcanic tuff beds. As shown by Sheppard and Gude (1968) and Surdam and Sheppard (1978), a zonation according to salinity is established. From fresh (basin margin) to saline (basin center), the following authigenic mineral formation is observed: smectites - zeolites (erionite, clinoptilolite, mordenite) - analcime - K-feldspar. This zonation can be used as a proximity indicator to basin center, but the mineralogic determination must be done by X-ray and microscopy.

The second type (b) is rich in Ca and SO_4 and poor in CO_3. This type is similar to seawater and never reaches a high pH. Hence bedded cherts are never formed from such waters. The sulfate source for such waters is either the dissolution of old evaporites or the oxidation of sulfide ore deposits.

The brief sedimentological-geochemical framework outlined here can now be used to summarize our field trip experience in the Qaidam Basin.

(1) Using the tectonic model proposed by A. W. Bally, we can deduce that by the end of the Oligocene a basin existed in the West with a SW-NE axis, dominated by the Altun Shan strike-slip fault. In the upper Miocene and middle Pliocene (specifically N_1 and N_2) we observed the presence of bedded chert of the

Magadi type indicating $Na\text{-}CO_3$ water types (alkaline waters). Water sources probably were dominantly from the Altun and Qilian Mountains.

(2) In the middle-upper Pliocene, the presence of synsedimentary nodular gypsum horizons (N_2^3) indicate that by this time the water chemistry had changed from $Na\text{-}CO_3$ to the $Ca\text{-}SO_4$ type. This change is probably due to the fact that the basin axis had changed to ESE-WNW because of the activity of the Kunlun fault, moving the depocenter from the South to the East. This brought shift waters from further East into the main trough, for example waters of a precursor of the Golmud River, draining the Tibetan Plateau. These waters must have been sulfate-rich, affecting the water chemistry of the whole basin. Many salt lakes of Tibet are rich in sulfate.

(3) Middle Miocene-middle Pliocene was a relatively quiescent time tectonically, and this may have been a propitious time for forming source beds, because of the relative protection from clastics. Toward the middle Pliocene, extensive evaporites seem to have formed, perhaps visible on seismic sections, and this event would have terminated source bed accumulation for the time being. On the other hand, these evaporite beds would also form excellent stratigraphic seals for the underlying source beds.

(4) Much more work is needed to verify some of these speculative ideas, but it is encouraging to note that structural and geochemical arguments seem to converge.

TABLE 1: Depositional subenvironments of chemical and biochemical lacustrine deposits.

A. Hydrologically open hardwater lake: fixed shoreline	
1. *Littoral*	Beaches, bioturbated micritic carbonate, massively bedded, with variable proportions of organic matter, siliclastics, diatoms Charophyte chalks, ostracod, molluse, debris and lag deposits. Bioherms, stromatolites, oncolites, cemented in part.
2. *Pelagic, oxygenated* (full circulation)	Bioturbated micritic carbonate muds and silts with organic matter, siliciclastics, and diatoms.
3. *Pelagic anoxic* (seasonally or permanently stratified)	Carbonate (algal) laminites, interbedded with carbonate turbidites. Variable amounts of siliciclastics, diatoms.
B. Hydrologically closed, perennial lake: shorelines moves	
1. *Supralittoral*	Laminated to thin-bedded carbonate muds, silts and sands with variable amounts of siliciclastics. Flat-parallel and lenticular laminations, scour-and-fill structures, mudcracking, burrowing, evaporative cements, efforescent crusts, salt casts, dry mud flats.
2. *Intralittoral* (saline mud flats)	Transgressive-regressive sequences of carbonate muds, silts and sands. Flat-pebble conglomerates, mudcracking, bioturbation, salt disruption. Coated pebbles, pisolites, oolites and dripstones.
3. *Eulittoral* (perennially flooded)	Laminated or bioturbated muds, silts, or sands. Oncolites, bioherms, stromatolites. Carbonate-bypsum laminates, carbonate-kerogen laminites (oil shales). Bedded salts.
4. *Pelagic*	Oxipelagic - full circulation: bioturbated muds, displaced fauna, flora, current structures, winnowing Oxoxic - carbonate-kerogene laminites (oil shales), carbonate-gypsum laaminites, turbidites, bedded salts.
	C. Ephemeral salt lake
	As above with additional efflorescent crusts, interstitial brine precipitates, bedded salts.

D. Conclusions (AWB)

The Qaidam Basin is a Tertiary synclinorium that is bound by the Altun Shan left lateral strike-slip system to the northwest, by north-verging thrust faults of the Kunlun Shan to the south, and by southwest-verging thrust faults of the Qilian Shan on the northeast flank of the basin. Numerous compressional anticlines occur within the basin. These anticlines typically have thrusted cores. Basement is involved in the formation of most anticlines.

Most of the Mesozoic and Cenozoic fluvio-lacustrine sediments can be described with a single depositional model (Figure 17). The occurrence of source reservoirs, beds, and evaporitic seals can be explained within the context of such a model.

We recommend that an integrated regional study of the origin and evolution of the Qaidam Basin be undertaken. Such a study would begin with the integration of the available regional seismic reflection profiles with surface and subsurface information. A paleohistory needs then to be developed for the whole basin. In other words, one needs to map regional and local structural gradients that control the hydrocarbon migration paths. A review of the source bed information is needed in order to assess the specific shale horizons that qualify as source beds. There is also a need to determine the regional distribution of sealing and reservoir formations. Such studies are in our judgment necessary to determine the long range exploration plans for the Qaidam Basin.

From the perspective of basic research we see two important projects:

1) Two deep wells in the south central portion of the basin north of Golmud. These wells should be cored as far as possible to assess the source bed potential of that area. Vertical seismic profiling would be particularly important to resolve the problem of poor seismic records in that area.

2) A crustal seismic reflection profile combined with and calibrated by refraction profiles. Such a profile could well reveal the presence of deep crustal reflectors. Such a project would envisage twenty-five second records to give an opportunity to see the base of the crust. We would hope that such a project would reveal the presence or absence of lithospheric strike-slip faults and/or deep decoupling levels, as well as any type of layering within the thick continental crust that underlies the area. Such a project could be tied to a crustal traverse across the Tibetan Plateau. It would be a very expensive project that would best be undertaken as a joint international effort.

Additional recommendations concerning the Qaidam Basin are listed in Chapter 11, applications of seismic stratigraphy.

8. Some conclusions concerning basins of compressional origin in Western China (AWB)

There is little doubt in our minds that the Western China basins acquired their individual outlines as a consequence of the India-Eurasia collision. To support this contention let us cite some key indicators.

--The Tertiary of the Junggar Basin thickens towards the Tian Shan basement overthrust.

--The Tertiary of the Tarim Basin thickens to the north and towards the southward vergent basement overthrusts of the Tian Shan and to the southwest towards the basement overthrust of the western Kunlun.

--The Tertiary of the basins of the Gansu Corridor (Jiuquan, Zhaoshui Basins) thicken toward the northward verging overthrusts of the Qilian Shan.

--The situation in the Qaidam Basin is less clear, to the extent that there is no conspicuous thickening of the Tertiary towards the margins of the basin.

Nevertheless, seismic reflection profiles in the Qaidam Basin indicate that the northside is overthrust towards the south by the Qilian Shan Range and that the eastern Kunlun is overthrust towards the north on the south side of the basin. In addition, the Paleogene to early Neogene growth of the basin is spectacularly displayed by the convergence of reflectors toward the Altun Shan or northwest side of the basin.

There are also some hints that perhaps Jurassic compression may be responsible for the thickening of the Jurassic in the following areas.

--The Jurassic in the Junggar Basin thickens towards the Tian Shan suggesting loading during that time.

--Also the Jurassic in the Tarim Basin appears to thicken towards the Tian Shan, although the evidence here is far from clear.

--There is a thickening of the Jurassic towards the northeast margin of the Qaidam Basin.

Note that these suggestions contrast with the view of our Chinese colleagues, who favor extension in the Mesozoic, a point that is supported by reflection seismic profiles. It is quite possible that increased Jurassic thickness towards basin rims is due to structural thickening. More detailed information is needed.

All in all, with the exception of small compressional faults in the Karamay area, there is little conclusive evidence for Jurassic compressional tectonics that could be linked to the docking of the northern Tibetan Plateau with the Litian Lake - Jinsha River suture zone. However, the possibility of Jurassic foreland compression should be kept in mind.

Next it must be emphasized that the pre-Paleogene history of the various basins of Western China differs substantially, as follows:

--The Junggar Basin probably has a Paleozoic basement overlain by dominantly continental upper Paleozoic and Mesozoic continental sequences, but on the northwest side of the basin we also recognize a distinct upper

Paleozoic thrust event, which is sealed by Triassic beds and reactivated during early and mid-Jurassic times.

--The Tarim Basin is underlain by a Precambrian platform (microcontinent) that is overlain by lower Paleozoic platform sequences that are in turn followed by upper Paleozoic. Most of the Paleozoic is marine, and there is a general similarity of the Paleozoic stratigraphy with the Yangzi platform suggesting that both areas at one time may have been connected.

--The Qaidam Basin and the Gansu Corridor Basins are underlain by a metamorphic Paleozoic basement that appears to be overlain directly by typically thin Jurassic and possibly Triassic sediments.

With regard to hydrocarbons it should be noted that there are two basic settings:

(1) Late Paleozoic paleostructures in the northwestern Junggar Basin and in the Tarim Basin.

(2) Tertiary compressional structures in the southern Junggar Basin, in parts of the Tarim Basin, in the Qaidam Basin, and in the basins of the Gansu Corridor.

Available source bed information is quite general, and it is difficult to identify specific source beds that would have, say, in excess of 1% organic matter. Of course it is fair to assume that in all basins Mesozoic and Tertiary lacustrine shales have provided a source for hydrocarbon. Furthermore, one may assume that there are source beds in the upper Paleozoic of the Junggar and the Tarim Basins as well as in the lower Paleozoic of the Tarim Basin. However, available documentation for source beds is less than satisfactory.

Let us now list some recommendations:

Recommendation: **We strongly recommend that Chinese petroleum geologists receive more training in modern structural geology and in the structural - kinematic analysis of seismic reflection profiles. On our visit we rarely heard a structural interpretation and argument. Sections should be properly constructed and, if possible, be balanced. While there are no textbooks that adequately explain modern structural interpretation methodology based on seismic reflection profiles, a number of commercial courses are given by U.S. specialists and by the American Association of Petroleum Geologists. Such courses can be successful only if accompanied by exercises using seismic reflection profiles across some Chinese basins.**

Recommendation: **We recommend that an attempt be made to use principles of modern seismic stratigraphy in the basins of Western China. We wonder whether unconformity bound lacustrine (and for the Tarim Basin, marine) sequences can be correlated from one basin to another. Such studies should be accompanied by the construction of detailed stratigraphic cross-sections.**

Recommendation: **Very little attention seem to be given to the presence or absence of regional seals. We suggest that a greater effort be undertaken to identify regional seals. Such studies are of great importance for the definition of major stratigraphic traps.**

It is clear that our recommendations can be carried out only if sufficient technical manpower is assigned to projects. Such manpower should not at the same time be involved in the day-to-day routine of exploration operations. We would like to emphasize that unless such studies are undertaken, it will not be possible to come up with a reasonable evaluation of the potential of these basins. In our judgment, previous attempts to estimate potential reserves of the basins of Western China are probably based on quite inadequate information.

References

Bradley, W. H. and Eugster, H. P., 1969, Geochemistry and paleolimnology of the trona deposits and associated authigenic minerals of the Green River Formation of Wyoming, U. S. Geological Survey Professional Paper 496-B, 71 pp.

Di Hengshu, 1984, Overthrust belts on the northern margin of the Qaidam Basin and their oil prospecting, Oil and Gas Geology, v. 5 No. 2, p. 79-88.

Eugster, H. P., 1969, Inorganic bedded cherts from the Magadi area, Kenya, Contributions to Mineralogy and Petrology, 22, p. 1-31.

Eugster, H. P., 1980, Lake Magadi, Kenya and its precursors, in: A. Nissenbaum (ed.) Hypersaline Brines and Evaporites, Elsevier, Amsterdam. Developments in Sedimentology, v. 28, p. 195-232.

Eugster, H. P., 1985, Oil shales, evaporites and ore deposits. Geochimica et Cosmochimica Acta, v. 49, p. 619-635.

Eugster, H. P. and Hardie, L.A., 1978, Saline lakes, in: A. Lerman (ed.), Chemistry, Geology and Physics of Lakes. Springer Verlag, New York, p. 237-293.

Eugster, H. P. and Jones, B. F., 1979, Behaviour of major solutes during closed-basin brine evolution. American Journal of Science, v. 279, p. 609-631.

Eugster, H. P. and Kelts, K., 1983, Lacustrine chemical sediments, in: Pye, K. and Goudie, A. (eds.), Chemical Sedimentation and Geomorphology. Academic Press, London, p. 321-368.

Geological Exploration and Exploitation Research Institute, Qinghai Petroleum Administration, 1985, A brief reconnaissance guide to Qaidam Basin for the Petroleum Academy of China and Sino-U.S. Science Technology Exchange Commission.

Geological Institute of Qinghai - Xizang Plateau, Chinese Academy of Geological Sciences, 1980, Geologic Map of Qinghai - Xizang (Tibet) Plateau.

Hardie, L. A., Smoot, J. P., and Eugster, H. P., 1978, Saline lakes and their deposits: A sedimentological approach, in: Matter, A. and Tucker, M. (eds.), Modern and Ancient Lake Sediments, 7-41. International Association of Sedimentologists Special Publication 2.

Hirn, A., Nercessian, A., Japin, M., Yobert, G., Xu Zhong Xin, Gao En Yuan, Lu De Yuan, and Teng Ji Wen, 1984, Lhasa block and bordering sutures - a continuation of a 500-km Moho traverse through Tibet.

Lee, K. Y., 1984, Geology of the Chaidamu Basin, Qinghai Province, Northwest China, U. S. Geological Survey, Open File Report 84-413, 46 pp.

Qian Kai, Qu Ping Yan, Fouch, T. D., and Keighin, C. W., 1985, Tertiary sedimentation and diagenesis in the Qaidam Basin, Qinghai Province, People's Republic of China: United States Department of the Interior Administrative Report, Project 2A.2, 52 pp.

*NOTE: This reference list includes titles that are not cited. It was felt the additional references may be useful for the reader.

Qiu Yinan, Wang Hengjian, Xu Shiche, 1980, Characteristics of oil water movement in fluvial detail sand bodies deposited in continental lake basin, Acta Petrolei Sinica, Special Issue, p. 73-94.

Sheppard, R. A. and Gude, A. J., III, 1968, Distribution and genesis of authigenic silicate minerals in tuffs of Pleistocene Lake Tecopa, Inyo County, California, U. S. Geological Survey Professional Paper 597, 38 pp.

Smoot, J. P., 1978, Origin of the carbonate sediments in the Wilkins Peak Member of the lacustrine Green River Formation (Eocene), Wyoming, U.S.A., in: Matter, A. and Tucker, M. E. (eds.), Modern and Ancient Lake Sediments, Special Publications International Assoc. Sedimentologists 2, 109-127.

Smoot, J. P., 1983, Depositional subenvironments in an arid closed basin; the Wilkins Peak Member of the Green River Formation (Eocene), Wyoming, U.S.A. Sedimentology, v. 30, 801-827.

Song Jianguo and Liao Jian, 1982, Structural characteristics and petroliferous regions in the Chaidamu (Tsaidam) Basin, Acta Petrolei Sinica, v. 8, p. 14-23.

Sun Dapeng, 1984, Distribution and Formation of salts and their relationship with petroleum generation in Qaidam Basin, Oil and Gas Geology, v. 5, No. 2, p. 132-139.

Surdam, R. C., Eugster, H. P., and Mariner, R. H., 1972, Magadi-type chert in Jurassic and Eocene to Pleistocene rocks, Wyoming, Geological Society of America Bulletin, v. 83, 2261-2265.

Surdam, R. C. and Sheppard, R. A., 1978, Zeolites in saline, alkaline-like deposits, in: Sand, L. B. and Mumpton (eds.), Natural Zeolites Occurrence, Properties, Use; Pergamon Press, Oxford and New York.

Ulmishek, G., 1984, Geology and petroleum resources of basins in western China, Argonne National Laboratory ANL.ES - 146, 131 pp.

Wang Ningguo, 1982, The Aerjin arcuate structural zone and its relationship with oil and gas, Acta Petrolei Sinica, v. 3, No. 2, p. 21-28.

Xie Mingqian, Di Shiqi, and Sun Zhaoyuan, 1985, The mechanism of formation and petroleum prospects of the Qaidam Basin, paper given to the delegation during the meeting in Zhuoxian.

Xu Yihe, 1982, Structural interpretation of Landsat images of the western part of Chaidamu Basin, Acta Petrolei Sinica, Special Issue, p. 21-28.

*NOTE: This reference list includes titles that are not cited. It was felt the additional references may be useful for the reader.

9. Remarks on Modeling Basins of Compressional Origin (ABW)

There have been a number of attempts in recent years to develop computer techniques to model compressional basins (e.g., Jordan, 1981; Beaumont, 1981; Quinlan and Beaumont, 1984; Karner and Watts, 1983; Lyon and Molnar, 1985). In these techniques, foreland basins are assumed to form as a result of the flexural downwarping of the lithosphere by thrust or fold loads in adjacent mountain belts.

Most models now incorporate the ability to sum the flexure caused by successive thrust/fold loads and therefore predict the stratigraphy of a foreland basin. In the models developed by Jordan (1981) and Karner and Watts (1983) there is a rapid relaxation of the lithosphere from its short-term thickness to its long-term elastic thickness. In the model developed by Beaumont and co-workers, however, the relaxation is slower. Both types of models predict an outward migration of the flexural bulge as thrust/fold loads advance over the foreland basin. In the Beaumont and co-workers model (Beaumont, 1981; Quinlan and Beaumont, 1984), however, there is also an inward migration of the bulge between successive thrust/fold loads.

The main results of these modeling studies from the point of view of oil exploration are as follows:

1) the prediction of basin-wide unconformities within a foreland basin sequence

2) the prediction of relative stratigraphic highs/lows within a foreland basin sequence because of flexural bulge migration

3) the models may also be used to compute the effects of flexural loading on the maturation of source beds in the deep parts of a foreland basin sequence.

A number of the basins in Western China appear to have formed by flexural downwarping of the lithosphere caused by thrust/fold loading in adjacent mountain belts. Others (e.g., Qaidam) are associated with thrust/fold loads on one or more of their margins but do not appear to have formed as simple flexural downwarps. These complex basins are of particular interest in basin modeling because no mechanism has yet been advanced to explain them.

It may be possible to explain complex basins such as Qaidam using the concepts of flexural loading. However, several specific data sets will be required first before such a possibility can be tested. These data sets include:

1) Isopach maps of each formation in the basin, especially those corresponding in time to thrust/fold emplacement in the adjacent overthrust belt.

2) Restored cross-sections of adjacent mountain belts showing the position of the mountain front prior to thrust/fold emplacement.

3) Bouguer gravity anomaly maps of the basin and flanking mountain belts showing the location of any buried crustal and/or sub-crustal loads.

4) Regional seismic reflection profiles of the flanks of the basin showing the contact relationships between the foreland basin and the adjacent overthrust belt.

Of particular importance will be to restore cross-sections of the basin to show the relationship of the strata prior to the thrusting in adjacent mountain belts. It may be that the basin developed as a flexural downwarp and that the evidence of thickening towards the adjacent mountain belt was removed by erosion following subsequent thrusting as the overthrust front migrated out over the foredeep. It is difficult, however, to explain the large thicknesses of sediments (up to 15 km) in the basin in terms of flexure - unless the flexural foredeep was significantly modified by "side-driven" compression due to the India-Eurasia collision.

Recommendation: Because of the potential importance of the western basins in China for oil exploration, we recommend that our Chinese colleagues together with researchers from Chinese and U.S. universities, develop theoretical models for the development of foreland basins. Initially the project should focus on well developed foreland basins such as Tarim, but later it should be extended to more complex basins such as Qaidam.

References

Beaumont, C., 1981. Foreland basins, Geophys. J. R. Astr. Soc., v. 65, p. 291-329.

Jordan, T. E., 1981. Thrust loads and foreland basin evolution, Cretaceous, Western United States, Am. Assoc. Pet. Geol. Bull., v. 65, No. 12, p. 2506-2520.

Karner, G. D. and A. B. Watts, 1983. Gravity anomalies and flexure of the lithosphere at mountain ranges, J. Geophys. Res., v. 88, p. 10449-10477.

Quinlan, G. M. and C. Beaumont, 1984. Appalachian thrusting, lithospheric flexure, and the Paleozoic stratigraphy of the Eastern Interior of North America, Can. J. Earth Sci., v. 21, p. 972-996.

10. Remarks about reflection seismic data acquisition and processing (RC)

The various Chinese exploration groups have acquired many reflection seismic profiles covering most of the basins in China. In the Qaidam Basin, for example, there are more than a dozen regional profiles and many more localized surveys. Most of the modern data appears to have been acquired by American/European geophysical contracting companies, and most of the processing also appears to be done with software supplied by these companies.

The seismic reflection data are in general of quite good quality. The modern data are typically acquired with 96-channel systems, with 24-fold stacks. Older data are often only 6-fold. The processing of the data generally follows a standard sequence of CMP velocity analysis, stack, and sometimes migration. Reflection and refraction status are also applied in certain areas.

Several typical reflection profiles at both the Zhuoxian museum (a cursory examination of stacked and sometimes migrated data from several basins) and the Qaidam Basin (a more detailed examination of stacked sections) were studied by us. It is evident that three problems often prevented the production of an interpretable seismic section. These problems are strong surface topography, complex folded and faulted structures, and poor signal penetration. However, these problems are by no means exclusive to Chinese reflection profiles, nor are there well established solutions to them.

The problem of topography is serious because it often coincides with subsurface structures. The simplest solution to this problem is to use crooked lines (and crooked line processing) to avoid high topographic relief. If this is not possible, very small areal source and receiver arrays should be used to avoid inter-array signal cancellation. It is also important to use small group intervals in order to maintain good trace to trace correlation. This correlation should be checked continually during the course of the survey. In using small group intervals with a fixed number of channels, one is trading off velocity estimation in favor of image formation. It is also important that very accurate surveying for elevation be done, since elevation statics will be the biggest component of the topographic correlation. Finally refraction statics should be done if possible to remove any residual static.

In the seismic profiles that were examined, there were numerous examples of complex fold and faulted structures that contain dip angles up to 85 degrees. It appeared that in many cases the stack and migration processing did not do justice to the data. Pre-stack migration would probably help in some cases, but before this expensive process is undertaken, we recommend the following procedure. First, the stack of the data should be done for several velocities (say 80%, 90%, 100%, 110%, and 120% of the estimated stacking velocities). By stacking for a suite of velocities, all events should appear on one of the sections. Similarly, the migrations should be done for a suite of velocities to focus all events. A preliminary structural interpretation should then be done, with both geophysicists and geologists participating. The structural model will then form the basis for a velocity model that can be used to re-stack and re-migrate these data. This process should be iterated until the interpreted structure and the input velocity model agree. Finally a pre-stack migration will reconstruct all the dipping energy in one section.

In regions where the dipping structures have extremely high angles (approaching 90 degrees) special steps will have to be taken to process the data.

Standard migration methods (F-K, Kirchoff, and wave equation) attenuate reflectors that are near vertical. To check if this is the case, the obliquity factors can be removed from the migration algorithms. However, to migrate the data properly a procedure such as reverse-time migration will have to be used.

The third problem is source penetration into the subsurface. The clearest example of this occurs in the salt-bed regions of the Qaidam Basin. Here 15-90 m of salt overlay approximately 500 m of soft mud. Seismic sections using both vibroseis and dynamite sources show no apparent signal anywhere in the section. It is not known whether the problem is due to scattering related to interbedding within the salt (like the basalts on the Columbia River Plateau in the U.S.) or due to alteration by the mud layer. One recommendation to help analyze this problem is to conduct a VSP survey through the salt and mud layers, into the competent rock below. This survey will be invaluable in determining the nature of the problem. If the problem is alteration, then one should concentrate the vibrator sweeps on the lower frequencies, and the processed data should be low-pass filtered. If the problem is scattering, then smaller group intervals is recommended to maintain trace to trace coherency.

Another problem with the saltbeds will be the static corrections. Since salt is substantially faster than the underlying mud, the rays will bend away from the vertical rather than toward it as in the normal weathering layer case. The problem is similar in nature to permafrost statics, and the techniques developed for that latter problem should probably be used.

11. Applications of Seismic Stratigraphy (SK)

Seismic stratigraphic analysis is based on the subdivision of the stratigraphic record using seismic reflectors and provides a method of physical and perhaps chronostratigraphic correlation both within and among sedimentary basins. This analysis has tremendous power as a tool in exploration because it permits recognition of patterns of sediment accumulation (timing, magnitude, and location of depositional intervals) as well as provides a framework for facies analysis. All of these applications are essential to the next phase of petroleum exploration in the Qaidam Basin.

For specific methodology, the reader is referred to Payton (1977), Sheriff (1980), and Anstey (1982). The basic precept is that seismic reflectors represent physical stratal surfaces in the sedimentary record, that is, bedding planes and unconformities (Mitchum et al., 1977a). They do not reflect time-transgressive boundaries such as the contacts between laterally intergrading lithofacies. Subdivision by seismic reflectors thus yields a series of genetically coherent, unconformity-bounded units referred to as depositional sequences. For physical correlation, depositional sequences are distinguished on the basis of the configuration of internal minor reflectors (which may be parallel to the sequence boundaries, mounded, or oblique) and by the way in which these minor reflectors terminate against the sequence-bounding reflectors (onlapping, downlapping, or concordant with the lower boundary; toplapping, truncated, or concordant with the upper boundary).

Chronostratigraphic analysis of seismic reflection profiles proceeds on the assumption that the seismically-revealed unconformities represent time lines -- that is, that rocks present above a bedding plane or unconformity are younger than rocks present anywhere below that stratal surface (Vail, Todd, and Sangree, 1977). This working assumption can be verified biostratigraphically (e.g. Powell and Baum, 1982). Well-constrained published data bearing on this question are sparse, however, and not all major reflectors are correctly identified as chronostratigraphically significant unconformities (e.g. Tucholke, 1981; Rawson and Riley, 1982; Flood and Shor, 1984).

Seismic stratigraphic analysis would have immediate value to further hydrocarbon exploration in the Qaidam Basin, especially as a framework for detailed facies analysis. Sedimentary facies having source, reservoir, or seal qualities can be distinguished in high-resolution seismic profiles (Mitchum et al., 1977b; Brown and Fisher, 1980; Anstey, 1980; Berg, 1982). Such facies can also be distinguished in seismic profiles using more conventional core data (depth calibrated using synthetic seismograms) or outcrop data correlated into the subsurface using well logs. Detailed stratigraphic analysis of these profiles will also reveal unconformities in the section and their physical relationship to source beds, thus indicating the potential for erosional destruction of source beds or for the role of the unconformity surface as a conduit for fluid migration.

Stratigraphic analysis from the perspective of overall basin history -- the interaction of tectonic, isostatic, eustatic/climatic, and sediment supply controls on sediment accumulation -- will be essential to regional studies of the Qaidam and other basins in Western China. Grids of seismic profiles can provide a complete (between-wells), three-dimensional view of the mutual relations of depositional sequences and the positioning of points of maximum sediment accumulation. Vail et al. (1977a, b; Vail and Todd, 1981; Vail et al., 1984) have maintained that cycles of eustatic sea level change are responsible for individual depositional sequences in continental margin and cratonic settings and for their typical pattern of onlap alternating with downward (basinward) shifts in the locus of sedimentation. This eustatic interpretation suggests that depositional sequences can serve as units for global chronostratigraphic correlation and, depending on the frequency of the eustatic fluctuations relative to rates of evolution, could in some situations provide finer chronostratigraphic subdivisions than is possible using conventional biostratigraphic methods.

Depositional sequences in continental records such as dominate the Cenozoic record of Qaidam and other western basins of China may also reflect eustatic fluctuations, although indirectly through alluvial adjustments to changes in regional baselevel. Vail (personal communication) suggests that regional and perhaps global correlation of continental sequences is possible, and that the age of these sequences can be calibrated by reference with marine depositional sequences on adjacent continental margins.

Eustatic fluctuations in sea level are only one of several possible explanations for depositional sequences in continental margins and cratons, and their significance in tectonically more active settings has not yet been explored fully in the published literature. Some reasonable alternative models for depositional sequences and onlap patterns are based on tectonic factors in basin subsidence and on variations in the rate of sediment supply. These explanations suggest that not all depositional sequences are useful for correlation beyond the boundaries of a single basin or tectonic province. For example, Watts (1982; Watts et al., 1982) has found that the Mesozoic-Cenozoic record of the U.S. Atlantic margin can be generated entirely by subsidence related to thermal contraction and sediment loading of basement. In this model, large magnitude fluctuations in sea level are not required to explain the pattern of stratigraphic accumulation, and the sequences would thus have value only for local or regional correlation within the [contemporary] tectonic province (see also Thorne and Watts, 1984). Brown and Fisher (1977) suggest that offlap-onlap cycles record the alternation of periods of continental shelf construction (progradation with offlap) and shelf destruction (erosional retreat of shelf and onlapping of slope depocenters) related to changes in sediment supply to the basin (see Field et al., 1983 for discussion of latitudinal variation in sediment supply). Base of slope fan-shaped deposits, wedged between successive offlapping sequences, are deep-water deposits composed of sediments winnowed from the shelf during submarine erosion and thus should be good reservoirs. This contrasts with the eustatic interpretation (Vail et al., 1981) of these fans as low-stand deposits formed in coastal environments during exposure of the shelf to subaerial erosion (poor reservoirs) (see Shanmugam and Moiola 1984, and Poag 1982 for further discussion on the relation of off-shelf deposits to shelf processes and eustasy). Brown and Fisher's model also indicates very limited utility of depositional sequences for regional and global chronostratigraphic correlation. Both the tectonic and sediment supply models bear testing in the Qaidam Basin, along with the eustatic-baselevel model of Vail, inasmuch as the controls of sequence accumulation in continental basins are poorly known at present.

Based on our short visit in China and particularly on our trip to the Qaidam Basin, we recommend the following:

--seismic stratigraphic facies analysis of the Qaidam Basin, with independent evaluation of the chronostratigraphic significance of the depositional sequences to the limits of resolution of the available ostracode and pollen-based biostratigraphy.

--broader evaluation of the chronostratigraphic significance of the sequences across the several basins of Western China, especially within the Mesozoic part of the section, (1) as a way of assessing their usefulness over even larger areas, and (2) to assess the idea of a similar tectonic history during that period. This basic research should constitute part of the regional geologic study of the basin.

--basic research on the identification and evaluation of unconformities, especially in continental settings.

Recommended Strategy for Basic Research on Unconformities

One of the outstanding problems in stratigraphic analysis is the chronostratigraphic significance of unconformities, along with criteria for their identification and the interpretation of modes of formation. Our relatively poor understanding of these stratigraphic features has become a particular problem in the last five to ten years, both with the advent of seismic sequence analysis, which relies upon unconformities to subdivide the record, and with the broader recognition that nondepositional surfaces of all scales -- from bedding planes to profound unconformities -- may well represent more elapsed geologic time than the sedimentary rock units that the surfaces separate. The great significance of unconformities for the exploration of oil and gas has recently been re-emphasized by Pan Zhongxiang (1983).

In North America in particular, the analysis of nondepositional intervals has been hampered (1) by an emphasis on research on sedimentary facies, and (2) by a dichotomous view of the stratigraphic record -- that is, that geologic time is recorded in the form of either a sedimentary deposit (bed, facies) or an erosional or omissional surface (bedding plane, unconformity). The quality of the stratigraphic record of a particular time interval can, however, range continuously between a perfectly complete depositional record on the one hand and a perfectly incomplete "non-record" (i.e., zero-thickness surface) on the other (Figure 18). A sedimentary record of average completeness, for example, will contain a series of bedding planes indicating minor discontinuities in sediment accumulation. Stratigraphic records of demonstrably lesser thickness and completeness are called condensed sections (Figure 18), and these contain a highly abbreviated but tangible record of elapsed geologic time (Heim, 1924, 1958; Wendt, 1970; Jenkyns, 1971; articles in Einsele and Seilacher, 1982 and Bayer and Seilacher, 1985). Usually the term condensed sequence is reserved for deposits in which fossils from different biostratigraphic zones have been mixed into a single bed or occur in stratigraphic order but in an extremely thin sequence. However, the processes of stratigraphic condensation can operate over shorter, subevolutionary periods of time (e.g. Fürsich, 1978; Kidwell, 1982; Seilacher, 1985), and in these situations fossils are condensed from the sequence of communities or depositional environments that occupied the site during the interval of low net sedimentation.

General biostratigraphic criteria for the recognition of unconformities and condensed sequences are illustrated in Figure 19. Non-biostratigraphic criteria are also necessary, both because biostratigraphically significant taxa are not always available and because some important breaks can be too brief in duration for even the best biostratigraphic data to resolve. These criteria include: angular discordance; lithologic contrast (that can have many causes other than a break in deposition); erosional relief and truncated bedding; lag deposits of pebbles, bones, and teeth; phosphatization or glauconitization of skeletal and organic matter; or silicification of beds or fossils below the unconformity; burrowed firmgrounds

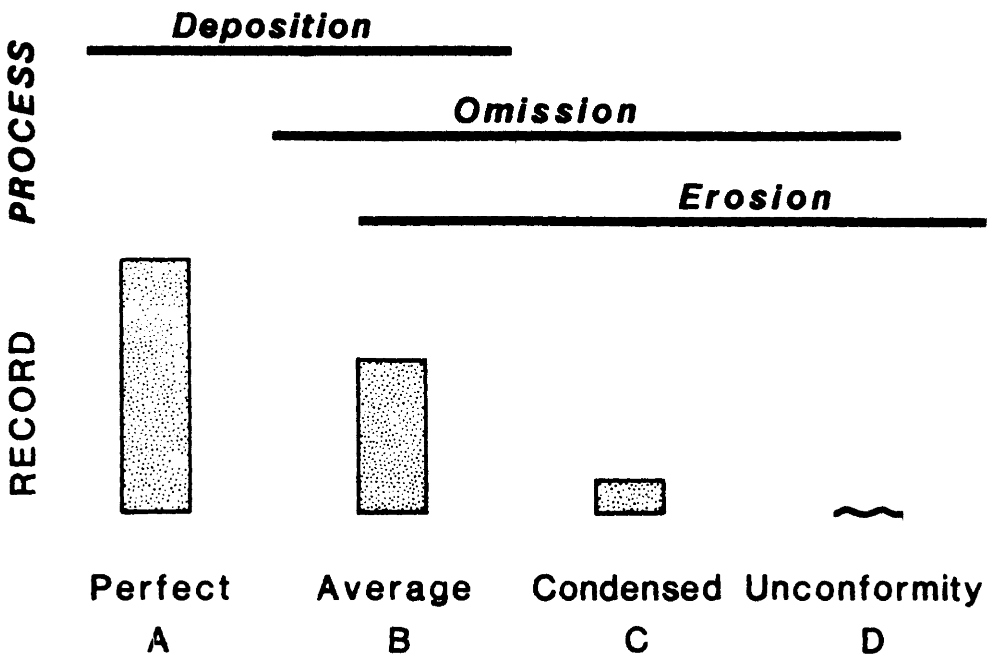


Figure 18

The local stratigraphic record can range in quality from perfectly complete (A), which records continuous, non-interrupted deposition, to perfectly incomplete (B), which is indicated by a discontinuity surface of some scale (bedding plane to unconformity) in the sedimentary sequence. The average facies record of a depositional environment will be reasonably complete (B), although it contains discontinuities marking brief episodes of erosion or omission. Condensed sections (C) are relatively thin compared to coeval records elsewhere, but have some finite thickness and contain guide species from several successive biostratigraphic zones.

BIOSTRATIGRAPHIC EVIDENCE

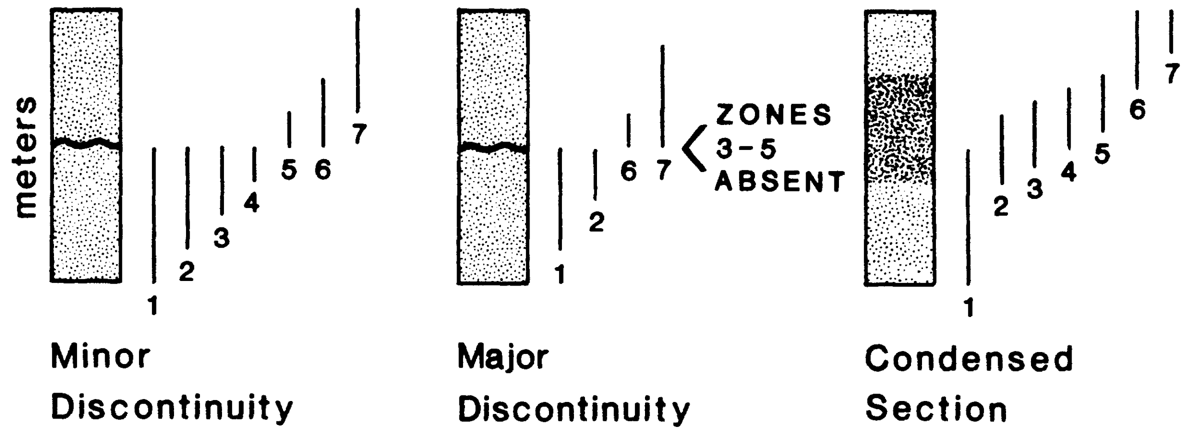


Figure 19

Stratigraphic range zones of fossil species (vertical lines 1-7) provide evidence for discontinuities aned condensed intervals in the rock record. Minor discontinuities truncate but do not eliminate species ranges, so that first and last appearances are concentrated at a single bedding plane. Breaks of greater duration can be marked by the absence of zones from the biostratigraphic succession. Condensed sections contain an abbreviated and compressed biostratigraphic sequence: successive species occur in their correct order with their ranges shortened (as illustrated here) or species from successive zones are mixed into a single bed.

(*Glossifungites* facies of Frey and Seilacher, 1980); concretionary burrow fills (intra-formational conglomerates; e.g., Bottjer, 1985; Fürsich, 1973); and hardgrounds (limestones cemented on the seafloor, usually bored or encrusted by organisms, and often coated by authigenic minerals; *Trypanites* facies of Frey and Seilacher, 1980; see Bromley, 1975). The state of preservation of fossil material (taphonomic criteria) can also be used to identify and evaluate stratigraphic breaks (see numbered paragraphs that follow).

As discussed in the section on seismic stratigraphy, the origin and significance of unconformities and condensed sections in nonmarine rocks -- such as characterize the Cenozoic sequences of Western China basins -- are poorly known at present. Basic research conducted in the context of ongoing, applied seismic stratigraphic analysis would therefore be very fruitful. What follows is a strategy for a systematic exploration of nondepositional intervals which could be applied to nonmarine as well as marine records. This prospectus also provides an updated checklist of information essential to modern evaluation of unconformities (Table 2).

1. Duration of break. This is the length of time represented by the unconformity surface, that is, the difference between the age of the rocks immediately on top of and immediately below the surface (= lacuna of Wheeler 1964; see Sloss 1984 for recent review).

2. Diachroneity. This term usually indicates geographic variation in the age of the youngest rocks found below the unconformity or in the age of the oldest rocks above the unconformity. It is also desirable to estimate geographic variation in the duration of the break.

3. Age. This is the most difficult kind of chronostratigraphic information to acquire, both because workers attach different meanings to the term and because it must be inferred from a regional analysis of the surface. Although the total duration of the break (lacuna) observed in the record usually varies laterally, Vail, Todd, and Sangree (1977) maintain that all rocks found below the surface are older than rocks found anywhere resting on top of the surface, so that a time line (synchronous surface) is inherent in the unconformity surface. Their best estimate of the age of this time line is the age of the correlative conformity and provides an operational definition of the age of the unconformity. From the perspective of geological processes, however, the age of the onset of erosion or sedimentary omission is most desired (= hiatus of Wheeler, 1964), and this may or may not be equivalent to the age of the correlative conformity in all tectonic settings. In general, the duration of the inferred hiatus is not equivalent to the duration of the observed lacuna, because the lacuna includes the time value of any rocks destroyed during the erosional interval. Exceptions are provided by instances where the unconformity formed primarily through omission (sediment bypassing or starvation). In these situations the age of the beginning of the hiatus can be approximated closely by the youngest rocks under the unconformity.

Ideally, information on duration and diachroneity should be based on a series of age determinations of rocks both above and below the unconformity at several points laterally along that surface. These biostratigraphic and radiometric data should be displayed on cross-sections of the basin. Information on the kind of age control (faunal or floral group, experimental error, and source mineral) should be keyed into the cross-section, and the accompanying report should include an explicit description of the procedure for dating the surface and a discussion of the relative merits of the data points (e.g., stratigraphic proximity of samples of

TABLE 2. Essential Information on Unconformities and condensed sections.

EVALUATION OF NONDEPOSITIONAL INTERVALS

1. DURATION
2. DIACHRONEITY
3. AGE
4. SEDIMENTARY DYNAMICS
5. BIOLOGICAL RESPONSE
6. PALEONTOLOGICAL DISTORTION
7. PALEOENVIRONMENT
8. STRATIGRAPHIC CONTEXT
9. CAUSE - TECTONIC,
   EUSTATIC,
   SEDIMENTARY

unconformity, method of extrapolation to unconformity). The information on age control that is typically made available is often inadequate for a reasonable chronostratigraphic assessment of the unconformity in question and is usually useless for more far-ranging research on the utility of unconformities in the different kinds of basins.

These three chronostratigraphic aspects -- duration, diachroneity, and age -- are the most common kinds of data available for unconformities, but a wealth of other information about the non-depositional interval can also be acquired.

4. Sedimentary dynamics. Discontinuity surfaces in the stratigraphic record can indicate single episodes of omission, in which no previously deposited rocks are removed, or erosion, in which there is net removal of previously accumulated record. Probably most unconformities and condensed sequences, however, resulted from multiple, short-term events of erosion and omission alternating with deposition. The sedimentary dynamics of the nondepositional interval can be revealed in the nature of fossil material and in the diagenesis of adjacent sediments. Paleontological and geochemical criteria for the interpretation of nondepositional intervals are based upon models for the formation of carbonate hardgrounds (Baird and Fürsich, 1975; Fürsich, 1979; Hook and Cobban, 1981; Brett and Brookfield, 1984), carbonate and phosphatic concretionary deposits (Kennedy and Garrison, 1975a, b; Baird, 1978), post-mortem patterns of skeletal destruction (Chave, 1964; Driscoll, 1970; Kidwell, 1986), complex stratification within fossiliferous horizons (Kidwell and Aigner, 1985; see Kidwell, 1985b), and the physical relationship of fossil-rich strata to discontinuity surfaces (Kidwell, 1985a, 1986).

5. Biological response. There is now growing appreciation that periods of nondeposition not only influence the composition and structure of fossiliferous horizons through post-mortem process of hardpart destruction but that they also engender a biotic response from local benthos. For example, assemblages of organisms with low tolerance for turbid water or frequent episodes of seafloor disturbance argue that low rates of net sedimentation were maintained by sediment starvation rather than by sediment bypassing. Nondepositional intervals in marine settings can be indicated by a shift in dominance from soft-bottom to firm-bottom dwelling fauna (1) during the gradual dewatering (and thus stabilization) of muds during the period of nondeposition or (2) during the gradual accumulation of dead hardparts, which make the original soft-bottom habitat coarser-grained, firmer, and topographically more complex (taphonomic feedback of Kidwell and Jablonski, 1983; Kidwell and Aigner, 1985). This shift can be recorded not only in the species composition of the fossil assemblages, but also in the morphology of species that are sensitive to substratum type (e.g., morphological differences among oysters on soft muds versus shell gravels, cf. Seilacher et al, 1985; see Kidwell and Aigner, 1985; and Kidwell,1986 for model and other examples).

6. Paleontological distortion. Biostratigraphic data need to be evaluated critically before they can be used to date the unconformity: age calls for strata immediately below the surface can be biased by the piping of younger fossils down through open burrows and fissures, and fossil assemblages found both immediately above and below the surface can be mixed or skewed by selective post-mortem destruction and condensation (Kidwell and Aigner, 1985; Kidwell, 1985a, 1986). The consequences of nondepositional intervals on biostratigraphic bias are discussed in detail in Kidwell (1982; 1985b; see also Behrensmeyer, 1982 for discussion of terrestrial vertebrate records).

7. Paleoenvironment of nondeposition. Nondeposition is usually inferred from paleoenvironmental analysis of facies adjacent to the unconformity and by features of the surface itself, e.g., paleosols and vadose cements provide evidence for subaerial exposure. To complement conventional depositional facies models, we need explicit "facies" models of nondepositional environments that describe the stratigraphic features produced by erosion and omission and that explore the circumstances of these processes in modern environments. Together with more systematic investigations of unconformities in the stratigraphic record, these models would improve criteria for paleoenvironmental interpretation of nondepositional intervals and thereby increase our ability to predict (1) the lateral extent and chronostratigraphic significance of unconformities and (2) the facies that should be juxtaposed against the unconformity as it is traced from outcrop into seismic sections.

8. Stratigraphic context. Equally important as the specific environment of formation of the unconformity is its larger context in the stratigraphic record: what is the paleogeographic setting (paleolatitude, oceanographic facing) of the basin during the nondepositional interval; did nondeposition characterize transgressive, regressive, or stillstand (mid-cycle) phases of shoreline migration (progradation or retrogradation of alluvial deposits); what is the nature of the paleoclimatic and tectonic regimes preceding and following the nondepositional interval? This information not only reveals the larger significance of the nondepositional interval in the history of a particular basin -- with implications for the location of source beds and reservoirs relative to the unconformity and for kinematic reconstruction of contemporaneously tilted beds -- but will contribute toward a more sophisticated understanding of the basic controls of sediment accumulation.

9. Cause. This is one of the most common questions regarding breaks in the record, yet is rarely answered satisfactorily. This situation is due both to inadequate information on particular unconformities (points 1-8 above) as well as to the lack of comprehensive theoretical models for comparison. Eustatic fluctuations may well explain unconformities of a variety of scales, especially in passive continental margin and cratonic settings, but tectonic mechanisms -- such as changes in rates and rotational poles of seafloor spreading, local inception and cessation of rifting, and migration and relaxation of compressive peripheral bulges -- provide reasonable alternatives. These tectonic mechanisms need not be confined to the explanation of local (within-basin) unconformities and condensed sections but might also apply to interregional and global features. Moreover, sedimentary factors -- such as sediment supply and its linkage to eustasy and orogeny and rates of sediment accumulation that do not keep pace with subsidence or sea level changes (i.e., non-equilibrial sediment accumulation) -- are rarely considered in either current inverse or forward models of sedimentary basins.

Recommendation. Progress in basic research on unconformities will require (1) more detailed and comprehensive documentation of unconformities and condensed sections in seismic sections and in outcrop; (2) systematic exploration of the occurrence of nondepositional intervals among different environments, paleogeographic and tectonic settings, and phases of basin history; and (3) interaction of geologists and geophysicists on forward models, which are held accountable to the ground truth of outcrop or seismic features and which incorporate the dynamics of non-equilibrial as well as equilibrial sedimentation.

References

Anstey, N. A., 1980. Seismic exploration of sandstone reservoirs. Boston: Inter. Human Res. Devel. Corp. 136 p.

Anstey N. A., 1982. Simple Seismics. Boston: Inter. Human Resources Devel. Corp. 168 p.

Baird, G. C., 1978. Pebbly phosphorite in shale: A key to recognition of a widespread submarine discontinuity in the middle Devonian of New York. Journ. Sed. Petrol. v. 48, p. 545-555.

Baird, G. C. and F. T. Fürsich, 1975. Fossil diagenesis, Nr. 15: Taphonomy and biologic progression associated with submarine erosion surfaces from the German Lias. N. Jb. Geol. Paläont. Mh. 1975, p. 321-328.

Bayer, U. and A. Seilacher, eds., 1985. Sedimentary and Evolutionary Cycles. Berlin: Springer Verlag, 465 p.

Behrensmeyer, A. K., 1982. Time resolution in fluvial vertebrate assemblages. Paleobiology, v. 8, p. 212-248.

Berg, O. R., 1982. Seismic detection and evaluation of delta and turbidite sequences: Their application to exploration for the subtle trap. Amer. Assoc. Petrol. Geol. Bull., v. 66, p. 1271-1288.

Bottjer, D. J., 1985. Trace fossils and paleoenvironments of two Arkansas Upper Cretaceous discontinuity surfaces. Jour. Paleont., v. 59, p. 282-298.

Brett, C. E. and M. E. Brookfield, 1984. Morphology, faunas, and genesis of Ordovician hardgrounds from southern Ontario, Canada. Palaeoclim. Palaeogeogr. Palaeoclimatol., v. 46, p. 233-290.

Bromley, R. A., 1975. Trace fossils at omission surfaces, in The Study of Trace Fossils (R. W. Frey, ed.), New York: Springer-Verlag, p. 399-428.

Brown, L. F., Jr., and W. L. Fisher, 1977. Seismic-stratigraphic interpretation of depositional systems: Examples from Brazilian rift and pull-apart basins. Amer.Assoc. Petrol. Geol. Mem., v. 26, p. 213-248.

Brown, L. F., Jr., and W. L. Fisher, 1980. Seismic Stratigraphic Interpretation and Petroleum Exploration. Amer. Assoc. Petrol. Geol. Continuing Educa. Course Note Series No. 16.

Chave, K. E., 1964. Skeletal durability and preservation, in Approaches to Paleoecology (J. Imbrie and N. D. Newell, eds.), New York: Wiley, p. 377-387.

Driscoll, E. G., 1970. Selective bivalve shell destruction in marine environments, a field study. Jour. Sed. Petrol., v. 40, p. 898-905.

Einsele, G. and A. Seilacher, Eds., 1982. Cyclic and Event Stratification. Berlin: Springer Verlag.

Field, M. E., P. R. Carlson, and R. K. Hall, 1983. Seismic facies of shelfedge deposits, U. S. Pacific continental margin. S.E.P.M. Spec. Publ. 33, p. 299-313.

Flood, R. D. and A. N. Shore, 1984. Synthetic seismogram generation from sediment composition data -- an initial study in the southwest Brazil Basin. Marine Geology, v. 58, p. 263-274.

Frey, R. W. and A. Seilacher, 1980. Uniformity in marine invertebrate ichnology. Lethaia, v. 13, p. 183-207.

Fürsich, F. T., 1973. Thalassinoides and the origin of nodular limestone in the Corallian Beds (Upper Jurassic) of Southern England. N. Jb. Geol. Paläont. Mh. 1973, p. 136-156.

Fürsich, F. T., 1978. The influence of faunal condensation and mixing on the preservation of fossil benthic communities. Lethaia, v. 11, p. 243-250.

Fürsich, F. T., 1979. Genesis, environments, and ecology of Jurassic hardgrounds. N. Jb. Geol. Paläont. Abh., v. 158, p. 1-63.

Heim, A., 1924. Über submarine Denudation und chemische Sedimente. Geol. Rundsch., v. 15, p. 1-47.

Heim, A., 1958. Oceanic sedimentation and submarine discontinuities. Ecologae Geol. Helvet., v. 51, p. 642-649.

Hook, S. C. and W. A. Cobban, 1981. Late Greenhorn (Mid-Cretaceous) discontinuity surfaces, southwest New Mexico. New Mex. Bur. Mines Circ., v. 180, p. 5-21.

Jenkyns, H. C., 1971. The genesis of condensed sequences in the Tethyan Jurassic, Lethaia, v. 4, p. 327-352.

Kennedy, W. J. and R. E. Garrison, 1975a. Morphology and genesis of nodular chalks and hardgrounds in the Upper Cretaceous of Southern England. Sedimentology, v. 22, p. 311-386.

Kennedy, W. J. and R. E. Garrison, 1975b. Morphology and genesis of nodular phosphates in the Cenomanian Glauconitic Marl of Southeast England. Lethaia, v. 8, p. 339-360.

Kidwell, S. M., 1982. Time scales of fossil accumulation: Patterns from Miocene benthic assemblages. Proc. 3rd North Amer. Paleontol. Conv., v. 1, p. 295-300.

Kidwell, S. M., 1985a. Palaeobiological and sedimentological implications of fossil concentrations. Nature, v. 318, p. 457-460.

Kidwell, S. M., 1985b. Genesis of fossiliferous horizons and their significance for basin analysis. Report for Sino-American Academic Symposium on Petroleum-bearing Sedimentary Basins (Zhuoxian, August 18-21, 1985), 19 pp.

Kidwell, S. M., 1986. Models for fossil concentrations: Paleobiologic implications. Paleobiology, v. 12, p. 6-24.

Kidwell, S. M. and T. Aigner, 1985. Sedimentary dynamics of complex shell beds: Implications for ecologic and evolutionary patterns, in Sedimentary and Evolutionary Cycles (U. Bayer and A. Seilacher, ed.). Berlin: Springer Verlag, p. 382-395.

Kidwell, S. M. and D. Jablonski, 1983. Taphonomic feedback: Ecological consequences of shell accumulation, in Biotic Interactions in Recent and Fossil Benthic Communities (M.J.S. Tevesz and P. L. McCall, eds.). New York: Plenum Press, p. 195-248.

Mitchum, R. M., Jr., P. R. Vail, and S. Thompson, III, 1977a. The depositional sequence as a basic unit for stratigraphic analysis. Amer. Assoc. Petrol. Geol. Mem., v. 26, p. 53-62.

Mitchum, R. M., Jr., P. R. Vail, and J. B. Sangree, 1977b. Stratigraphic interpretation of seismic reflection patterns in depositional sequences. Amer. Assoc. Petrol. Mem., v. 26, p. 117-133.

Pan Zhongxiang, 1983, Significance of unconformity to oil and gas migration and accumulation, Acta Petrolei Sinica, v. 4, p. 1-10.

Payton, C. E., Ed., 1977. Seismic Stratigraphy - Applications to Hydrocarbon Exploration. Amer. Assoc. Petrol. Geol. Mem., v. 26, 516 p.

Poag, C. W., 1982. Stratigraphic reference section for Georges Bank Basin - Depositional model for New England passive margin. Amer. Assoc. Petrol. Geol. Bull., v. 66, p. 1021-1041.

Powell, R. J. and G. R. Baum, 1982. Eocene biostratigraphy of South Carolina and its relationship to Gulf Coastal Plain zonations and global changes of coastal onlap. Geol. Soc. Amer. Bull.. v. 93, p. 1099-1108.

Rawson, P. F. and L. A. Riley, 1982. Latest Jurassic - Early Cretaceous events and the "Late Cimmerian Unconformity" in North Sea area. Amer. Assoc. Petrol. Geol. Bull., v. 66, p. 2628-2648.

Seilacher, A., 1985. The Jeram model: Event condensation in a modern intertidal environment, in Sedimentary and Evolutionary Cycles (U. Bayer and A. Seilacher, eds.). Berlin: Springer Verlag, p. 336-341.

Seilacher, A., B. A. Matyja, and A. Wierzbowski, 1985. Oyster beds: Morphologic response to changing substrate conditions, in Sedimentary and Evolutionary Cycles (U. Bayer and A. Seilacher, eds.). Berlin: Springer, p. 421-435.

Shanmugam, G. and R. J. Moiola, 1984. Eustatic control of calciclastic turbidites. Marine Geology, v. 56, p. 273-278.

Sheriff, R. E., 1980. Seismic Stratigraphy. Boston. Inter. Human Res. Devel. Corp., 227 p.

Sloss, L. L., 1984. Comparative anatomy of cratonic unconformities. Amer. Assoc. Petrol. Geol. Mem., v. 36, p. 1-6.

Thorne, J. and A. B. Watts, 1984. Seismic reflectors and unconformities at passive continental margins. Nature, v. 311, p. 365-368.

Tucholke, B. E., 1981. Geologic significance of seismic reflectors in the deep western North Atlantic Basin. S.E.P.M. Sepc. Pub., v. 32, p. 23-37.

Vail, P. R., R. G. Todd, and J. B. Sangree, 1977. Chronostratigraphic significance of seismic reflections. Amer. Assoc. Petrol. Geol. Mem., v. 26, p. 99-116.

Vail, P. R., R. M. Mitchum, Jr., and S. Thompson, III, 1977a. Relative changes of sea level from coastal onlap. Amer. Assoc. Petrol. Geol. Mem., v. 26, p. 63-81.

Vail, P. R., R. M. Mitchum, Jr., and S. Thompson, III, 1977b. Global cycles of relative changes of sea level. Amer. Assoc. Petrol. Geol. Mem.,v. 26, p. 83-97.

Vail, P. R. and R. G. Todd, 1981. Northern North Sea Jurassic unconformities, chronostratigraphy and sea level changes from seismic stratigraphy. Petroleum Geology of the Continental Shelf of Northwest Europe. London: Heyden, p. 216-235.

Vail, P. R., J. Hardenbol, and R. G. Todd, 1984. Jurassic unconformities, chronostratigraphic and sea level changes from seismic stratigraphy and biostratigraphy. Amer. Assoc. Petrol. Geol. Mem., v. 36, p. 129-144.

Watts, A. B., 1982. Tectonic subsidence, flexure and global changes of sea level. Nature, v. 297, p. 469-474.

Watts, A. B., G. D. Karner, and M. S. Steckler, 1982. Lithospheric flexure and the evolution of sedimentary basins. Phil. Trans. Roy. Soc. London, v. A305, p. 249-282.

Wendt, J., 1970. Stratigraphische Kondensation in triadischen und jurassichen Cephalopodenkalken der Tethys. N. Jb. Geol. Paläont. Mh., v. 1970, p. 433-448.

Wheeler, H. E., 1964. Baselevel transit cycle. Kansas Geol. Surv. Bull., v. 169, p. 623-630.

12. <u>Source bed studies</u> (HPE, LM)

Chinese petroleum geologists express organic richness for a major stratigraphic interval (e.g., Eocene) as an average value in weight percent total organic carbon (wt % TOC). This average value for a thick sequence of rocks does little to define the precise stratigraphic position of the source rock and its lateral extent. A more useful way to express source rock richness is to plot a profile of wt % TOC values for a given stratigraphic interval and emphasize the richest part. Such a plot, for example, might indicate that the best source rock is concentrated in a 40 m thick interval that averages 1.8% TOC. In our opinion a rock should have a TOC value of at least 1% to be considered a petroleum source rock. The distribution of organic matter in the source rock is also important because theoretical considerations indicate that oil can only be expelled in a continuous phase. Therefore, the continuity and thickness of a layer rich in organic matter should be noted; rocks in which organic matter has been greatly diluted by carbonates or terrigenous clastics are not the best source rocks. Once a source rock interval is identified, its thickness can be mapped either with lithologic samples or with resistivity logs. Rich source rocks, in general, have high resistivity values. If logs are unavailable, the location of source rocks may in some cases be predicted from lithofacies and/or diagenetic-mineralization models. The final step in constructing a source rock/maturity map is to superimpose maturity values on the source-rock isopachs; measured maturity values such as those derived from vitrinite are preferred to calculated maturity values using the Lopatin method.

<u>Recommendation:</u> As will be discussed below, we were surprised at how unspecific the source bed information typically was. For exploration for oil it is advisable to identify specific layers that have an organic content in excess of 1 percent. We also believe that more use could be made of inorganic geochemical data to characterize the source bed environment. We recommend that source bed studies be undertaken that will pinpoint specific source beds. These source beds should then be identified on seismic reflection profiles.

13. Some stratigraphic considerations in petroleum exploration, particularly for subtle hydrocarbon traps. (LM)

Seismic data, subsurface log suites, lithologic samples, and formation test data provide the basic tools for evaluating the stratigraphic framework of a basin and the hydrocarbon potential of selected stratigraphic intervals. The seismic data should be in both nonmigrated and migrated form, be converted from time to depth, and have true amplitude preserved. A suite of modern logs for each drill hole is required; these include spontaneous potential, resistivity, gamma ray, sonic, and density. The lithologic samples may be obtained from drill hole cuttings, cores, and outcrops. Formation test data may be derived from wireline tests, drillstem tests, and production flow tests.

The final product of these four basic types of data is maps showing the hydrocarbon potential and/or preferred drilling locations for a given basin. Our American delegation saw many source rock charts and tables, many isopach maps, a few lithofacies interpretations, but no maps by which a drillhole could be located. We conclude that either Chinese petroleum geologists do not make these types of maps or that maps have been made and they were not shown to us.

American petroleum geologists commonly make four kinds of maps: 1) a source rock/maturity map, 2) a fluid/pressure map, 3) a structure contour map, and 4) a reservoir map.

The source rock/maturity map indicates where the source rocks are located and where they are mature with respect to hydrocarbons. Criteria for source bed maps have been discussed in the preceding section.

A fluid/pressure map records the distribution of hydrocarbon shows with respect to the formation-pressure gradient in the basin and thus indicates the probable dispersal pattern of the hydrocarbons after their generation. The hydrocarbon fields and shows are recorded by age. If possible, the organic compounds in the oils should be analyzed to determine whether one source rock or multiple source rocks are involved. Similar geochemical analyses of oil extracts of organic-rich rocks permit an oil-to-extract comparison that in some cases identifies the oil with specific source rock intervals. Gas and/or condensate accumulations are much more difficult to match with their source.

Structure contour maps indicate possible pathways and traps for hydrocarbons migrating out of the basin. The relative timing between the inception of a given structure and peak hydrocarbon migration is very important. Only those structures that originated before or during hydrocarbon migration are likely to have trapped hydrocarbons. In general, the older the structure, the better are its chances of containing hydrocarbons, and thus the age of a structure should be identified on the map wherever it is known. Moreover, a structure may have been in place at the time of peak migration, but, owing to the regional structural configuration, hydrocarbons may have bypassed it in favor of more accessible structures. Hydrocarbon migration tends to be focused on broad anticlinal noses that plunge into the basin.

The reservoir map shows the distribution and quality of existing and/or potential reservoir units. Reservoirs may be of the conventional type such as a channel sandstone or of the unconventional type such as fractured, thin-bedded, low-permeability offshore sandstone and carbonate mudstone units. In areas where structural closure is absent, the reservoir map is used to identify potential stratigraphic traps. An accurate reservoir map depends on good time-stratigraphic correlations, and on the correct identification of major lithofacies, diagenetic facies, and unconformities. Maps that are commonly used to show the distribution and quality of conventional reservoir units include net sandstone, porosity, and lithofacies maps.

High-quality seismic lines, used in conjunction with available drill hole data, are helpful in constructing reservoir maps. The stratigraphy in available drill holes must be calibrated to the seismic data either by synthetic seismograms or by vertical seismic profiles (VSP). Digital seismic models should be generated for known fields of the stratigraphic trap variety and compared with field seismic data gathered across the field. Measurable waveform anomalies associated with the field, both in the model study and in seismic records, suggest that undiscovered fields with similar geologic attributes also may be visible on seismic data.

When analogue fields are not available, we believe the exploration program should be organized in the following way:

1. Study the regional stratigraphy.

2. Decide whether or not potential stratigraphic traps exist on regional stratigraphic cross-sections.

3. Generate a velocity model.

4. Generate synthetic seismic profiles (a seismic model) along the regional stratigraphic cross-sections.

5. Shoot seismic lines only if an anomaly is present in the model.

6. Drill only those seismic anomalies that have a plausible geologic explanation.

7. Drill; if the hole is dry, reevaluate; gather as much information as possible from the drill hole including cores, modern well logs, drillstem tests, source rock data, and a vertical seismic profile. These data help to determine whether or not oil and/or gas are present in the basin.

8. An oil and/or gas discovery also requires an evaluation. For example, are the prospective targets (producing zones) large enough? In this regard, one needs to remember that many small fields can add up to substantial reserves.

Concluding Recommendation:

The single most important factor in evaluating the hydrocarbon potential of a basin is whether or not mature source rocks are present. The distribution of source rocks may be totally different in adjacent basins because of different histories of sedimentation and tectonism: source rocks are present in some basins and absent in others. Moreover, source rocks mature in different basins at different times for different reasons. Therefore, basin classification is not a reliable forecaster of undiscovered petroleum reserves; for every type of basin (e.g. rift basin) that is rich in hydrocarbons, we argue, there is one that is deficient in hydrocarbons. The lesson to be learned here is that source rocks must be critically evaluated for each individual basin.

14. Exploring for pervasive gas accumulations in deep basins (LM)

It is now recognized that vast gas fields can occur in the deep synclinal parts of many onshore basins in the United States and Canada. These fields are not conventional structural or stratigraphic traps. The fields are very large to enormous in aerial extent, some covering more than 16,000 square kilometers. The recoverable reserves are also typically large, being several TCF to 10's of TCF, making them truly giant fields.

The first large gas fields in North America were discovered by conventional methods, such as drilling deep structures in the basin. Not until much later was it realized that the traps were not just on the crest of individual structures but covered vast areas in the deep part of the basin, including the synclines between the anticlinal structures. Industry in North America is now deliberately exploring for these types of accumulations. Finding this type of gas accumulation has been relatively easy. Producing gas economically can be a bigger problem. Because the reservoirs are deep in the basin and can be quite tight, proper drilling and completion practices are essential.

These giant gas fields seem to show a number of common attributes that help shed some light on the unusual nature of these accumulations.

Fluids

A. Totally gas saturated section. Updip on the shallow flanks of these basins the reservoirs are conventional structural or stratigraphic traps with gas over water. However, in the deeper parts of these basins the same reservoirs become totally gas saturated. The gas saturation (1) covers large geographic areas (over 16,000 square kilometers), (2) spans thick stratigraphic intervals (over a thousand meters), (3) is independent of structures, and (4) occurs not only in sands but also in interbedded shales.

B. Water production. There is no movable water in the rocks so there is no (or negligible) associated water production. There is no downdip gas-water contact; it is updip!

Reservoirs

C. Tight reservoirs. The reservoirs typically occur in low porosity and low permeability sandstones. Typical porosities are 7-12%. Typical permeabilities are less than 1 millidarcy and commonly are measured in hundredths of a millidarcy. Because they are tight, hydraulic fracturing is an important completion practice.

D. Sweet spots. The best field wells are those that contain reservoirs with the best permeability. Once one understands the geology of a field, there are usually depositional or structural parameters that control the trend of the most productive wells. These parameters include:

(1) Well-sorted beach conglomerates having permeabilities up to several darcies (Elmworth Field, Alberta Basin, Canada).

(2) Thick turbidite channels (Red Oak-Kinta and Ozona-Sonora Fields, Arkoma Basin, Oklahoma-Arkansas).

(3) In-situ natural fractures (Wattenberg Field, Denver Basin, Colorado).

<u>Pressures</u>

E. Each accumulation is either underpressured or overpressured with respect to the regional water gradient. In other words, abnormal field pressures are critical to the existence of these traps. Because of these abnormal pressures, some people refer to them as "pressure traps."

For the two most recent fields, discovered in 1970 (Wattenburg) and 1976 (Elmworth), many dry wells had previously been drilled through the gas pay zone(s) prior to the discovery well being drilled. At Wattenberg about twenty older wells (all dry) penetrated the gas section in the area now occupied by the 3 TCF field. In Elmworth several hundred wells penetrated the productive Cretaceous sands within the present field area prior to the discovery well being drilled.

We believe there is a key message in these two examples: there are important clues in older data. Namely, one can make use of existing log and test data to anticipate the occurrence of one of these giants.

<u>Tests:</u> At both Wattenberg and Elmworth (probably also the other fields mentioned, if we go back to a prediscovery map) there was a sizeable area where tests were made that only recovered gas or mud, but no water. The gas flows were typically very small and judged to be non-commercial by the initial operators who abandoned the wells. Subsequent operators came in and hydraulically fractured the units to produce commercial gas wells.

<u>Log evaluations:</u> Careful log evaluation on these early dry holes indicated that the sands were gas saturated and should be productive with proper drilling/completion techniques. The logs must be calibrated to the rocks by using samples or cores.

Of importance, the resistivity logs nicely reflect the gas saturated section. The resistivities of <u>both</u> the sands and the shales increase with respect to the updip water-wet section. The higher resistivities reflect both tighter reservoir and gas saturation. Of interest, a resistivity value of 20 ohms nicely defines the gas saturated zones in both the San Juan Basin and Elmworth Fields: namely, sand-shale sections exceeding 20 ohms are gas saturated! This observation means that one can use older wells for which only electric logs are available (but no porosity logs available). However, it is not clear yet that 20 ohms is necessarily the critical limit in all basins. Likely this value will vary, depending on the type of rock with which one is dealing.

It is fair to say that we still have a great deal to learn about these vast pervasive, abnormal pressured gas fields. The biggest unknown is perhaps why do the fields occur in some basins and not others?

These types of huge gas fields should not be unique to North America and may occur in Chinese onshore basins. The Chinese either do not have or did not present to us sufficient data to determine whether these huge gas fields do exist in their basins. It is the opinion of two of us (LM and AWB) that they do. Meaningful exploration plays can only be made by the careful integration of geology, well log evaluation, and proper drilling/completion practices.

References.

Masters, J. A., 1984, Elmworth - Case Study of a Deep Basin Gas Field: AAPG Memoir 38, 316 pp.

Davis, T. B., 1984, Subsurface Pressure Profiles in Gas Saturated Basins: in AAPG Memoir 38, p. 189-204.

Matuszczak, R. A., 1973, Wattenburg Field, Denver Basin, Colorado: Mountain Geologist, V.10, p. 99-105.

Sneider, R. M., et al., 1981, Methods for Detection and Characterization of Reservoir Rock, Deep Basin Gas Area, Western Canada: SPE Reprint 10072, 56th Annual SPE Meeting in San Antonio, Texas.

Masters, J. A., 1979, Deep Basin Gas Trap, Western Canada: AAPG Bulletin, V.63, p. 152-181.

McPeek, L. A., 1981, Eastern Green River Gasin: A Developing Giant Gas Supply from Deep, Overpressured Upper Cretaceous Sandstone: AAPG Bulletin, v. 65, p. 1078-1098.

Smith, R. D., 1982, Deep Basin Gas "The Sleeping Giant": Paper presented at the AAPG Annual Meeting, Calgary, Alberta, June 27-29.

*NOTE: This reference list includes titles that are not cited. It was felt the additional references may be useful for the reader.

15. <u>Some comments regarding data confidentiality of reflection seismic profiles, gravity, and well data</u> (AWB)

It is at present customary for petroleum exploration companies in the U.S. and in many other countries to keep many of their data confidential. Many of the reasons for this practice are quite understandable, but other reasons have been built on historical premises that are no longer valid. Today most oil companies share a large number of data sets (e.g., group surveys, joint ventures, etc.). We believe that a judicious relaxation of confidentiality rules could greatly benefit the overall progress of research and education in the earth sciences.

On our visit we were kindly and generously shown the beautiful exhibits in Zhuoxian, but at the same time we were forbidden to take notes or make sketches. This exposure to seismic reflection profiles was sufficient for us to get interested but not sufficient for us to come up with a good impression of the profiles across many Chinese basins. A day after our visit to the exhibit hall we were asked to give our expert opinions on and evaluations of the material we saw. This request was obviously an impossible one. Even the most astute experts in the world cannot and should not give a balanced opinion after only a couple of days of exposure to papers mainly concerned with basin classification and one day at a display showing many seismic profiles across over a dozen sedimentary basins without permission to take any notes!

One may also consider that our group was brought to China at substantial expense to Chinese organizations. Many of us have had considerable experience in the interpretation of seismic data. The results of an exchange visit are obviously sharply reduced and limited if visiting experts are not permitted to take notes and make sketches of seismic profiles. In other words, this restriction on access is an inefficient use of potentially valuable expertise.

We only reluctantly discuss the delicate and complex question of data confidentiality, but we think that the issue is important enough to point out some of the difficulties and inefficiencies that could arise in the future if data confidentiality regulations and practices are not somewhat relaxed. Let us hasten to add that the situation we encountered is similar in many other countries, including parts of the U.S. For instance, some eighty years after the discovery of major oil fields in the Gulf Coast basin of the U.S., there is as yet not a single regional seismic profile across the onshore Gulf Coast published! The consequence is that educators, students, research scientists, and co-workers cannot use this important source of information. Here let us list here only two important problems related to excessive data confidentiality in the earth sciences in China.

(1) Future cooperative projects with foreign academic scientists aimed at basin analysis will be severely limited for China if selected seismic profiles cannot be made available.

The same caveat can be made with regard to training courses given by foreign experts in seismic stratigraphy and in the structural interpretation of seismic profiles. It is nearly pointless for outsiders to give such courses in China without the availability of examples from Chinese basins.

(2) We also sensed in the course of our short visit a very serious training gap in Chinese universities. How is it possible for academic institutions in China to train students in the interpretation of seismic profiles if the data are not made

available? Most of the population centers of China are in sedimentary basins, and many of the most serious earthquakes are related to faults in sedimentary basins. How will it be possible to teach students and researchers about the sedimentary basins of China -- or about earthquakes -- without adequate seismic documentation?

An objective view of reality is that all exploration activity in China is and will be firmly controlled by the government and particularly by the Ministry of Petroleum Industry. Any foreign company that is qualified, interested, and invited to participate in exploration will insist on access to many pertinent data before making a decision to enter into a venture. It is probable that - as in the U.S. - most regional seismic data and key well logs are shared by the majority of competing companies. The only people who do not have sufficient access are outsiders, and among them, many academic researchers who are eager to contribute to research on sedimentary basins and to teach students what is known in industry about sedimentary basins.

On the positive side there has been much progress in terms of access in many parts of the world. For instance, a number of countries require that logs and reflection seismic profiles become available to the public a few years after they have been obtained. Such countries include Canada, Australia, England, France, Spain, Italy, etc. In the U.S. data obtained by the federal government are made available after a few years. These data provide an invaluable teaching and research resource.

Finally, one of us (AWB) has been involved with the compilation of an atlas series of seismic reflection profiles, of which three volumes have been published by the American Association of Petroleum Geologists. This example of compilation was followed by colleagues in Australia and by the Rocky Mountain Association of Geologists. These atlases are now widely used for instruction in universities and surprisingly by the same companies that previously thought that these data ought to remain confidential. The secret behind the success of the atlas project was a special format that allowed the reproduction of seismic profiles without loosing legibility. Secondly, the editors insisted on both interpreted and uninterpreted copies. The copies of reflection seismic profiles without interpretation are particularly useful for training because they permit us to explore alternative interpretations. Most important, the atlas project does not insist on precise location of the profiles and shotpoints; thus any confidentiality problems are easily overcome.

Recommendation: We suggest that the Ministry of Petroleum Industry give careful consideration to relaxing some of the rules related to release of well data and seismic profiles across the sedimentary basins of China. Without the availability of at least some of these data, joint projects with foreign researchers probably will not be possible. Also teaching by foreign specialists would be greatly improved with the availability of such data.

Recommendation: It is suggested that the Ministry of Petroleum Industry use the exhibits at Zhuoxian as the basis for a seismic atlas project in China that could easily be modeled after the format adopted by the American Association of Petroleum Geologists and the Rocky Mountain Association of Geologists. (See Appendix F, for an example of instructions.)

16. The need for basin research in connection with exploration programs (AWB)

Integrated basin studies are essential. Major basinal resources are hydrocarbons, coals, and, above all, fresh water. Note also that many sedimentary basins are the locus of regional population centers. It is quite important that sedimentary basins be studied as a system of reservoir rocks and seals that control the distribution of fluids and resources. The problems of resources extraction and environmental maintenance should always be viewed in the overall context of the sedimentary basin.

In the U.S., some integrated basin studies are undertaken by the major oil companies. Much of that work remains confidential. Other studies of this type are undertaken by the U. S. Geological Survey and by some of the state surveys (e.g., Bureau of Economic Geology of Texas, California Division of Mines and Geology, and others). Selected research aspects are undertaken by individuals in some universities.

Our short visit in China does not permit us to comment in depth on the status of integrated basin studies in China, but we sense that there are significant organizational obstacles that prevent the integration of such studies. One gains the impression that contacts and communications among the scientists of the Ministry of Petroleum Industry , the scientists of the Ministry of Geology, and the researchers of the Academia Sinica, for instance, are very limited. Such communication obstacles are also known to us in the U.S. However, in the U.S. the earth science societies -- and particularly with regard to basin studies the regional geological societies (e.g., the Rocky Mountain Association of Geologists) -- play a very important role by providing a marketplace that brings together much information on basin studies.

We felt that in China circumstances are particularly favorable for sponsoring some integrated basin studies because, after all, in China all resources are owned by the State and therefore confidentiality of information could at least in principle be relaxed.

In China it would be easy to visualize one or more basin research centers that would bring together talented researchers from various organizations who could carry out significant research tasks. We visualize a research organization that would combine the research tasks that in the U.S. and other western countries are carried out independently by the petroleum industry research labs and by a number of federal and provincial (or state) research organizations. Major areas of research would include:

- Origin and structural evolution of sedimentary basins

- Hydrocarbon genesis and distribution in sedimentary basins

- Other resources such as coal and potash

- Regional hydrology and hydrological research

- Technical training of earth scientists

Aside from these general research areas, there would also be basic research in geophysics, geochemistry, subsurface geology, and hydrology.

A specialized basin research institute could take the lead in organizing major research initiatives such as the acquisition of deep crustal seismic reflection profiles or the drilling of stratigraphic tests in poor data areas. Such tests could be combined with vertical seismic profiling..

There will always be the question of what constitutes basin research on the one hand and what is exploration, surveying, and resource management on the other hand. The boundary between research and applications is often shifting, and it is probably not worthwhile to get into a profound philosophical debate over this distinction. It is best to visualize research as an activity with long-range goals that include the development of new concepts and methods. Often expensive specialized equipment has to be shared by teams of earth scientists. In contrast to basin research, exploration, surveying, and management activities start with existing concepts and methods and use shorter planning schedules. There is little doubt, however, that the applied side of the earth sciences often contributes most significantly to the definition of long-term research goals. The way to good integration of basic long-term research and applications to the earth sciences involves a healthy traffic and personnel exchange between research and applications. An obvious prerequisite for this exchange is relaxed data confidentiality. Open communications is a most vital key to a successful earth science enterprise.

A special note on training is in order . On our trip we all were approached regarding the training of Chinese earth scientists in the U.S. and specifically in our own institutions. Needless to say, our Chinese colleagues are always welcome to visit with us in the U.S., and we look forward to greater exchanges of our scientists.

There are, however, some real limitations to these collaborative activities, the most important ones being money and language. Most U.S. institutions have only very limited funds to support foreign students. It is often very difficult for us to assess the academic background of student applicants who are intent on acquiring an academic degree in the U.S.

Perhaps more important, the language difficulties are probably more difficult than anybody is willing to admit. This factor is especially true for training assignments with industry. There often exist contractual agreements in industry to train foreign earth scientists in the U.S. These contractual agreements can easily be fulfilled by allowing Chinese earth scientists to sit in industry-sponsored training courses. It should, however, be noted that such courses typically do not provide any means to test whether the student has actually absorbed the subject matter of the course. Thus it sometimes happens that individuals can honestly say that they attended a course without realizing that because of the language difficulties they learned only a small fraction of what was offered in the course.

Basin exploration and research is a field that will be active for many decades to come. Quite independent from any worldwide economic fluctuations, China will always need energy and water to support its own economy. These are many resources that occur within sedimentary basins, and specialized training for sedimentary basin research, exploration, and management will be necessary to solve future problems. The time may be ripe for our Chinese colleagues to consider establishing their own specialized facilities for basin-related earth science training. Such facilities could be jointly sponsored by the various ministries and government agencies.

In our opinion such training should initially include immersion in a foreign language (preferably English). Foreign speakers could then be invited to give courses in their own language that would transfer their specialized knowledge to Chinese trainees. Initially, there may still be a need for professional translators.

Let us assume that all trainees already had a solid university training in the earth and basic sciences. The specialized, more advanced training would then focus on subsurface techniques (the use of the most modern logging techniques, basic drilling techniques, petrophysics), seismic exploration techniques (mostly reflection seismology), geochemical techniques (organic geochemistry and groundwater related geochemistry), and hydrology. Finally, courses should be given to illustrate the use of integrated basin studies for resource exploration and basin management.

Except for the hydrological training what we propose is close to the typical training plans of major oil companies, a very limited number of universities in the U.S., and some foreign organizations like the Institut Francais de Petrole. Shifting the training of sedimentary basin specialists from relatively short training assignments abroad to intensive training within China would reduce language-related problems and would expose a much larger number of young Chinese earth scientists to the skills required for a modern basin-oriented earth scientist. Training in China would also provide a means of testing trainees for the skills they are supposed to acquire. Last but not least, such training would be cheaper and more efficient.

In conclusion, we recommend that our Chinese colleagues consider establishing a Basin Research Institute in China that would focus on integrated basin studies and related basin research. The Institute would best be a cooperative effort involving all the relevant ministries and organizations that have a vital interest in sedimentary basin studies. Attached to the Institute should be a training center that will provide advanced training for Chinese earth scientists who want to make a career in the area of basin exploration and management. An international advisory panel could be helpful in setting up such a facility.

APPENDIX A

Sino-American Symposium on Sedimentary Basins
Zhuoxian, Hebei
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APPENDIX B

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APPENDIX C

American Delegration's Reprints and Papers Sent to China Prior to Visit

Bally, Albert W. and John S. Oldow, Plate tectonic, structural styles, and the evolution of sedimentary basins, an AAPG Short Course, held in conjunction with the SEPM mid-year meeting, 238 pp.

Eugster, H. P., 1980, Geochemistry of evaporitic lacustrine deposits, Ann. Rev. Earth Planet. Sci., v. 8, p. 35-63.

Eugster, H. P., 1980, Lake Magadi, Kenya and its precursors, in: A. Nissenbaum (ed.), Hypersaline brines and evaporites. Elsevier, Amsterdam, Developments in Sedimentology, v. 28, p. 195-232.

Eugster, H. P., 1985, Oil shales, evaporites and ore deposits, Geochimica et Cosmochimica Acta, v. 49, p. 619-635.

Eugster, H. P., in press, Lake Magadi, Kenya: A model for rift valley hydrochemistry and sedimentation? in: Frostick, Renaut, Tiercelin (ed.), African Rift System, Geol. Soc., London.

Kidwell, Susan M. and Thomas Aigner, 1985, Sedimentary dynamics of complex shell beds: Implications for ecologic and evolutionary patterns, in: Sedimentary and Evolutionary Cycles (U. Bayer and A. Seilacher, eds.), Berlin: Springer Verlag, p. 382-395. (University of Chicago)

Kidwell, Susan M. and David Jablonski, 1983, Taphonomic feedback. Ecological consequences of shell accumulation: in, Biotic Interactions in Recent and Fossil Benthic Communities (M.J.S. Tevesa nad P. L McCall, eds.), New York: Plenum Press, p. 195-248. (University of Chicago)

Kidwell, Susan M., 1982, Time scales of fossil accumulation: Patterns from Miocene benthic assemblages, N. Amer. Paleo. Conv., Proc., v. 1, p. 295-300. (University of Chicago)

Kidwell, Susan M., 1984, Outcrop features and origin of basin margin unconformities in the Lavei Chesapeake Group (Miocene), Atlantic coastal plan, Amer. Assoc. Petrol. Geol. Mem., v. 36, p. 37-58. (University of Chicago)

Kidwell, Susan M., 1985, Genesis of fossiliferous horizons and their significance for basin analysis, Report for Sino-American Academic Symposium on Petroleum-bearing Sedimentary Basins (Zhuoxian, August 18-21, 1985), 19 pp. (University of Chicago)

Meckel, Lawrence D., Seismic mapping of sandstone stratigraphic traps. (L. D. Meckel & Co.)

Meckel, Lawrence D., Deep pervasive gas field in North America. (L. D. Meckel & Co.)

Ryder, R. T., 1985, Patterns of sedimentation in the Rocky Mountain foredeep, USA: U.S. Geological Survey Administrative Report for Sino-American Academic Symposium on Petroleum-bearing Sedimentary Basins (Zhuoxian, August 18-21, 1985), 43 p. (U. S. Geological Survey)

Ryder, R. T., 1985, Seismic expression of sandstone stratigraphic traps in Rocky Mountain basins, USA: U.S. Geological Survey Administrative Report for Sino-American Academic Symposium on Petroleum-bearing Sedimentary Basins (Zhuoxian, August 18-21, 1985), 28 p. (U. S. Geological Survey)

Balch, A. H., M. W. Lee, J. J. Miller, and R. T. Ryder, 1981. Seismic amplitude anomalies associated with thick First Leo sandstone lenses, eastern Power River Basin, Wyoming: Geophysics, v. 46, no. 11, p. 1519-1527.

Clayton, J. C. and R. T. Ryder, 1984. Organic geochemistry of black shales and oils in the Minnelusa Formation (Permian-Pennsylvanian), Power River Basin, Wyoming, in Woodward, Jane, F. K. Meissner and J. L. Clayton, Eds., Hydrocarbon source rocks of the greater Rocky Mountain region: Rocky Mountain Association of Geologists, Denver, p. 231-353.

Lee, M. W., J. J. Miller, R. T. Ryder, and A. H. Balch, 1981. Processed and interpreted U.S. Geological Survey seismic reflection profile and vertical seismic profile, Niobrara County, Wyoming: U.S. Geological Survey Oil and Gas Investigations Chart OC-114.

Miller, J. J., R. T. Ryder, A. H. Balch, and M. W. Lee, 1981. Processed and interpreted U.S. Geological Survey seismic reflection profile and vertical seismic profile, Powder River and Carter Counties, Montana: U.S. Geological Survey Oil and Gas Investigations Chart OC-110.

Perry, W. J., Jr., R. T. Ryder, and E. K. Maughan, 1981. The southern part of the southwest Montana thrust belt: a preliminary re-evaluation of structure, thermal maturation, and petroleum potential, in Tucker, T. E., ed., Field conference and symposium guidebook to southwest Montana: Montana Geological Society, Billings, p. 261-273.

Peterson, Fred and R. T. Ryder, 1975, Cretaceous rocks in the Henry Mountains, Utah and their relation to neighboring regions, in Fassett, James, ed., Canyonlands: Four Corners Geological Society Guidebook for 8th Field Conference, p. 167-189.

Ryder, R. T. and H. T. Ames, 1970. Palynology and age of Beaverhead Formation, and their paleotectonic implications in the Lima region Montana-Idaho: American Association of Petroleum Geologists Bulletin, v. 54, No. 7, p. 1155-1171.

Ryder, R. T., T. D. Fouch, and J. H. Elison, 1976. Early Tertiary sedimentation in the western Uinta Basin, Utah: Geological Society of America Bulletin, v. 87, No. 4, p. 496-512.

Ryder, R. T., M. W. Lee, and G. N. Smith, 1981. Seismic models of sandstone stratigraphic traps in Rocky Mountain basins: American Association of Petroleum Geologists, Methods in Exploration Series, Tulsa, 77 p., 15 foldouts.

Ryder, R. T. and Robert Scholten, 1973. Syntectonic conglomerates in southwest Montana: their nature, origin, and tectonic significance: Geological Society of America Bulletin, v. 84, No. 3, p. 773-796.

Vail, P. R. and R. M. Mitchum, Jr., 1978, Global cycles of relative changes of sea level from seismic stratigraphy. Amer. Assoc. Petrol. Geol. Mem., v. 29, p. 469-472.

Hardenbol, J., P. R. Vail, and J. Ferrer, 1981, Interpreting paleoenvironments, subsidence history and sea-level changes of passive margins from seismic and biostratigraphy: Ocenologica Acta.

Vail, P. R. and R. M. Mitchum, Jr., 1980, Global cycles of sea-level changes of their role in exploration, Proc. Tenth World Petroleum Congress, 2, Expl. Supply and Demand, p. 95-104.

Vail, P. R. and Jan Hardenbol, 1979, Sea-level changes during the Tertiary, Oceanus, v. 22, p. 71-79.

Vail, P. R. and Jan Hardenbol, 1984, Jurassic unconformities, chronostratigraphy and sea-level changes from seismic stratigraphy and biostratigraphy, GCSSEPM Foundation 4rd Annual Research Conf. Proceedings, p. 347-363.

Steckler, M. S. and A. B. Watts, 1978, Subsidence of the Atlantic-type continental margin off New York, Earth Planet. Sci. Lett., v. 41, p. 1-13.

Watts, A. B., 1982, Tectonic subsidence, flexure and global changes of sea level. Nature, v. 297, p. 469-474.

Watts, A. B., G. D. Karner, and M. S. Steckler, 1982, Lithospheric flexure and the evolution of sedimentary basins. Phil. Trans. Roy. Soc. Lond., v. A305, p. 249-282.

Watts, A. B., G. D. Karner, and M. S. Steckler, 1982, Lithospheric flexure and the evolution of sedimentary basins, in The Evolution of Sedimentary Basins, (eds.) P.Kent, M.H.P.Bott, D.P.McKenzie, C.A. Williams, Phil. Trans. Roy. Soc. Lond., v. A305, p. 249-281.

Watts, A. B. and J. Thorne, 1984. Tectonics, global changes in sea level and their relationship to stratigraphic sequence at the U. S. Atlantic continental margin, Marine and Petroleum Geology, v. 1, p. 319-339.

Karner, G. D. and Watts, A. B., 1983, Gravity anomalies and flexure of the lithosphere at mountain ranges, J. Geophys. Res., v. 88, p. 10449-10477.

Steckler, M. S. and A. B. Watts, 1981, Subsidence history and tectonic evolution of atlantic-type continental margins, Amer. Geophys. Union, Geodynamics Series 8, p. 184-196.

APPENDIX D

CHINESE PRESENTATIONS AT ZHUOXIAN

1. ON THE CHARACTERISTICS AND THE MECHANISM OF FORMATION OF THE WESTERN PACIFIC BACK-ARC BASINS: THEIR GEOTECTONIC SIGNIFICANCE AND THEIR BEARING WITH OIL-GAS ACCUMULATION
   Guo Lingzhi, Shi Yangshen, Ma Ruishi, Lu Huafu, and Dong Huogen (Department of Geology, Nanjing University) and Wu Baoqing (Sichuan Petroleum Administration, Ministry of Petroleum Industry) (MPI)

2. *CLASSIFICATION AND ORIGIN MECHANISM OF CHINA'S CENO-MESOZOIC CONTINENTAL SEDIMENTARY BASINS
   Guan Shicong (Ministry of Geology and Mineral Resources)

3. FRAMEWORK OF CHINESE PETROLIFEROUS BASINS
   H. J. Chen, Z. C. Sun, and Y. C. Zhang (Central Laboratory of Petroleum Geology, Ministry of Geology and Mineral Resources)

4. FORMATION AND EVOLUTION OF TARIM BASIN
   Tian Zaiyi, Chai Guilin, and Lin Liang (Petroleum Exploration and Development Institute of MPI and Bureau of Geophysical Prospecting of MPI)

5. EVOLUTION FEATURES AND TECTONIC TYPES OF THE JUNGGAR BASIN
   Peng Xilin, Li Lichen, Zhou Demin, Wu Zhixuan, Wu Qingfu, Liu Zhaorong, and Yuan Wenxian (Xinjiang Petroleum Administration Bureau)

6. THE MECHANISM OF FORMATION AND PETROLEUM PROSPECTS OF THE QAIDAM BASIN
   Xie Mingqian, Di Shiqi, and Sun Zhaoyuan

7. REGIONAL STRUCTURE FEATURES AND STRUCTURAL MODE OF SICHUAN BASIN
   Bao Ci, Yang Zianjie, and Li Dengxiang (Sichuan Petroleum Administration)

8. THE GEOTECTONIC CHARACTERISTICS IN ERLIAN BASIN
   Wu Huayuan and Fei Baosheng (North China Oil/Gas Exploration and Development Company)

(*) Written paper not yet available.

APPENDIX E

Sino-America
Symposium on Sedimentary Basins
Zhuoxian, Hebei

PROGRAM
August 18-21, 1985

Sunday, August 18

Opening Ceremony — **Sponsors:** Lu Banggan, Albert W. Bally

Speakers:
Tian Zaiyi, Professor, Chairman for the Chinese side
Albert W. Bally, Professor, Chairman for the American side

Morning Session:
1) Albert W. Bally - Basin and Folded Belt Classification
2) Guo Lingzhi - On the Characteristics and the Mechanism of Formation of the Western Pacific, Back-Arc Basin: Their Geotectonic Significance and Their Bearing with Oil-Gas Accumulation
3) Anthony Watts - Modeling of Sedimentary Basins

Afternoon Session:
4) Guan Shicong - The Classification, Distribution, Regulation and Mechanism of Origin of the Chinese Mesozoic - Cenozoic Continental Sedimentary Basin *
5) Robert Clayton - Processing Reflection Seismic Data
6) Chen Huanjiang - Framework of Chinese Petroliferous Basins
7) Robert Ryder - Patterns of Sedimentation in Rocky Mountain Foredeep

Monday, August 19

Morning Session:
8) Chai Guilin - Formation and Evolution of Tarim Basin
9) Susan Kidwell - Evaluation of Non-Deposition Intervals
10) Peng Xilin - Evolution Features and Tectonic Types of the Junggar Basin
11) Lawrence Meckel - Deep Basin Fields
12) Xie Mingqian - The Mechanism of Formation and Petroleum Prospects of the Qaidam Basin

Afternoon Session:
13) Hans Eugster - Sedimentation and Geochemistry of Closed Basins
14) Bao Ci - Regional Structure Features and Structural Mode of Sichuan Basin
15) Robert Ryder and Lawrence Meckel - Exploration in Lacustrine Basins
16) Fei Baosheng - Structure Characteristics of Erlian Basin

(*) Mr. Guan could not prepare a written paper.

Tuesday, August 20

Morning and Afternoon

Visit to the geological exhibit, the Research Institute of Geophysical Prospecting Bureau of MPI

Wednesday, August 21

Morning and Afternoon

Small Group Discussions

Group 1: Petroleum geology
Leaders: Ye Lianjun
Xu Wang
Albert W. Bally

Group 2: Petroleum geophysical prospecting
Leaders: Meng Ersheng
Lu Banggan
Lawrence Meckel

Closing Ceremony

Speakers:
Guo Lingzhi
Ye Lianjun
Albert W. Bally
Zhai Guangming

APPENDIX F

Instructions for:

SEISMIC ILLUSTRATIONS OF STRATIGRAPHY - AN ATLAS PUBLISHED BY THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

Introduction and purpose

The three volumes "Seismic Expression of Structural Styles" have been quite successful. The publication of numerous seismic reflection profiles has helped to bridge the information gap that exists between academia and industry. The AAPG would now like to expand this project and publish an atlas that would focus primarily on stratigraphy, as illustrated by seismic reflection profiles.

We hope that users of the Atlas will include petroleum geologists concerned with stratigraphic interpretations, exploration companies that provide in-house training, and above all, colleges interested in updating their curricula by inclusion of sections from the "real world" in their teaching, the AAPG Continuing Education program, and many other groups. The AAPG will again try to keep the Atlas price low enough that students can afford to purchase it.

Each group of reflection lines covering one theme will be treated as a formal paper citing the author and the sponsoring company. The Atlas will be assembled, edited and provided with introductory comments by A. W. Bally.

Scope and tentative organization

1. Modern seismic processing and display techniques: If submitted, the AAPG will consider color displays. This section would also include papers concerned with synthetic seismic profiles and models.

2. Stratigraphy as displayed on high frequency profiles: High frequency seismic profiles should illustrate classical stratigraphic situations in details that are comparable to outcrop geology.

3. Seismic stratigraphy: Regional sections that display sequences and unconformities, as well as basin-filling processes.

4. Structural control of stratigraphy and sedimentation:

5. Stratigraphic case histories:

   a. clastics
   b. carbonates and evaporites
   c. volcanic sequences

In this segment, it would be particularly useful to have well documented examples of seismic profiles that have been calibrated by wells. The seismic description should be complemented by lithologic sections, and hopefully velocity information.

Our outline is incomplete and will be modified in light of suggestions by contributors and also in response to the contributions we hope to receive.

Authors should feel free to choose among regional reflection profiles or else among profiles across individual features and/or local details. What is important is that the message concerns and illustrates basic stratigraphic principles.

Copies of lines that have already been published elsewhere but which would profit from a larger scale reproduction would be a substantial contribution. However, if we can obtain more modern versions of similar lines or else other modern lines, we will be most grateful as it will greatly enhance the quality of our Atlas.

Illustrations

We would like to have good quality seismic reflection profiles. In all cases we emphasize legibility. Thus, to avoid excessive reduction, it may be necessary to break a regional line into several segments (we prefer to avoid foldouts); in other cases, enlargements of critical features may be necessary. The choice is left entirely to the judgment of the authors.

A major reason for the success of the structural atlas was that most of the profiles were published in three versions:

1. An unmarked version in time,

2. A marked version of the same line or else an annotated line drawing on the same scale as No. 1,

3. A version of the same line that was subjected to different processing, e.g., migration, depth conversion, etc.

It is important for the stratigraphic atlas to have at least the same three basic versions, to see the impact of different interpretation possibilities and differing display techniques.

Location and identification of seismic lines

Ideally, an accurate location of the seismic profile would be desirable. However, we fully realize the confidential aspects of exploration work and know that it may not always be possible to provide the accurate location of a profile. Because we are concerned only with the illustration of principles of stratigraphy, an exact location may not be necessary. In that case a simple map showing the outline of the geological province and an approximate location may suffice. On the other hand, even with an approximate location, it still would be useful to have an index map showing the azimuth of the profile, positions of selected marker points, or shotpoints and changes in the orientation of the line and a horizontal scale; all this could be shown without specific geographic location.

Scales

For the benefit of an international audience, the scales should be in both the metric and the English system. On depth converted sections or drawings, the vertical metric scale should be on the left side ofthe profile and the vertical English scales on the right side. The graphic horizontal scale should be on the bottom of the section.

We do not think it advisable to standardize scales because both regional as well as local phenomena may be illustrated. In all cases legibility of the profile should be the most important consideration.

Preparation of illustrations

Illustrations for submittal: Supply a negative and an original positive, all at 100 percent of the final image size, in order to reduce the need for reworking and reshooting the material. This procedure will help us to cut down the final cost of the Atlas.

Illustration size: Final page size is 11 inches by 24 inches (23 cm x 36 cm). Our final image area is 9 inches by 22 inches, and all illustrations should fit the final image area to avoid additional reproduction costs.

Title block: Place the title blocks of each illustration in the bottom lefthand corner, one inch from the bottom and left margins (suggested block not to exceed 3 inches by 4 inches if possible).

Type: Use only the sans serif family of type, and preferably Helvetica, Kroy, Herios, etc. No type should be smaller than 10 point nor larger than 18 point when presented in the final size (illustrators who plan to letter their work before a final reduction should plan to oversize their type).

Type style: Type in the legend box should be bold for titles and author names, and medium for numbers and information.

Of course, we would like for you to include any information that you judge important for a better understanding of the illustrations.

Text: We prefer the text to be short and to focus specifically on the structural interpretation of the seismic profiles. An introduction should briefly summarize the regional setting of the line.

The main text should describe the features illustrated by the profile, point out ambiguities in the interpretation, and briefly discuss the stratigraphic significance of the data. The economic significance of the information may also be discussed.

If particularly interesting techniques were used in the acquisition and processing of the data, these should, if possible, be described. Also, any comments on techniques of geological interpretation should be included. An up-to-date list of references that would provide additional background would be most helpful.

The text may be accompanied by additional illustrations such as line drawings,geological maps, etc. Because we expect the seismic profiles and the interpretations to speak for themselves, we feel that the text should not exceed one Atlas page size, that is, a maximum of about 9 double spaced, typewritten pages, including list of key references and illustrations. We realize that in some cases the text may be longer (or else shorter). Thus, the above comments should only serve as a guide.

To provide cohesion and some continuity among the different contributions, A. W. Bally plans to write a short introductory chapter for each of the major groupings of contributions.

Compilation schedule

Participation in this project will be solicited during the spring 1985.

We ask you kindly to let us know soon, but at the latest by October 1985, what kind of seismic profiles (area and stratigraphic characteristics) you plan to contribute; and, of course, if you foresee any particular problems, do not hesitate to let us know.* We also welcome any suggestions you may have regarding the overall plan for the project.

Deadline for submission of final manuscript will be May 1, 1986.

We do not expect to edit any of the illustrations, but for the sake of some uniformity, the AAPG will finalize the title blocks according to your draft title blocks. The text will also be set (typed) by the AAPG. To reduce costs and gain time, we urge you to do all the editing in-house. Manuscripts are not to be submitted for outside review, because such a collection of valuable data with accompanying preferred interpretations should not be controversial. Thus, the editorial review will be brief and be handled by A. W. Bally and the AAPG staff.

With the proposed schedule and perhaps one brief iteration for the text, we hope that the final product will be ready for sale by mid-1986.

*All correspondence or telephone calls should be directed to:

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If he cannot be reached, contact:

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P. O. Box 979
Tulsa, Oklahoma 74101
Telephone: (918) 584-2555

The final contributions should be mailed directly to Ronald Hart.