Progress of China Case Study  
(Western Depression of Sichuan Basin)

The PPM Third Seminar  
Chiang Mai, September 20-23, 2004

1. Short repetition of the country overview

1.1 Tectonic setting and basin outline

The western depression is the deeply subsided part of the Sichuan continental basin since late Triassic, with great tight sandstone gas resources.
The basin appears a geomorphologically rhombic basin, where widely occur Mesozoic and Cenozoic red clastic rock series. It is about $200 \times 10^3 \text{km}^2$ in area. The western depression is about $30 \times 10^3 \text{km}^2$ in area.

The basin is a structural basin, founded above crystalline and metamorphic basements formed before the Jinning age, then having experienced two major geological processes of carbonate platform and continental clastic sedimentary basin, and, finally, deformed by late tectonic event, especially by Himalayan movement. The Western Depression is a Foreland Basin.
1.2 Characteristics of reservoir, source and seal rocks

The deposition in Sichuan basin began in Sinian and ended in Eocene. Two Sedimental stages are recognized by different sedimentary characteristics.

(1) Carbonate Platform Stage
The stage before late Triassic was dominated by marine deposition with a thickness of 3000-6000 meters. After middle Triassic, the early Indosinian movement ended the extensive carbonate deposition and formed gentle structures.

(2) Continental Basin Stage
Due to the uplifting of Longmenshan Mountain in late Triassic, Sichuan foreland basin was formed, and the continental basin evolution stage started. The thickness of continental deposits ranges from 5000 to 8000 meters. But the existing thickness at present is 2000-6000 meters due to denudation.

Rich Source Rock —basis for large-middle scale gas fields

- Rich gas source rock in the continental clastics in west Sichuan basin, being the basis of forming large-middle scale gas fields.
- The main source rock is in upper Triassic.
- The secondary, gray mudstone in Jurassic.
Source Rocks for $T_3x^2$

Maantang Formation ($T_3m$)
Xiaotangzi Formation ($T_3t$)
2nd member of Xujiahe Formation ($T_3x^2$)

Characteristics of Reservoir
2nd member of Xujiahe formation ($T_3x^2$)

Seal Rock
$T_3x^2, T_3x^3$ mudstone

Trap Type
fractural-porous

Reservoir Lithology
fine-middle sandstone

Porosity & Permeability
$\Phi \sim 2-8\%$, $K = 0.02 - 0.2\text{md}$

Buried Depth
4530-4850m

Pressure Factor (MPa/100m)
1.55-1.73

Resources in Place
$6.7 \times 10^9\text{m}^3$

Proven Reserves in Place
$6.7 \times 10^9\text{m}^3$

Triassic Xu$^2$ Play

Super-high geo-pressure
Large buried depth
Super-tight sandstone
Low exploration maturity
1.3 History of petroleum business in the basin:

Licensing

Petroleum exploration, development, production and sales

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Exploration:

Exploration activities started in 1950’s. A dozen of gas fields have been found in Western Depression. The proved and probable reserves in place are \(260 \times 10^6\) m\(^3\).
Petroleum developments, production and sales:

The activities of development and production began in 1980’s. Annual gas production increased rapidly in recent years. 1.7 billion cubic meters of gas was produced in 2003. Main consumers are residents, chemistry factories and power plants.
1.4 Petroleum supply-demand

Nature gas production was $35 \times 10^9 \text{m}^3$ in 2003. But gas supply is less than demand in China.

It is expected that China’s annual gas production will reach to $50-60 \times 10^9 \text{m}^3$ for 2005 and $100 \times 10^9 \text{m}^3$ for 2010.

1.5 Current fiscal regime

1. Nature gas price \[ \text{RMB 669/1000 m}^3 \] ($81/1000 \text{m}^3$)
2. Sale tax: 11.5-14.5%
3. Income tax: 33%
4. Resource tax: 5-15 RMB/1000m$^3$

5. Land tax

(1) Exploration Block
- Year 1,2: none
- Year 3: $100/\text{km}^2$
- Year 4: $200/\text{km}^2$
- Year 5: $300/\text{km}^2$
- Year 6: $400/\text{km}^2$
- Year 7: $700/\text{km}^2$

(2) Production Block
- $1000/\text{km}^2$

The fiscal regime keeps the same in recent years. The current fiscal regime mentioned above is only applicable to national oil companies. There are pending to PSC for foreign oil companies. It need negotiate with national oil companies. Such as PetroChina, SINOPEC, or CNOOC.
2. Country’s programs in the case study basin

The mean value of natural gas resource are estimated to be $2150 \times 10^9$ m$^3$ (in the western depression of Sichuan basin). The proved and probable reserves is $260 \times 10^9$ m$^3$. Only 12% of the resources has been discovered. Therefore, it still has large, potential volumes that have not yet been discovered. The undiscovered resources are mainly in the deep, very tight sandstone among Xujiahe Formation.

2.1 Exploration

Because of tight reservoir and low gas flow rate, about one-third of the proved reserves has not been developed. Hydro-fracturing is the major method to stimulate the reservoir. But it does not work for tighter reservoirs. Natural fracture prediction is very important to develop the tight gas.

2.2 Development

SWPC has about 126 billion cubic meters of proved reserves. If the rate of production is 3%, 3.5 billion cubic meters of annual production could be expected. But now the annual production is only 1.9 billion cubic meters, half of the expected production. Apart from the reservoir stimulation technology, other production technologies are also needed, such as the technique that one well produces gas from several pay zones separately at the same time.
2.4 Petroleum companies active in the basin

Three main domestic companies:
- Southwest Oil & Gas Field Company, PetroChina
- Southwest Petroleum Company, SINOPEC
- South E&P Company, SINOPEC

One foreign company:
- Enron—Berlinton

2.5 Short/long term programs to increase the exploration activities

SINOPEC Plan in Sichuan Basin
1. Net Increase of Proved Reserves:
   2005               95 × 10^9m³,
   2006-2010    131 × 10^9m³
   2011-2015   100 × 10^9m³
   2015-2020      80 × 10^9m³

2. Exploration Activities
   2D                    36630km
   3D                     8770km²
   Wells                381

3. Gas Production:
   2005        2.1 × 10^9m³
   2010        5.5 × 10^9m³
   2020    10-15 × 10^9m³

2.6 Government strategies

1. Legislate to protect environment, encourage using natural gas

2. Derate tax
3. Case Study Workshop

3.1 Agenda topics and resource persons

Two workshops of China case study have been held since last seminar. Both were held in Chengdu, Sichuan province. The first was on October 20-25, 2003. The second on May 22-27, 2004.
Agenda of the first workshop:

1. Case Study Plan and main contents for the first workshop… Mr. Wang Chuan

2. Brief introduction to the geology, exploration and development in Western Depression of Sichuan Basin …Mr. Chen Zhaoguo

3. The application of GeoX in China… Mr. Yang Dengwei

4. Procedures and principles of the geological risk analysis of NPD …. Ms. Inger Pedersen Fjaertoft

5. Procedures and principles of the geological risk analysis of NPD (Continue) …Ms. Inger Pedersen Fjaertoft

6. The CCOP Resource Classification System…..Mr. Gunnar V. Søiland

7. The CCOP Guidelines for Risk Assessment…..Mr. Simplicio P. Caluyong

8. New features in GeoX 5.2 and insight on the multisegment tool (from 6AM to 9AM Oslo time) ……Ms. Inger Pedersen Fjaertoft


10. Introduction to the X2 play and exercise on X2 play assessment………..Mr. Yang Dengwei
Resource persons: (The first workshop)

MS. INGER PEDERSEN FJAERTOFT (NPD)
MS. MA. CORAZON STA.ANA (DOE)
Mr. Yang Dengwei (SINOPEC)

The Second workshop

Agenda of the Second workshop:

1. Report on the Expert Visits—Sinopec, Mr. Li Shubing
2. China Petroleum Resource Classification System – Ministry of Land and Recourses, China, Mr. Hu Yundong
3. The application of resource classification principles in presentations of resource figures, NPD, Ms. Inger Fjærtoft

4. Introduction to prospect (play) analysis (and the experience of prospect (play) evaluation) - NPD, Ms. Inger Fjærtoft

5. Review of the geology and reservoir parameters of the Sichuan Basin for volumetric calculation – Sinopec, Mr. Yang Dengwei

6. Using GeoX in prospect and play analysis, and resource modeling of the Hexingchang prospect – NPD, Ms. Inger Fjærtoft

7. Introduction to Basic Petroleum Economy- NPD, Ms. Benvenutta Henriksen

8. Introduction to exploration economy – NPD, Ms. Benvenutta Henriksen

9. Introduction to GeoX fullcycle analysis and economic analysis on gas prospect from other country (Norway)—NPD, Ms. Benvenutta Henriksen


11. Introduction to some aspects of fiscal systems and the application of after tax analysis using the GeoX software – NPD, Ms. Benvenutta Henriksen
12. Application of Norwegian (or other fiscal system and costs) system to Sichuan reserves, and make comparison to China – NPD, Ms. Benvenutta Henriksen

13. Introduction to multisegment economic analysis using the GeoX software - NPD, Ms. Benvenutta Henriksen and Inger Fjærentoft

14. China’s petroleum policy and management and market in the Western Depression of Sichuan Basin – Sinopec, Mr. Chen Zhaoguo

15. Petroleum policy and management– CCOP, Mr. Gunnar Søiland

16. Petroleum policy in Norway (or other countries) to compare with China – NPD, Ms. Inger Fjærentoft

Resource persons: (The Second workshop)

MS. INGER PEDERSEN FJAERTOFT (NPD)
Ms. Benvenutta Elise Henriksen (NPD)
Mr. Hu Yundong (PetroChina)

3.2 Accomplishment

The 1st WS’s tasks and program were on play and prospect resource assessment.

The 2nd WS’s tasks and program were on resource classification system, prospect economic analysis, petroleum policy and management.

All tasks and program have been met!
3.3 Expert Visits

Mr. CYRUS ESPHAHANIAN
Geologist

Dr. BEN E. LAW
Engineer

The 1st Expert Visit

- March 15-19th, 2004
- Mr. CYRUS ESPHAHANIAN
- Stimulation and completion
- Participants: 16, most are engineers

Mr. Espahanian’s presentation topics
- Resource assessment on Jonah gas field
- Case study on shear fault in Wyoming, USA
- Reservoir stimulation in Dfit area
- The effect of proppant on the conductivity of proppant supported fractures
- Evaluation of fracturing from the operation design, restoring testing and production analysis
- Details of fracturing operation on multiple pay zone gas well

7. The property and distribution of permeability, capillary force and relative permeability are very important to the evaluation, harm analysis and reservoir stimulation of tight gas reservoir.
8. Operation curve analysis for multiple tight sands of Mamm Creek gas field in Piceance basin, Colorado.
9. The current situation and development trend for tight sand gas reservoir.
10. Production evaluation after reservoir stimulation in Jonah gas field
Discussion topics
(1) The current status of well completion techniques in high temperature and high pressure gas wells
(2) Development obstacles in sour gas reservoir
(3) The main concerns of the fracturing design in natural fractured gas reservoir

(4) How to control the fracture height on the condition of weak barrier
(5) How to decrease the pressure during fracturing operation
(6) How to optimize perforation procedures in tight gas reservoir
(7) The main concerns of fracturing operation in gas-bearing horizon
(8) The major problems of reservoir stimulation in horizontal wells.

Dr. Law’s presentation was focused on “Basin-Centered Gas system” (BCG)
(1) The concept of basin-centered gas system, BCG: abnormally pressured, lack of obvious downdip water contact, accumulating in the low-permeability reservoirs (<1.0 md).
(2) The development history and classification of basin-centered gas system
(3) Distribution of the basin-centered gas system: by now the discovered basin-centered gas only accounts for the small part of the total basin-centered gas resources. The unconventional gas reserves are largely greater than conventional gas reserves.
(4) Exploration strategy of basin-centered gas system: reconnaissance phase; recognition phase; delineation phase; sweet-spot identification phase

(5) The Method to identify BCG: R0-T mapping.

A case study was done during the visit.

(6) Through on-site studying, Dr. BEN LAW thought the gas accumulation in Sichuan Basin is BCG. The water-gas transition is located far east.

(7) He thinks we just explored the structural sweet spots.

(8) He thinks that fracture prediction can not get breakthrough in near future.

What we got from the expert visits

1. Resources would be much bigger—BCG.

2. Increased our confidence to achieve success in the Western depression of Sichuan Basin. The reservoir quality here is similar to that in Rock Mountain.

Discovered 1955, commercial production not established until 1997 using techniques developed at Jonah.

- Depth 8,000 – 13,500 feet (Tertiary and Upper Cretaceous)
- Pay ~800 feet
- Sweet Spot due to high gas saturations.
- Initial spacing 40 acres, may go to 10 acres.
- Cumulative 0.2 TCF.
- Oct 2003 rate = 300 MMCFD from 150 wells.
3. New ideas and techniques we should try:

1. Perforation: short interval, less shots, best reservoir
2. Pump in and mini-frac: pay zone not missed, right reservoirs chose
3. Frac operation: no tube, much larger scale, under balance
4. Reservoirs with different pressure can be treated and produced at the same time
5. Total treatment interval can reach to 500m
6. More time on frac, much more money on frac

3.4 Documented benefits for the participants and host organization

1. On the first workshop of China, the experience and idea regarding the principle of geological risk analysis and comparison of predrilling estimates and postdrilling results in NPD were introduced by Norwegian experts, which is useful in the improvement of China’s petroleum resource assessment.

2. On the second workshop of China, the basic concept and methods of basin and play economic analysis introduced by Norwegian experts will be a good instruction for our future work.
3. On the 2nd workshop, the petroleum policy and management concept has been introduced by Norwegian experts.

4. Participants from China have learned the principles and procedures of play and prospect resource assessment, and prospect economic analysis in GeoX software.

4. The advanced drilling and completion technology introduced by Cyrus (1st expert visit of China) will be a good reference to the development of tight gas in Western Depression.
5. Foreign participants:
- Getting familiar with the geologic characteristics and E&D methods, especially the E&P experience of tight sandstone gas in western depression
- Joined in the exercises in the play and prospect resource assessment and prospect economic analysis in western Sichuan basin.

4. Long term plan for PPM case study

4.1 Long term plan

Workshops:

Expert visits:
- 3rd expert visit: Apr, 2005
- 4th expert visit: Sep, 2005

4.2 Main topics and Resource persons and PPM experts

1. Petroleum policy and management
2. Exploration strategies
3. Natural gas demand and price forecast

We would like to invite 3-4 resource persons and experts related to above topics to visit Chinese case study area.

5. Dissemination

The way knowledge, procedures and ideas from PPM are transferred within own organization and within host country.

Although the PPM project has been conducted by SINOPEC, the knowledge, procedures and ideas from PPM project have been transferred into all organizations related to oil industry.

---annual reports of PPM project progress
---key technical reports
---lectures on the PPM project introduction in the national technical meeting
Following benefits for our organization can be expected:

• The way to do resources assessment and risk analysis
• Learning to do resources assessment and risk analysis by GeoX
• Knowledge of fiscal regime in different country

Knowledge about fracture prediction and recovery methods of tight gas sandstone
• Economic analysis on a play, a prospect, a field
• Management knowledge of petroleum resources

• Petroleum policy and management
• Exploration strategies
• Natural gas demand and price forecast

How PPM can be made more beneficial

1. More documents was issued in the PPM website
2. More training seminars for PPM goals
6 Participation in other case studies

6.1 China’s case study is one of the four case studies of PPM. And we have taken part in all of other three case studies’ WS. The topics in the WS attended are relevant to the specific office work of the attendees.

Cambodia’s workshop:

1st: Ms. Wang Xiaohui
Ms. Zhou Jin
Mr. Yang Dengwei
Mr. Guo Baoshen

2nd:
Mr. Yang Dengwei
Mr. Guo Baoshen
Mr. Wang Xin

3rd:
Mr. Yang Dengwei
Mr. Guo Baoshen
Mr. Zhan Guowei

Indonesia’s workshop:

1st: Mr. Long Shengxiang
Mr. Wang Chuan
Mr. Qiu Liwei

2nd:
Mr. Yang Kemin
Mr. Long Shengxiang
Mr. Wang Chuan

Philippines’ workshop:

1st: Ms. Tang Hongjun
Mr. Li Shubing
Mr. Wang Liangguo

2nd:
Ms. Li Huaji
Mr. Bai Zhenrui
Mr. Wang Liangguo

3rd:
Ms. Zhang Yanqiu
Ms. Chen Lan
Mr. Bai Zhenrui
Mr. Wang Liangguo
6.2 Experiences from WS and seminar

All WS agendas are interesting and beneficial.
All discussions are very active.
All topics are magnetic. It helps us to gain knowledge quickly and unforgettably.

1. Philippines WS
   - Petroleum resource assessment & risk analysis in Sulu sea/East Palawan basins.
     using prospect & lead concept to define different potential petroleum trap.
   - Philippine resource classification system and risk model. It can be used for reference in China case study.

- risk quantification and risk table, risk effectiveness-presence
- using Common risk segment map to calculate the number of one play.
- offshore field development, development options & strategy, phased development & facilities optimization

- Oil & gas price forecast
  - marketable
    long-term price forecasting
    short-term price forecasting
  - non-marketable
    real sales prices’ correlation
    relative equations(functions)

- GeoX Using in play & prospect assessment in risk analysis in economic evaluation
2. Indonesia WS
- Indonesia petroleum policy and management
- present status of Indonesia petroleum exploration & development
- Indonesia fiscal system in petroleum exploration & development

3. Cambodia WS
- exploration status of Cambodia basin
- principle of petroleum classification and risk model
- petroleum exploration plan and strategies

- Indonesia PSC blocks
- CCOP petroleum classification and risk model
- petroleum exploration economic evaluation

- energy development plan in Cambodia
- economic evaluation in field development
6.3 dissemination

1. How did you apply the knowledge gained from the other case studies into your own organization?
   (1) We plan to do resources assessment and risk analysis of prospects by Multisegement module of GeoX.
   (2) We shall predict prospects in Longmenshan frontier area in the way that Philippines did at the area where seismic lines are rare.

(3) Good experiences from other countries, especially those experiences on petroleum management, will be written in our final report. We think it may have some affects on our petroleum policy and management.

2. What are your recommendations in order for the case study participation to be useful in your organization?
   ▲ The participants should be experts.
   ▲ Taking part in other country’s case studies actively, and discuss difficult problems with experts.

▲ Study other country’s case studies methods of resource assessment, economic evaluation, petroleum policy and management.

▲ The host country experts should introduce more details about their methods and experiences.
Conclusion

1. Are the expectations to PPM met so far?
   So far so good. We have benefited a lot from PPM. The main benefits are:
   (1) Help us making out the agenda and main topics of China first workshop;
   (2) Contact the source persons of the first workshop;
   (3) Contact the experts of the first visit;
   (4) Provide funds for us to take part in other case studies;
   (5) Provide chances for us to share foreign experts’ experiences on resources assessment and risk analysis.

2. Kindly give constructive advise to the other three Case Studies host organizations, case study participants and PPM coordinators.
   If host organizations can provide more real data for foreign participants at the workshop, they may take more advantages from the participants.

7. Special Topic
   – Development of marginal fields
7.1 Country definition of a marginal field

Based on the market condition of the time, oil and gas production is not economic, but in the projected feasible market condition or in the conjectural probably occurring market condition, or in the condition with the investment environment improved, the production would be economic.

7.2 Are there marginal field in your country that have not been developed? Why are these fields not developed?

Yes.

- Low gas price
- Low flow rate
- Sour gas

7.3 incentives offered

At present, there isn’t any incentives offered to develop marginal fields. But now government official and experts are discussing the topic.

Some incentives should be offered:

- different price
- derate tax

7.4 Are there plans to modify the incentive package currently offered to companies?

Maybe in near future.
7.5 Develop marginal field

At present, no management systems are implemented to develop marginal fields. But almost all companies are developing technologies to improve the economics of these fields. Such as combining economic fields with marginal field, or use new technologies to develop marginal fields.

7.6 List topics that PPM should address in order to help the host organization:

- Introduce other country’s incentives to develop marginal fields to the host organization
- Analysis the advantages and disadvantages of the host country’s current management system for marginal fields
- Proposing petroleum policy and management which is beneficial or attracting domestic and foreign investments and increased petroleum activities