# 周1井二叠系玄武岩储层评价

牛善政* 庞家黎

（四川石油管理局川西北矿区）

**摘 要** 周公山构造位于四川雅安市东南，为一被两条断层抬起的断垒式背斜。周公1井位于构造顶部，于二叠系玄武岩中获高产工业气流，这开辟了四川油气勘探的新领域。利用 $GR—R_t$ 交会图，可判别喷发岩及其风化后的各种岩性，从而在剖面中划分出10个喷发旋回。喷发岩的原生孔隙为气孔和未填死的杏仁结构残余孔，次生孔隙为蚀变溶孔和裂缝；渗滤通道为蚀变作用和构造作用产生的溶蚀间隙和裂缝，渗透率与孔隙度无相关性；储层属裂缝—孔洞型。由于该类储层的特殊性，根据其测井资料的不同响应，可建立三种类型储层的常规测井响应模式：①孔洞与发育的裂缝组合型；②孔洞与裂缝组合型；③孔洞基本孤立存在型。前两类为有效储层，后者为无效储层。有效储层可用孔隙度、含水饱和度等参数划分为五级，即特好储层、好储层、中等储层、差储层及非储层。有效储层多分布于每个喷发旋回的中上部，说明其形成与原生孔隙发育程度和蚀变作用有关。就整个剖面而言，有效储层发育于上部的旋回，向下逐渐变差，表明其形成与构造作用产生的裂缝有关。

**主题词** 四川西部 二叠纪 玄武岩 储集层 测井 评价

周公山构造位于四川省雅安市东南，为一被两条断层抬起的断垒式背斜。周公1井位于构造顶部，在井深2 804.8～3 104 m为喷发岩及其伴生岩类、蚀变岩类，钻厚299.2 m（测井井深）。主体为斜长玄武岩，中夹薄层凝灰岩、凝灰质角砾岩、砂岩、泥质砂岩、粉砂质泥岩及页岩等。

根据井漏、气测显示及测井解释等资料，选择井段2 883～2 870 m进行射孔试油，获高产工业气流，发现了二叠系峨眉山玄武岩气藏，开辟了四川油气勘探的新领域。

## 岩性判别和喷发旋回划分

### 1.岩性判别

玄武岩经风化、搬运、再沉积，逐次形成砂岩、泥质砂岩、粉砂质泥岩和页岩。随着粒度变细、岩石颗粒比面的增加，沉积过程中吸附放射性物质逐渐增多，自然伽马值将上升；同时，随着粒度变细、束缚水含量的增加，电阻率逐渐下降。故在 $R_t—GR$ 交会图上砂岩到页岩的层点表现为自然伽马上升、电阻率下降的趋势。玄武岩自然伽马为30～60 API，取60 API作砂岩的自然伽马基值，页岩自然伽马值取125 API，则以玄武岩为基岩形成的砂岩到页岩的自然伽马值在60～125 API间，泥质含量计算应服从较老岩石测井计算泥质含量公式：

$$V_{sh}=\frac{2^{2\cdot\Delta GR}-1}{2-1} \quad (1)$$

$$\Delta GR=\frac{GR-GR_{min}}{GR_{max}-GR_{min}} \quad (2)$$

式中：$V_{sh}$ ——泥质含量；

$\Delta GR$ ——自然伽马相对值；

$GR$ ——计算层自然伽马值；

$GR_{max}$ ——剖面自然伽马最大值；

$GR_{min}$ ——剖面自然伽马最小值。

以 $V_{sh}<25\%$ 为砂岩、$V_{sh}=25\%\sim50\%$ 为泥质砂岩、$V_{sh}=50\%\sim75\%$ 为粉砂质泥岩、$V_{sh}>75\%$ 为页岩，各种岩性对应的自然伽马值为：砂岩60～86 API；泥质砂岩86～102 API；粉砂质泥岩102～115 API；页岩115～125 API。

凝灰岩具有高自然伽马、高电阻率测井特征，其层点分布于 $R_t—GR$ 交会图右下方，不服从玄武岩风化沉积岩性的层点趋势。沉凝灰岩风化后沉积为凝

* 牛善政，1938年生，高级工程师，1957年毕业于北京石油地质学校；长期从事测井解释和测井地质研究工作，完成科研报告和论文20余篇，其中一篇转载于日本《天然气》，获各级奖励多项。地址：(621709)四川省江油市川西北矿区地质公司。电话：(08244)21211转4106。

灰质角砾岩、角砾状砾泥岩，这类岩性在高电阻率情况下，自然伽马值逐渐升高。各种岩性在 $R_t$—$GR$ 交会图上处于不同岩性区(图 1)。

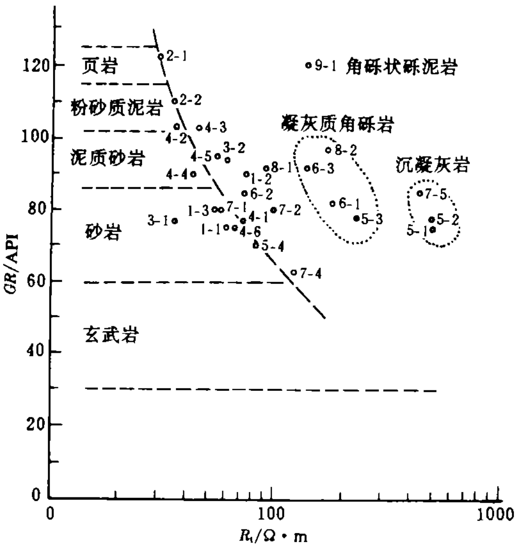


图 1　岩性划分 $R_t$—$GR$ 交会图

2. 喷发旋回划分

玄武岩一次喷发的垂向和侧向组合模式如图 2，在玄武岩上部存在有凝灰岩、玄武质或凝灰质角

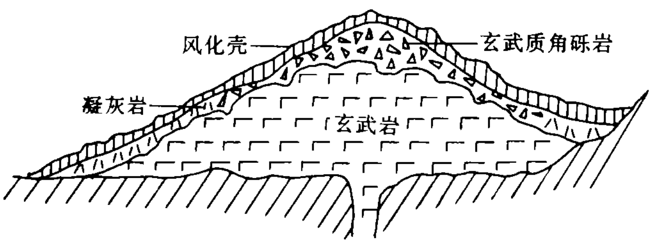


图 2　玄武岩垂向和侧向组合模式

砾岩及风化所产生的各类岩性。由峨眉山龙门洞上二叠统沉积相分析，大陆喷发玄武岩相主要岩性为玄武岩。其上为冲积扇火山碎屑沉积岩相，系一套玄武岩喷发物遭受强烈风化侵蚀又伴随火山碎屑降落的沉积。岩性自下而上有沉凝灰岩、凝灰质角砾岩、角砾状砾泥岩及粉砂质泥岩、页岩、铝土岩等。

据此可以认为在多次喷发的玄武岩剖面中，出现冲积扇火山碎屑沉积岩相的岩类时，即是一个喷发旋回的完成。测井资料显示为自然伽马由 30～60 API 层段到顶部出现自然伽马升高至 60 API 以上层为一个喷发旋回。周公 1 井 299.2 m 以玄武岩为主剖面，可划分 10 个喷发旋回，旋回厚度 13.8～55.4 m 不等，其中玄武岩累计厚 268.6 m，沉凝灰岩、凝灰质角砾岩、角砾状砾泥岩厚 10.6 m，砂岩、泥质砂岩、粉砂质泥岩、页岩厚 20 m。

## 玄武岩储集层的测井响应模式

### 1. 喷发岩与沉积岩储层的储渗条件差异

沉积岩是岩石碎屑堆积，经压实成岩作用形成。储集空间有原生粒间孔和次生孔—粒内溶孔、微裂缝、粒间溶孔、杂基孔等，原生孔隙随压实作用的增加而减小。渗滤通道为粒间隙和裂缝，次生孔隙的形成一般也与粒间隙有关，所以岩石基块渗透率与孔隙度有相关性。储集层属于裂缝—孔隙型。

喷发岩为喷发岩流冷却而成。玄武岩一次喷发，开始为致密状，以后随气体的逸出，所形成的气孔不断增加，岩石密度逐渐减小，再后由于气孔不断被充填而形成杏仁状结构，导致岩石致密化，经蚀变作用和构造应力作用又形成了新的储集空间。原生孔隙为气孔和未填死的杏仁结构残余孔，喷发旋回上部发育，向下渐低；次生孔隙为蚀变溶孔和裂缝。原生孔隙一般不受压实作用影响。渗滤通道为蚀变作用和构造作用产生的溶蚀间隙和裂缝，渗透率与孔隙度无相关性。玄武岩不经蚀变作用和构造作用，即便存在原生孔隙，也难形成良好储集层。储集层属于裂缝—孔洞型。

### 2. 玄武岩储集层常规测井响应模式

由于玄武岩储渗性能的特殊性，测井响应也有别于砂岩储层。根据测井资料分析，可以归纳为以下三种类型储层的常规测井响应模式(图 3)。

Ⅰ模式：孔洞与发育的裂缝组合，渗透率高，泥浆侵入深。补偿中子测井探测半径较小，反映冲刷带的含氢量，测量值反映储层的总孔隙度。声波测井受发育的裂缝影响，产生周波跳跃，其值不能反映储层孔隙度真实情况。受泥浆滤液深侵影响，电阻率低。

Ⅱ模式：孔洞与裂缝的组合，渗透率好，存在一定侵入带。补偿中子测井反映总孔隙度。在孔洞型储层，声波的传播有两条途径，一是通过岩石骨架和孔洞，二是不通过孔洞由岩石骨架直接传播。当第一种传播时，声波测井值反映储层孔隙度；第二种传播时，测得的孔隙度偏小。电阻率为中值。

Ⅲ模式：孔洞基本孤立存在或仅有少量微缝，渗透率极低。钻头破碎地层，将于井壁产生裂缝沟通孔洞形成泥浆冲刷带。补偿中子测井可能反映地层孔隙度，声波测井反映的孔隙度正常或偏小。电阻率高。

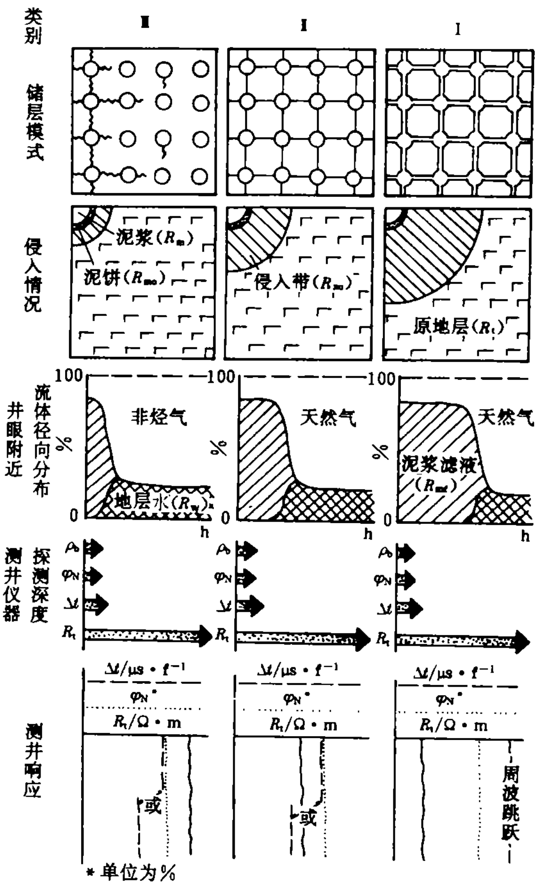


图3 玄武岩储集层测井响应模式

3. 三种模式的判别及认识

电阻率测井在玄武岩储层的分析中为至关重要的资料，它不仅反映储层的含油气性，也可定性分析储层的渗透性能，从而判断储层有否油气运移发生。当储层孔洞被裂缝或蚀变间隙所沟通，储集空间首先饱和地层水，而后油气向其中运移，为一排水过程。聚集为气藏后，孔洞空间有残余束缚水存在，故电阻率一般为中值。当裂缝极发育，泥浆滤液侵入较深，已占侧向测井探测范围的一定比例时，电阻率下降为低值。当玄武岩的原生孔洞无裂缝沟通时，则不可能有地层水存在，也不会产生油气的运移和聚集，孔洞中存在的是岩流冷却时产生的非烃气，故地层电阻率高。

对玄武岩测井特征研究结果认为，Ⅱ模式地层电阻率为100～300 Ω·m，Ⅰ模式地层电阻率<100 Ω·m，Ⅲ模式地层电阻率>300 Ω·m。三种模式层点在 $\varphi$—$S_w$ 交会图中分布于不同区带(图4)。有效储层存在于Ⅰ、Ⅱ模式之中，该井射孔试油产工业气流井段的层点，均位于 $\varphi$—$S_w$ 交会图中Ⅰ、Ⅱ模式分布区即是证明。第Ⅲ模式分布区带中，尽管也有高孔层点，但因孔洞孤立，无裂缝沟通，因此为无效储层。

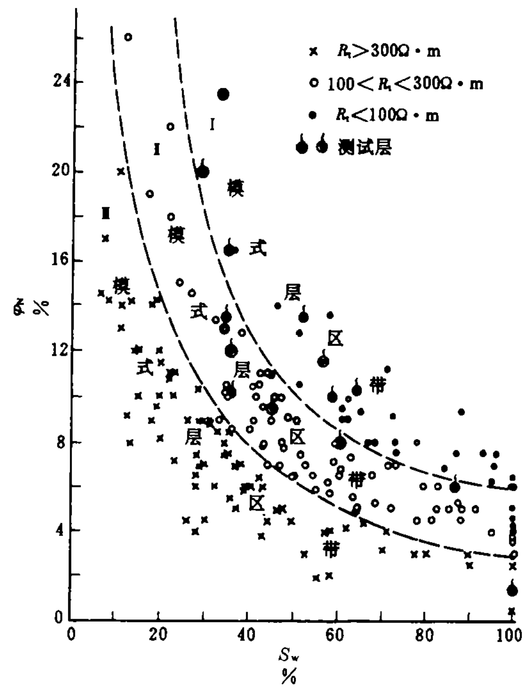


图4 玄武岩 $\varphi_N$—$S_w$ 交会图

## 储层参数计算及评价

川西地区砂岩地层用声波测井资料计算孔隙度效果好，声波时差($\Delta t$)与岩心孔隙度有很好的相关性，相关系数一般在0.9以上。对于玄武岩裂缝—孔洞型储层，用声波测井资料求孔隙度效果差，一般计算的孔隙度偏小，而遇发育的裂缝段时，产生周波跳跃，使计算的孔隙度不能代表实际情况(图5)。所以

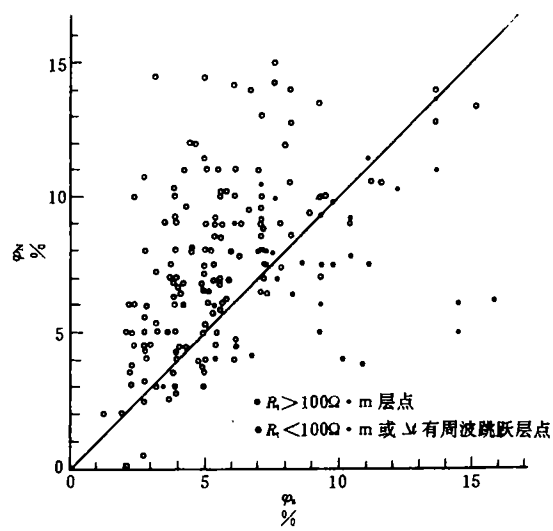


图5 玄武岩 $\varphi_N$—$\varphi_S$ 交会图

采用补偿中子测井资料求储层孔隙度较好。补偿中子测得的视石灰岩孔隙度，对其它岩性储层要作基值校正，在没有玄武岩中子孔隙度校正参数的情况下，可取玄武岩剖面最低值作为基值。

含水饱和度计算公式：

$$S_w = \sqrt[n]{\frac{R_w}{\varphi^m R_t}} \quad (3)$$

式中：孔隙度指数 ($m$) 和饱和度指数 ($n$) 取 2；地层水电阻率 ($R_W$) 利用致密层的 $P^{1/2}$ 正态分布法选取。

据储层孔隙度和含水饱和度分析，Ⅰ类储层均属气层范畴，层点在交会图上呈双曲线形态分布，经 75 层点统计，孔隙度与含水饱和度关系式为：

$$\varphi_N = 354.937\, S_W^{-0.9665} \quad (4)$$

相关系数 ($r$) 为 0.97。

Ⅰ类储层也为气层范畴，由于裂缝发育，泥浆滤液深侵，电阻率降低，导致计算的含水饱和度升高，需要进行校正。其含水饱和度校正值用储层孔隙度根据式(4)进行计算。

以孔隙度、含水饱和度双参数对储层进行分级评价如表 1。储层孔隙度<7%者，以含水饱和度分为差储层和非储层，这是由于玄武岩储渗性造成的，裂缝张开度大形成差储层，小的为非储层。

表 1　玄武岩分级数据表　　　　%

| 储层级别 | 孔隙度 | 含水饱和度 | 定　名 |
|---|---|---|---|
| 1 | >15 | <35 | 特好储层 |
| 2 | 11～14.9 | 20～35 | 好储层 |
| 3 | 7～10.9 | 30～25 | 中等储层 |
| 4 | 5～6.9 | 45～75 | 差储层 |
| 5 | <7 | >75 | 非储层 |

该井玄武岩有效储层厚 125.2 m，占玄武岩厚度的 46.6%。其中 1 级储层 12.4 m，2 级储层 20.0 m，3 级储层 65.2 m，4 级储层 27.6 m。有效储层在旋回中的分布为：中上部比例大，下部渐少；上部有效储层占 43.23%，中部占 35.40%，下部占 21.37%。这种分布情况表明，有效储层与玄武岩原生孔隙的形成和蚀变作用有关，玄武岩的原生气孔和杏仁状孔隙多发育于喷发旋回上部，向下渐少；蚀变作用也是上部优于下部。就 10 个喷发旋回而言，有效层发育最好的是第六至第九旋回，$h \cdot \varphi/m$ 值均高于 5。其中以第八旋回(射孔试油段)最好，$h \cdot \varphi/m$ 值达 11.44，第一至第五旋回 $h \cdot \varphi/m$ 值均低于 5，并有向下渐小趋势。这表明储层形成与构造作用有关，上部地层位于中性面之上，受构造应力作用，易产生张性缝，沟通原生孔洞形成有效储层的机遇大。

## 建　　议

(1)根据玄武岩裂缝—孔洞型储层特点及其储层形成与沉积岩的不同，测井分析应有别于砂岩地层。在完善测井系列、取全取准资料的基础上，以岩心资料为基础，确定玄武岩的各种测井参数，逐步总结适合于玄武岩的测井解释思路和方法。

(2)玄武岩厚度大、多旋回，各旋回均可能发育有效储层。在裸眼情况下，采用 RFT 逐层测压并取样，可及时了解储层情况及含流体性质，为完井试油层位的选择提供依据。

(3)据测井资料初步分析，玄武岩存在无效储层，该类储层及旋回顶部的泥质层可能形成盖层或隔层，则气藏有构造和岩性双重圈闭性质。完井试油以录井显示、测井解释、RFT 成果等综合资料，于每个喷发旋回中确定试油层位，逐层试油，了解各层产能及压力系统情况。

(4)玄武岩裂缝—孔洞型储层，以小岩样作物性分析代表性差，应作全直径岩心分析。

(本文收稿　1994—05—17　编辑　韩晓渝)

Song Wen-hai (*Geological Exploration and Development Institute of Sichuan Petroleum Administration*), Pang Jia-li: **GAS-BEARING STUDY OF $P_2$ BASALT IN THE SOUTHWEST PART OF SICHUAN BASIN**, NGI 14(5), 1994: 11～15

**Abstract**: It is verified that the basalt in Sichuan Basin is a new gas-bearing domain being of wide exploration potential by Zhou-1 well of which open flow capacity is $50\times10^4$ $m^3/d$, drilled in $P_2$ basalt of Zhougongshan structure in southwest part of the basin. The domain has $1.9\times10^4$ $km^2$ explorative area and 40 structures being able to drill. The reservoir belongs to vug-fissure type, some area is fissure-vug type. Gas source is sufficient. The gas is mainly from $P_2$ coal measure on the basalt side or is the mixing source gas from Lower Yangxin Series. In the light of reservoir changes, oil-gas mothballing conditions and differential accumulation principle, the structural zones being nearer gas souce and higher elevation such as Zhongongshan, Zhanmaoshan, Hanwangchang, Sanshuchang, Shoubaochang, Laolongba, Tiangongtang etc are considered having the best gas-bearing conditions and should be firstly explored.

**Subject Headings**: northwest part of Sichuan, Permian, basalt, natural gas, reservoir formed condition.

**Song Wen-hai**, Senoir engineer, graduated in the petroleum department from Beijing Geology Institute in 1958. He is engaged in geological survey and research for a long term. He published 20 papers such as Study of Yangxin Series Sedimentary Facies and Accumulation Condition in Sichuan Basin etc. He won the first and second awards of the provincial and national science-technology progress many times. Add: (611051)No. 1, Sec. 1, Fuqing Rd., Chengdu. Tel: (208)3324911—215500.

Huang Ji-zhong (*Geological Exploration and Development Institute of Sichuan Petroleum Administration*), Gou Xie-min: **ANALYSIS OF GAS SOURCE AND EXPLORATION POTENTIAL OF PERMIAN BASALT UNCONVENTIONAL GAS RESERVOIR IN SICHUAN BASIN**, NGI 14(5), 1994: 16～19

**Abstract**: In the light of gas components, carbon isotope value of commercial gas flow of Zhou-1 well drilled in Permian basalt of Zhougongshan structure in west area of Sichuan and the geochemistry features, combining the former researches and explorative achievements, the gas source and exploration potential are expounded. The gas of basalt unconventional. Reservoir is high maturation paulopost one of organic origin coal measure and has the characteristics of high methane, high drying coefficient, high isotope value, low heavy hydrocarbon without $H_2S$. The gas maturity is identical with the show of thermal evolution tendency in $P_2l$ coal measure area, having enough hydrocarbon source supply. It is possible to obtain the same gas reservoirs in Longtan formation of Permian basalt, tight sand and carbonate rock in Sichuan Basin. The favourable explorative area of basalt is to the west of the line of Weiyuan-Yibin-Xuyong and the other rocks for availably exploring are the rich hydrocarbon areas of Longnüsi, Jiangjin as well as the vicinal regions.

**Subject Headings**: Sichuan Basin, Permian basalt, unconventional gas reservoir, gas source, geochemistry, exploration potential.

**Huang Ji-zhong**, senior engineer, graduated in geology from Chongqing University in 1953; He is engaged in the studies of petroleum geology and organic geochemistry for a long term, published a great number of papers. Add: (611051)No. 1, Sec. 1, Fuqing Rd., Chengdu. Tel: (028)3324911—215619.

Niu Shan-zheng (*Northwest Sichuan Gas Field of Sichuan Petroleum Administration*), Pang Jia-li: **EVALUATING THE PERMIAN BASALT RESERVOIR OF ZHOU-1 WELL**, NGI 14(5)1994: 20～23

**Abstruct**: By the use of $GR$-$R_t$ Crossplot, the lithology of the Permian basalt in Zhougongshan structure is discriminated to divide 10 eruptive cycles in the cross section. The primary pores of effusive rock are gas pockets and residual pores of incomplete filled amygdaloidal structure. Secondary pores are altered solutional voids and fissures. Infiltration channels are the Karast clearance and fissures produced by altered actions and structural effects. The permeability has incooherence with the porosity. The reservoir belongs to fracture-vug type. In the light of the conventional log-

ging response models of 3 types of reservoir can be set up: The first is the type of combining vugs with growth fissures; The second is the type of combining vugs with fissures; The third is vug type. They are effective reservoirs except the third one. By using the parameters of porosity, water saturation etc, the effective reservoirs can be divided into five grades, i.e. the best, good, middel, bad and fault.

The effective reservoirs mostly distribute in the middle and upper part of eruptive cycle, which indicates that the formation of them relates to the primary pore growth degree and altered action. The effective reservoirs developed from upper cycle and gradually became bad at the lower levels, which indicates the formation of them relates to the fissures produced by structural effects.

**Subject Headings**: west part of Sichuan, Permian, basalt, reservoir, logging evaluation.

**Niu Shan-zhang**, senior engineer, graduated from Beijing Petroleum Geology School in 1957; He is engaged in the studies of logging analysis and logging geology for a long term. He finished over 20 papers of science reports and treatises. One of them was reprinted in the Japanese magazine named Natural Gas. Add: Jiangyou, Sichuan. Tel: (08244)21211—4106.

Chen Sui-zu (*geological Exploration and Development Institute of Sichuan Petroleum Administration*), Zeng Shu-yong: **MOTHBALLED BOX AND GAS POOL-FORMED MODE OF UPPER TRIASSIC SERIES**, NGI 14(5), 1994: 24~27

**Abstract**: Through studying the plane expansion lows and vertical evolution characteristics of Upper Triassic stratigraphic pressure in Sichuan Basin, the Upper Triassic Series is considered having the typical mothballed box pool-formed characteristics: The top mothballed stratum is thick shale of Middle Jurassic Series; The bottom one is the shale of Upper Triassic Series basement and the tight limestone of Middle Triassic Series; Continuous superpressure is between the top and the bottom, and the average buried depth of the superpressure top is —1 150 m. In the light of the distribution characteristics of exposure strata and stratum pressures, the mothballed box can be horizontally divided into three parts of the superpressure district inside the box, the superpressure district on the box border and the normal pressure border inside the box. Among them, the circular zone (Superpressure district on the box border) near Upper Triassic hydrocarbon-generating centre is the favourable area for surveying the gas pools in Upper Triassic Series and Jurassic. Guankou-Nanshan structure and Daxing nose-like structure in the area are favourable explorative targets.

**Subject Headings**: Sichuan Basin, Later Triassic, fluid pressure, mothballed pressure, natural gas, pool-formed mode.

**Chen Sui-zu**, senior engineer, studied at Chongqing Petroleum Polytechnic School in 1961; He is engaged in the studies of petroleum geology and oil-gas resources evaluation methods for a long term. He won the first and third awards of sichuan science-technology progress, the first, second and third awards of science-technology progress (SPA) for many times. Add: (610051) No.. 1, Sec. 1, Fuqing Rd. Chengdu. Tel: (028)3324911—215633.

Chen Guang-jun (*Logging Company of Sichuan Petroleum Administration*), Nie Xun-yu, Cheng Qi-yong: **A METHOD TO DISCRIMINATE THE STRATA OF GAS BEARING, WATER BEARING AND DRY ONE IN $O_1m_5{}^4{}_1$ OF SHANGANNING GAS FIELD BY LOGGING INFORMATIONS**, NGI 14(5), 1994: 28~30

**Abstract**: The $O_1m_4{}^5{}_1$ in Shanganning Gas Field is a significant reserve gas pool with dolomite lithological character, low shale content, 4~8 m thickness, 1%~9% porosity without unified gas -water interface. The stratum laws of gas bearing, water bearing and dry one are studied by single-interval test and logging information, A set of interpretation methods for working site are summarized. If $R_{tcp}$ is $>150\ \Omega\cdot m$ in resistivity curve, the stratum is dry; Conversely, it is gas bearing or water bearing; If $\Delta t_{cp}$ is $<158\ \mu s/m$ in acoustic logging curve, the stratum is mainly dry; In natural potential curve, if the SP curve of the $O_1m_5{}^5$ tight limestone is selected as ground line and deflects to posi-