# 塔中地区火山岩预测的综合地球物理方法

陈业全　李宝刚　刘春晓　著

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## 内容简介


本书系统论述了塔里木盆地沉积特征、构造演化以及各时代火山岩发育情况，全面探讨了火山岩航磁、钻井、测井、地震、正反演等综合预测技术，分析了塔中地区二叠系火山岩的地化特征和形成环境，对二叠系火山岩地层进行了对比，分析了火山岩喷发期次，探讨了火山岩与油气的关系，并评价了塔中地区油气勘探前景。本书重点分析了各种火山岩的地质和地球物理响应，突出了以测井、地震相、合成地震记录、正反演等为主的火山岩预测综合地球物理方法，首次在塔中地区应用电阻率曲线合成了地震记录，得到了适合塔中地区的法斯特经验常数，利用实际钻遇火山岩地层进行了模型正演，研究了薄层火山岩地层的地震反射特征；重点总结了火山活动与油气的关系，研究了塔中地区二叠纪及其以前的火山活动对油气生成、运移、聚集以及保存的影响。

本书可供从事塔里木盆地研究、火山岩研究、地球化学、石油地质学及含油气盆地分析的地质研究人员参考。



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# 序　言

陈业全、李宝刚、刘春晓所著《塔中地区火山岩预测的综合地球物理方法》的出版问世，为我国石油地质知识宝库和火山岩研究增添了新的一页。

书中首先分析了塔里木盆地基底特征、构造演化、塔中地区沉积体系和各层系地层特征，并分析了在塔中地区进行火山岩研究的必要性。

书中资料显示，塔中地区火山岩埋藏深，岩性变化大，识别难度大。作者根据多年从事地质和物探工作的经验，综合使用了多种火山岩的识别方法，包括钻井、测井、合成地震记录、地震相、地震资料特殊处理、正演、波阻抗反演、三维水平切片、保幅处理技术以及叠前深度偏移处理技术等，取得了较好的应用效果，对各项识别技术的原理也进行了简单的探讨。在合成地震记录制作的过程中，创造性地利用了电阻率转声波时差的方法，获得了塔中地区法斯特经验常数；研究了火山岩顶底界面的地震反射特性以及与地震属性（瞬时频率、瞬时相位、瞬时振幅）的关系。

作者利用中1井及巴楚地区火山岩的常量元素、微量元素以及稀土元素等资料，分析了塔中地区二叠系火山岩的地化特征，并借助于久野1965年提出的（$K_2O+Na_2O$）$-SiO_2$ 关系图解和都城秋穗1974年提出的 $TiO_2-FeO/MgO$ 关系图解研究了火山岩的形成环境。火山岩层序识别和地层对比一直是困扰地质工作者的大难题，作者创造性地借助于电阻率曲线和自然伽马曲线将火山岩地层划分为岩流组和岩流单元等不同的单元，并以岩流组为单元对火山岩地层进行了对比，研究了二叠系火山岩的喷发期次，取得了较好的效果。

火山活动与油气的关系是书中的另一个重要内容，作者综合各个方面的资料，分析了火山活动与烃源岩演化，油气生成、运移、聚集和保存的关系。并且对对塔中地区生储盖各地质静态要素进行了分析，圈定了塔中地区最有利的层系和地区，为下一步油气勘探指明了方向。

陈业全院长从20世纪80年代开始，一直负责中原油田地质综合研究，主持和参与重点课题研究及勘探方案设计，积累了丰富的勘探经验。在初次进军塔里木的过程中，他和广大科技工作者以多做贡献、为国分忧、为国争光为己任，深入现场，刻苦钻研，在全盆地整体勘探的系统资料基础上，高水平地完成了地质科研工作，成绩显著。陈业全院长等人所著的《塔中地区火山岩预测的综合地球物理方法》汇集了作者20多年来从事地质和物探工作的研究成果，该书内容新颖，资料翔实，具有旁征博引、理论创新与实践紧密结合的特点。本书对石油勘探与科研人员具有重要的参考价值。

2004年3月

# 前　言

塔里木盆地位于新疆维吾尔自治区南部，南邻昆仑山脉、阿尔金山脉，北接天山山脉，是我国最大的内陆盆地，面积约 $56\times10^4$ $km^2$，盆地中部被塔克拉玛干沙漠覆盖，面积达 $33\times10^4$ $km^2$。

塔里木盆地的发展演化受不同时期板块构造背景的控制，形成了陆内裂谷、裂陷槽、克拉通内拉张盆地、克拉通内挤压盆地、被动大陆边缘盆地、弧后拉张盆地、弧后前陆和周缘前陆盆地等多种原型盆地并相互叠加和改造。

塔里木盆地塔中地区是形成于晚加里东—早海西期的下古生界残余古隆起，具有丰富的油气资源。塔中低凸起具有多套油源层、多套含油气层系、多种圈闭类型、多成藏期、多元复合含油气系统的特点。

新中国石油天然气勘探最早始于我国西部，20 世纪 50 年代末大庆油田的发现，标志着油气勘探战略的向东转移。到了 80 年代末期，西部新疆塔里木盆地油气勘探不断有新的发现，人们把寻找大油气田的目光重新投到了西部地区。塔里木盆地的油气勘探，从 1981 年算起已经有 20 多年的历史了，在这 20 多年里先后发现了塔北轮南地区中生界高产油气田群，中国陆上第一个石炭系海相砂岩高产油田——东河塘油田，我国目前埋藏最深(5 953 m)的英买力地区奥陶系碳酸盐岩油藏，轮台断隆带上的第三系、白垩系天然气高产富集带，并且第一次在塔克拉玛干沙漠腹地发现了高产的古潜山油气藏和石炭系亿吨级海相砂岩油藏。

实践证明，塔里木盆地油气资源的确十分丰富，它是我国目前测算油气资源量在 $100\times10^8$ t 以上的三大盆地之一，其他两个——松辽盆地和渤海湾盆地，都找到了几十亿吨的油气储量，因此可以推断塔里木盆地也一定能找到大油气田。塔中地区位于塔里木盆地有利的油气聚集带上，是油气运移的指向地区，因此是实现突破的重点地区。

然而，塔中地区油气层埋藏很深，一般在 3 600～4 500 m 以下，最深达到 6 000 m；地层复杂，高压盐水层、膏盐层、盐岩层、欠压实泥岩层、裂缝火山岩层广泛分布；油气水关系复杂。它的某些地区局部构造幅度小，广泛分布的二叠系火山岩对下伏地层具有屏蔽作用，使得盆地中地震波速度变化较大，这就为准确圈定构造带来许多困难。

本研究对塔里木盆地塔中地区沉积体系、构造演化、各层系的火山岩分布、火山岩多种识别方法、火山岩地化特征及形成环境、火山岩层序识别与地层对比、火山岩形成及分布控制因素、火山岩与油气关系及火山岩油气藏类型等进行了全面分析。首先，利用钻井资料、测井资料和地震资料，借助于多种识别方法(钻井、测井、合成地震记录、地震相、地震资料特殊处理、正演、波阻抗反演以及三维水平切片)对火山岩进行了识别，首次在塔里木盆地利用电阻率曲线制作了合成地震记录，并研究了火山岩纵、横向分布规律。其次，利用火山岩全岩分析资料和微量元素资料研究了塔中地区二叠系火山岩的地化特征和形成环境，对火山岩地层进行了层序识别和喷发期次研究，并提出塔中地区二叠纪存在 4～6 期火山喷发。最后，结合塔中地区分析

了火山活动与油气生成、运移、聚集成藏的关系，总结了塔中地区可能的火山岩油气藏类型，并对塔中地区的油气勘探前景进行了评价。本研究取得了以下成果和认识：

1. 塔中地区火山岩分布广泛，几乎遍及整个地区，但火山岩分布不均，厚度突变性强。塔中地区二叠系火山岩以中基性喷出岩为主。

2. 在塔中地区及其邻近地区，可以借助于法斯特经验公式 $V=KH^{\frac{1}{6}}R^{\frac{1}{6}}$，利用电阻率近似求取声波速度。塔中地区的法斯特经验常数 $K=756.645$。

3. 火山岩顶底由于薄层反射叠加往往显示为高瞬时频率，而火山岩内部往往由于火山岩顶部屏蔽作用显示为低瞬时频率，因此可以利用瞬时频率剖面上的高瞬时频率来研究火山岩的横、纵向特征，利用低平均瞬时频率来研究火山岩在平面上的分布规律。火山岩顶界面还往往出现高反射强度、正瞬时相位，而且瞬时相位绝对值出现极小值。

4. 塔中地区二叠纪火山喷发以断裂式为主，兼有中心式喷发；塔中地区火山岩为大陆裂谷型。塔中Ⅰ号断裂断至盆地南缘的俯冲消减带，为岩浆喷发提供了通道。塔里木盆地早二叠世存在两个火山喷发旋回，库普库兹满旋回发生于早二叠世栖霞期，开派兹雷克旋回发生于早二叠世晚期(茅口期)，巴楚一满西分区火山岩属于库普库兹满旋回。

5. 一次熔岩流构成的一个冷却单元称之为一个岩流单元；岩流组由一个或多个岩流单元组成，代表同期若干次喷发熔岩流的叠合。岩流组的划分和对比表明：塔中地区二叠纪可能有4～6期火山喷发。

6. 火山活动与油气生成、运移、聚集成藏都有十分密切的关系：火山活动为生物提供丰富的矿物质，间接提高坳陷有机质丰度；提供大量热能，使生油岩生油门限提前；提供微量元素和过渡金属元素作为催化剂，有利于有机质向油气的转化；提供大量火山物质，改变地表起伏，有利于沉积中心的转移和形成。同时火山活动也可以使生油岩遭受高温烘烤作用而发生变质，失去生油能力。火山活动形成的断裂可以为油气运移提供良好的通道。火山活动先于油气主要运移期对油气成藏有利，否则会破坏油气藏。

7. 塔中地区可能的火山岩油气藏类型有：志留系、二叠系抬升淋滤型油气藏，石炭系岩颈刺穿型油气藏，寒武系、奥陶系、石炭系侵入岩侧向遮挡型油气藏，上二叠统一三叠系披覆背斜油气藏。

陈业全

2004年2月

# Abstract

Tarim basin is the largest intracontinental basin in China, located in the south of Sinkiang, with Kunlun Mountain and A'erjin Mountain in the south and Tian Mountain in the north. Its area is $56\times10^4$ km$^2$, and the central part of the basin is covered by desert, with an area of $33\times10^4$ km$^2$.

The evolution and development of Tarim basin were controlled by the background of the plate tectonics in different periods, forming various types of primary basins, such as intracontinental rift valleys, rifted trenches, tensional basins and compressional basins inside craton, passive continental margin basins, back-arc-torsion-extentional basins and others, which were superposed and transformed by each other.

Mid-Tarim Area with abundant resources in Tarim Basin is a remnant Paleozoic uplift formed during late Caledonian and early Hercynian orogenies. The uplift possesses several multisets of source beds and oil-bearing horizons, several types of traps, multi-stage of hydrocarbon formation, and is characterized by complex petroleum system.

The development of oil and gas industry of the new-born China (after 1949) was first concentrated in the west of the country. The discovery of Daqing Oil Field at the end of 1950's the shifting of the Chinese oil and gas exploration strategy. Towards the end of the 1980's, there had been continuous new discoveries during the oil and gas exploration in the Tarim Basin, Xinjiang. People refocused their attention to the western area of the country and were looking forward to finding big oil and gas fields. From 1981, oil and gas exploration in the Tarim Basin has already been going on over 20 years. A series of highly productive oil and gas fields have been revealed in the Mesozoic in Lunnan area, the northern part of the Tarim Basin as well as a highly productive onshore oil field, the Donghetang oil sandstones in China. The currently deepest-burred (5953 meters) oil pool in China has been located in Ordovician carbonate rocks in the Yingmaili region. High-yielding gas accumulation belts have been discovered in Tertiary and Cretaceous in the Luntai fracture-uplifted zone. Discoveries of high petroleum-yielding buried hill reservoirs and a 100-million-ton-sized oil field in Carboniferous marine sandstones have been made for the first time in the hinterland of the Taklimakan Desert.

It has been proven by practice that the Tarim Basin is very rich in oil and gas resources. It is one of the three biggest basins in China which have been predicted to have oil and gas resources over 10 billion tons. Over billions of tons of oil and gas reserves have been found in the other two basins—the Songliao Basin and Bohai Bay Basin. There is no doubt that big oil and gas fields can certainly be found in the Tarim Basin. The Mid-Tarim area, located in the

favorable zone of oil accumulation, is a very important mark of the migration of oil and gas, in which breakthrough of oil and gas exploration is expected to be made.

However, the oil-and gas-bearing horizons are located deep under the surface; the depths reach more than 3 600 meters and 4 500 meters in different areas, with the deepest being 6 000 meters. The stratigraphy of the basin is very complicated. High pressure saline aquifers, gypsum layers, salt horizons, less compacted mudstone and fractured volcanic rocks are widely distributed. There is a complex oil, gas and water relation. The scale of structural movements in some parts of the basin is small. Permian volcanic is widely distributed in Mid-Tarim area, which has high shielding action to the stratum below. So the variation of seismic velocity in the center of the basin is the greatest in the country. This has brought many difficulties for the accurate outlining of structures in the basin.

In this book, some questions are discussed including sedimentary systems, tectonic evolution, distribution of volcanic rocks, methods of identification of volcanic rocks, geo-chemical character and forming environment of volcanic rocks, identification of sequence and correlation of volcanic rocks, controlling factor of distribution of volcanic rocks, relationship between volcanic activities and oil & gas and research of volcanic reservoirs in Mid-Tarim area.

Firstly, volcanic rocks are identified by using various identification methods (drilling, well-logging, synthetic seismogram, seismic faces, instantaneous frequency, forward modeling, impedance inversion and horizontal slices). The method of making synthetic seismogram by use of apparent resistivity is adopted in Mid-Tarim area for the first time and laws of distribution of volcanic rocks are studied.

Secondly, geo-chemical character and forming environment of volcanic rocks in the lower Permian are studied by technologies of whole rock analysis and microelement analysis. On the basis of identification of sequence and correlation of lower Permian volcanic rocks, four to six epochs of volcanic rocks are identified in the lower Permian.

Finally, combining with Mid-Tarim area, the relationship between volcanic activities and generation, migration and accumulation of oil and gas is studied, and four types of volcanic reservoirs are concluded. Some original achievements are as follows:

1. Volcanic rocks are widely distributed in Mid-Tarim area, and volcanic rocks in the lower Permian is mainly mid-basic effusive rock, with its thickness varying greatly.

2. In Mid-Tarim area, sonic speed can be gained from apparent resistivity by formula of $V=KH^{\frac{1}{6}}R_t^{\frac{1}{6}}$, which is the formula of Fasite, and the experiential constant of Mid-Tarim area is $K=756.645$.

3. Because of superposition of reflection from many thin strata, the bottom and top of the volcanic rocks in the lower Permian shows high instantaneous frequency, and for the reason of shielding action of the top, the interior of the volcanic rocks shows low instantaneous frequency, so we can study the laws of distribution of volcanic rocks by the

instantaneous technology. The top also shows high instantaneous reflection coefficient, positive instantaneous reflection phase, and the absolute value of instantaneous reflection phase often shows low value.

4. In the late Permian in Mid-Tarim area, magma erupts mainly through faults, but there are still other places where magma erupts through neck-like piping. Volcanic rocks are of the type of continental rift valley. The number one fault in Mid-Tarim uplift connects the subduction zone of south basin and provides pipes for magma. There are two cycles of volcanic activities for the Tarim basin, that is, cycle of Qixia in the early Permian and cycle of Maokou in the late Permian, but there is only one for Mid-Tarim area in the late Permian, which can correlate with the cycle of Maokou.

5. Lava cell is defined as a cooling cell of lava from one volcanic eruption, and lava group consists of one or more lava cells of the same time. The division and correlation of lava groups show that there are about four to six times of volcanic eruption in Mid-Tarim area.

6. There is a very close relationship between volcanic activities and generation, migration, accumulation of oil & gas. An abundance of mineral elements that volcanic activities provide can increase the quantity of organic matter in depression indirectly; a large supply of heat energy brings forward the time of oil generation; microelement and transition metal elements derived from volcanic rocks can serve as activators, which do great catalysis in hydrocarbon generation; giant volcanic matter can no doubt change the physiognomy greatly, which can help a lot in the process of generation and migration of depocenter. However, source rocks may be destroyed by volcanic rocks because of its high temperature. Faults going with volcanic activities can become good migration pathways. Volcanic activity before main migration time is favorable to the forming of reservoirs.

7. There are five possible volcanic reservoirs in central Tarim area, that is, rock pillar piercement type, overlapping and draping type, volcanic rock body lateral-screening type, tectonic fracture type and uplifting leaching type.

Chen YeQuan

2004. 2

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# Contents

# 第一章　区域地质概况

## 第一节　塔里木盆地地质概况

塔里木盆地位于我国新疆维吾尔自治区南部，夹于天山、西昆仑山和阿尔金山三大褶皱山系之间(图 1-1)，构成了中国西部地区盆—岭景观的重要组成部分。现有资料表明，塔里木板块北邻哈萨克斯坦和西伯利亚板块，南接特提斯羌塘板块和柴达木板块，处于几个板块的交汇处，是构造最活跃和地貌最壮观的地带。

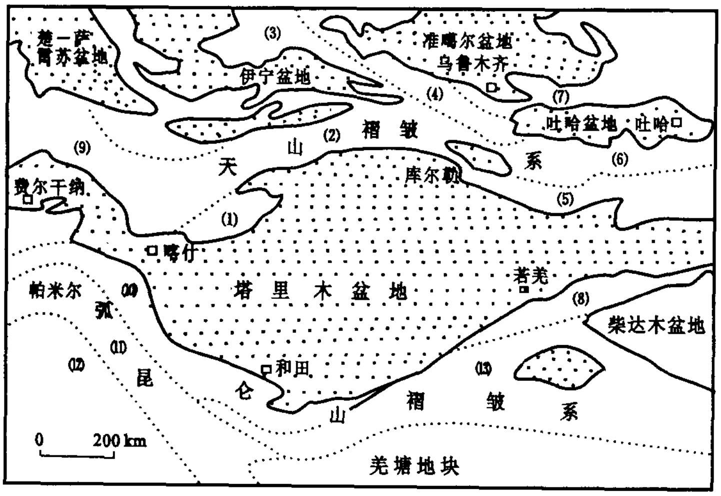


图 1-1　塔里木盆地大地构造位置图(据贾承造，1995)

(1)柯坪断隆；(2)哈里克套褶皱带；(3)博罗科努褶皱带；(4)伊连哈比尔尕褶皱带；(5)库鲁克塔格断隆；(6)觉罗塔格褶皱带；(7)博格达褶皱带；(8)阿尔金断隆；(9)卡腊山褶皱带；(10)西昆仑褶皱带；(11)喀喇昆仑褶皱带；(12)冈底斯褶皱带；(13)东昆仑褶皱带

塔里木盆地自显生宙以来发育数条板块边界，其中古生代—三叠纪存在 4 条主要的板块边界，即：北部的汗藤格里峰—库米什—星星峡缝合线、西南部库地缝合线、康西瓦缝合线以及东南部的阿尔金转换缝合线。这些边界控制了塔里木板块的形态，并受板块间离散和聚敛运动影响，在板块内部形成了若干与其动力学系统相配套的变形构造样式(周清杰等，1990)。

### 一、地球物理异常及深部构造

#### 1. 地幔形态

根据地壳均衡理论，地壳厚度的差异反映了组成地壳物质密度的不同，一般来说，区域重

力背景场总体上反映了上地幔形态。塔里木盆地重力区域背景场由一个从东向西伸入的椭圆形重力梯度带所环绕、大面积的平缓重力高组成。大体上以－200 mGal 等值线圈出了塔里木盆地的主体轮廓。区域重力最高值大致沿阿拉干北至喀什一线近东西向展布，反映了上地幔隆起的最高部位。其中，在区域重力场－110～－115 mGal 的范围内是重力场变化最小、地幔起伏不大、隆起较高的部位，现今地壳厚度为 41～44 km。向盆缘山系区域重力场逐渐下降，南面的西昆仑山，阿尔金山区域重力场下降从－200～－400 mGal，上地幔随之下降，地壳厚度增至 60 余千米。北面的南天山山系，区域重力场以每百千米 70 mGal 的梯度下降至－280 mGal，地壳厚度相应增至 54 km。根据重力梯度带的存在，说明塔里木断块区与周围山系存在着壳层断裂(图 1-2)。

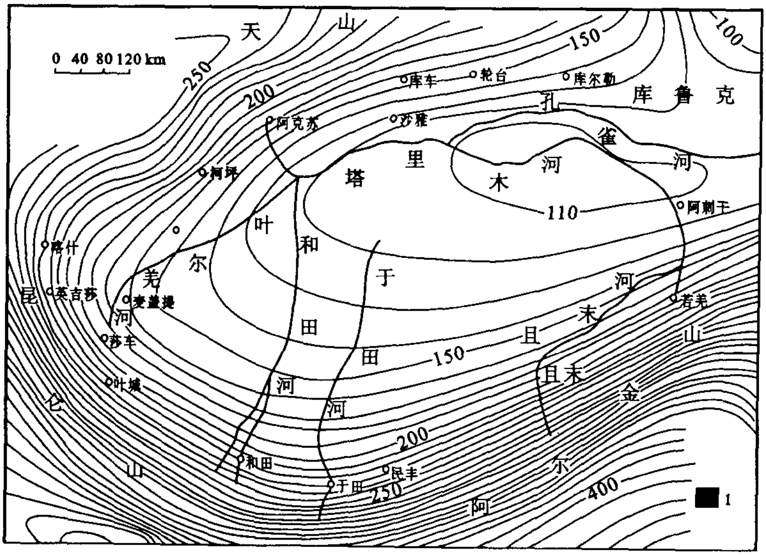


图 1-2　塔里木盆地重力区域背景图(据腾吉文，1991)

塔里木盆地在演化过程中，地幔热流不断地从盆地中间上升，并向四周对流，最终消亡在盆地边界，所以盆地中央是地壳厚度最薄、最脆弱的地带，也是地幔能量最高的地方。当能量积累超过岩石所能承受的强度时，往往会沿着某些脆弱的深大断裂形成火山喷发，塔里木盆地二叠系普遍存在的火山岩就是这样形成的。相反，盆地周缘地壳厚度大，热流能量相对小，形成强烈喷发的可能性相对较小。然而在盆地周缘，火山岩厚度不但没有减小，反而有增大的趋势，盆地周缘火山岩在岩性和化学特性上与盆地内部火山岩也有较大差异，据研究，盆地周缘巨厚火山岩是由板块碰撞引起的，属于岛弧型火山岩。

2. 前震旦纪结晶基底结构

塔里木盆地基底磁异常清楚地显示出 3 种性质不同的背景磁场及其对应的基底构造层磁性状态(图 1-3)。

1) 北部负磁场区

北部(天山南侧及盆地北部地区的乌什—库车—库尔勒一线)表现为平静的负磁场区，磁场强度为－100～－200 γ(1 γ＝7.957 75×$10^{-4}$A/m，后同)。根据基岩露头标本测得的磁性数