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编著

塔河油田

奥陶系缝洞型 碳酸盐岩油藏开发

石油工业出版社
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内 容 提 要

本书从油藏的静态和动态特征、储层的改造、开发的技术对策和开发前景等方面对塔河油田进行了描述、分析和评价,对指导塔里木盆地碳酸盐岩油气藏的开发具有一定作用。

本书可供从事油气田勘探开发的技术人员参考。

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序

塔河油田的发现是塔里木盆地石油勘探史上的重大成果；塔河油田的开发是塔里木盆地石油开发史上的重要篇章。塔河油田的发现和顺利地投入开发，更是新星石油公司近十多年来，在塔里木盆地实施与时俱进、滚动勘探开发方针的重大成功。56 万平方公里的塔里木盆地，多么辽阔、多么风光、多么迷人，它令人遐想、向往和探索。而塔河油田却是油芳四起的塔里木盆地中的一颗金星。

塔河油田是一个整装高产，但又非常复杂的大型油田。它的发现让几代石油工作者付出了无比艰辛的劳动和汗水；它的发现又给人们带来了无比的喜悦和期盼。人们从实践中发现了它，认识了它，掌握了它，利用了它。它的开发造福了祖国人民。截至 2002 年底，塔河油田已累积探明石油地质储量 2.4 亿吨，是目前塔里木盆地中储量最大的油田。2002 年塔河油田年产原油 253 万吨，也是目前塔里木盆地中产量最高的油田。

塔河油田丰满的油气，储集于千姿百态、千变万化的奥陶系古岩溶缝洞的迷宫之中。聪明智慧的石油工作者，利用地震、钻井、测井、完井、测试和生产等手段获取的大量有关信息，经过去伪存真、由表及里、由此及彼的综合研究，终于逐步认识、掌握和驾驭了复杂的客观。这再一次证明：实践出真知，实践是认识客观的唯一源泉。实践、认识、再实践、再认识，必将使今后塔河油田的勘探与开发取得更大的成果。

我受三位主编之约，能为该书写序，甚感荣幸。感谢他们对我的信任和委托。同时，要为这样一部广泛涉及到塔河油田（勘探）开发各个方面的书写序，我也深感能力之不足。因此，我把写序作为一次很好的学习机会，这就有可能使我成为该书的第一位读者。通过对本书的粗读，归纳起来有以下三方面的内容：一是，该书汇总了近十多年来，塔河油田滚动勘探开发的基本经验；二是，该书提供了解决许多带有世界性技术难题的成功经验；三是，该书介绍了富有独到和创新内容的科研成果。总之，这是一本内容丰富、资料翔实、理论联系实际的好书。广大热心的读者，可以从中找到自己感兴趣而值得阅读的篇章。最后，我想对为本书付出辛勤劳动和智慧的各位作者和主编表示敬意！并对本书即将正式出版发行表示热情地祝贺！

陈元平
2002.12.25
北京

前 言

塔河油田位于新疆维吾尔自治区库车县和轮台县境内，地处塔克拉玛干大沙漠北缘。油田自下奥陶统至三叠系发育多个油藏，其中包括碳酸盐岩岩溶缝洞型油藏、碳酸盐岩孔隙型油藏、碎屑岩油藏等。在诸油藏中，奥陶系碳酸盐岩油藏是目前开发的主力油藏。该油藏在很大范围内连片含油，但含油气丰度完全受缝洞发育程度的控制。油田内现称的不同油气区更多地是属于人为划分，并没有完全以可靠的地质界限作为依据。

塔河油田 3、4 区是塔河油田投入试采和开发最早的油气区。这两个区的奥陶系油藏均为地层不整合—岩溶缝洞型。储层埋藏较深，一般都大于 5300m。缝洞分布的随机性很强。作为碳酸盐岩储集体，其油藏的类型不同于中东地区缝洞非常发育的碳酸盐岩油藏，和华北任丘以断层控制的碳酸盐岩油藏相比也有很大的区别。油藏的碳酸盐岩基质部分基本不含油，油气的有效储集空间均为岩溶缝洞。区内所产原油既有含硫、高蜡、低粘度的轻质油，也有高硫、高蜡的重质油。油藏中所含的天然气多为成熟油田气。

这是迄今为止国内外少见的一种特殊油气藏类型。很显然，其油藏储集体和流体性质非常复杂，可以说是集中了目前开发领域多种世界级难题于一身。客观地说，要想高效开发这类油藏，其困难程度是可想而知的。更何况目前国内外对这类油田的开发还没有可供借鉴的成功经验。

在为时 5 年的开发过程中，油田的技术人员感到最为困难的是对油藏的认识无法尽快深入。尽管应用了多种手段，但对于 5300m 以下的缝洞还是很难识别，压力资料取不准，油水关系摸不透，布井位时缺乏足够的地质和油藏依据。其次，是难以及时地对储量和产能的规模作出准确地判断，致使地面建设的规模不协调。再者，就是在深部高粘度稠油的采油工艺方面缺乏经济有效的手段。

鉴于这种超深层和极不均质岩溶—缝洞储集体的发育特征，在油田开发初期开展滚动勘探开发无疑是合适的。通过不断地探索和实践，目前技术人员已经在开发方面初步积累了一些成功的经验，其中包括缝洞系统的初步预测技术、负压钻进技术、先期裸眼完井技术、高温高压下的压力测试技术、大规模深穿透酸压技术、稠油掺稀开采技术、短曲率半径开窗技术等等。这些技术为塔河油田的快速上产，为将地下油气资源及时地转变为经济效益提供了有力的技术保障。

为了能对这些年来塔河油田开发工作所取得的成果进行初步总结，我们在发动工程技术人员撰写学术论文的基础上编撰成此书，旨在从油藏的静态和动态特征、储层的改造、开发的技术对策和开发前景等方面，对塔河油田进行较为客观的描述、分析和介绍，并希望从中获得对油藏地质、油藏工程等方面规律性的认识，以利于指导下一步的开发生产。同时，也希望能通过此书，让从事油气田开发工作的同仁进一步了解塔河油田的开发，这必然对分析和研究此类油田的开发有所裨益。

本书的编著者均在生产和科研的管理岗位，或从事于众多科研项目，未能有更多的时间静心于此项工作，加之本身的学术水平有限，故书中的错误和不足之处在所难免，望读者和有关同行不吝指教。

在本书编著过程中，承蒙中石化勘探开发研究院、中石化新星公司西北分公司研究院、中石化新星公司开发部的大力支持和帮助，在此深表谢意。

编者
2002 年 9 月

Preface

Take Oil Field is located at Luntai and Kuche counties in Xinjiang Uygur Autonomous Region, i.e. in the northern boundary of the TaklaMakan desert. Many hydrocarbon reservoirs are found from lower Ordovician to Triassic System, and among them include the carbonate caved fracture and hole type reservoirs, carbonate porous type reservoirs and clastic reservoirs etc.. The Ordovician carbonate reservoir is the main reservoir, developing at present in all hydrocarbon reservoirs. The reservoir is uninterrupted at the very big scope, but hydrocarbon abundance is controlled completely by the level of fracture and hole development. The different petroliferous areas at present named by the crew are artificial dividing, and are not in confidence with geologic boundary completely.

3 and 4 areas in the Take Oil Field are the earliest production test and development area in it. The Ordovician reservoirs in these 2 areas are all stratigraphic unconformity – caved fracture and hole type. Buried depth of the reservoir is big and usually greater than 5300m. The distribution of fracture and hole is quite random. As the carbonate reservoir, its type is different from the carbonate reservoir in Middle East, which the inside fracture and hole is very developed, and is quite different from the carbonate reservoir in North China, which is controlled by fault. The carbonate host of the reservoir basically does not contain oil and the effective space of hydrocarbon reservoirs are all caved fracture and hole. In this area, there's not only sulphur – bearing, high wax and low viscosity light – weight oil, but also high sulphur and high wax heavy oil. Natural gas in the reservoir is mostly matured oil field gas.

Up to now, this is a special type of reservoir, which is seldom seen at home nor abroad. Obviously, its reservoir space and fluid property are very complicated and can be concluded that the reservoir included many world class difficult problems at present in the development respect. Objectively speaking, it is very difficult to develop this kind of oil field with high efficiency. Much less the development to this kind of oil field still have no successful experience for reference at present at home or abroad.

For time 5 years in the development course, the most difficult problem that the technical personnel of the oil field felt is they can not go deep into to the knowledge of the reservoir as quickly as possible. In spite of applying many kinds of means, it is still very hard to identify the fracture and hole that is below 5300m. Pressure material is not taken correctly, the oil – water relationship is known thoroughly, lack of enough geology and reservoir data during the planning of wells. Next, it's hard to make accurate judging with the amount of reserves and off – take potential, thus led to the fact that the scope of ground construction don't seem to be in tune with practical case. Moreover the oil recovery technology of high viscosity oil in great depth is short of active and economic means.

In view of the development characteristic of this kind of extra – deep and very eterogeneous

caved fracture and hole reservoir, the progressive exploration and development at the initial tage of development oil field is suitable beyond doubt.

By way of constant exploring and practicing, technical staff at present had accumulated initially some successful experiences on the development, including initial forecasting technology of the fracture and hole system, negative pressure drilling technique, initial open hole completion technique, pressure measuring technique under the high temperature and high pressure, large – scale deep penetrating acid fracturing technique, thinned heavy oil recovery technique, short radius of curvature sidetracked hole technique etc. .

These technologies provided the strong support for a quick putting into production of Tahe Oil Field and changing the subsurface hydrocarbon resources to the economic performance in time.

For initial summary the achievements of the development work in Tahe Oil Field for these years, we called engineers and technicians write thesis compile into this book, for the purpose of carrying on comparatively objective description, analysis and introduction to Tahe Oil Field, from the static and the dynamic characteristics of the reservoir, the reservoir reconstruct, the development technical gaming and the development foreground etc. , and hope to gain the knowledge of the regularity on hydrocarbon reservoir geology and reservoir engineering etc. , in order to guide next development production. At the same time, it is also hoped that this book will help those friends who are engaged in development work in oil – gas field to have a better understanding of the development work of Tahe Oil Field, and that this book may be beneficial to analysis and study the development of this kind of oil field.

Since chief compilers are all in management post of production and scientific research, or in busy of research work, fail to have still heart of too much time on this work, in addition to limited scholar lever, mistakes and shortcomings can hardly be avoided in the book, we hope readers and concerned colleague will not stint your criticism.

Thanks a lot for the support from Academy Enploration and Development, SINOPEC; Academy of Design and Plan, Northwest Branch Company, Star Oil and Gas Company, SINOPEC; Development Department, Star Oil and Gas Company, SINOPEC; in Compiling the book.

editor
Sep 2002

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第一章 对勘探和初采史的回顾与认识

塔里木盆地是我国最大的内陆盆地。其油气资源的勘查和研究已有 100 多年的历史。新中国成立后，全盆地的油气资源开始有了计划性的勘查。经过广大石油地质工作者近半个世纪的艰苦努力，积累了大量的基础资料和宝贵的经验，对盆地油气富集规律及资源前景建立了丰富的认识，尤其是 20 世纪 80 年代通过沙参 2 井的突破，取得了盆地内碳酸盐岩领域油气勘查的重大进展，使塔里木盆地的油气勘探成果产生了一个质的飞跃。随着国家油气勘探战略西移重大举措的实施，盆地内相继在中部、北部发现了十余个大中型油气田（藏）。其中，原中国新星石油公司西北石油局在滚动勘探开发方针的指引下，凭借着丰富的勘探经验，长年坚持艰苦奋斗和不懈探索、敢为人先，于 1997 年在盆地北部发现了由多套油气层系叠置的巨型油气田——塔河油田。据最新统计的数据表明，其探明的油气地质储量已达 $2 \times 10^8 \text{t}$ （近年内可望增至 $5 \times 10^8 \text{t}$ ）。

油田中的主力油藏——奥陶系碳酸盐岩缝洞型油藏，由于其储集体的形成过程较为特殊、控制因素复杂，故在平面分布上具极强的非均质性，开发难度极大，国内外尚无可借鉴的对象。因此，唯有采用滚动勘探开发的技术思路，才有较强的适应性。几年来，正是通过边滚动开发边深化油藏认识，边建设产能边扩大储量的基本策略，从事开发的工程技术人员已经对此类复杂油藏的开发积累了一些经验，在一定程度上也填补了国内此类油气田开发技术的空白，丰富了相关的基础理论。可以说，滚动勘探开发模式为塔河油田快速、高效地增储上产奠定了坚实的基础，提供了强有力的保障。

本章对塔河油田勘探开发历程中的发现和试采史进行了较为详细的回顾，并就开发过程中取得的成绩和存在的不足进行了实事求是的总结，提出了在技术上应该开展攻关研究的方向。同时，阐述了针对该油藏的特点开发工作所持有的阶段性特征。

Chapter One A Review and Cognition of Exploration and Test Production

The Tarim Basin is biggest inland basin of our country. The surveying and studying of its oil and gas resources have a history of more than 100 years. Since the foundation of the new China, the oil and gas resources surveying in the whole basin have begun putting into plan. Many petroleum geology experts, technologists and workers have worked arduously in the past 50 years in the Tarim Basin, and accumulated large quantity of foundational data and precious experience, and established plentiful cognition on oil and gas gathering rules and resources prospecting. Especially, the Shacan 2 wells's breakthrough in 1984 made an important progress in the realm of oil and gas surveying in carbonate rock in the basin, and made the Tarim Basin's oil and gas exploration a qualitative forward leap. Along with the nation's oil and gas exploration strategy moving to west of China, more than ten big and middle sized oil and gas fields (pools) found in succession in central and north section of the basin. Among them, the former NWPB of the Chinese National Star Petroleum Company, under the guide line of progressive exploration and development, relying on rich exploration experience, and persists in hard struggle and untiringly to explore all the year round, and found the giant oil and gas field – the Tahe Oil Field in 1997, which lies in north part of the Tarim Basin, not far from the Tarim River. The data according to the newest statistics indicate, its explored reserves have already exceeded 200 millions tons (it is hopeful that it may increase to 5×10^8 t in the near future) .

In the main oil reservoir of the oil field, Ordovician carbonate oil reservoir of fracture and hole type, the process of its formation are rather special, and its control factors are complicate, so there's a very strong heterogeneity on the surface view, and its development is very difficult. There's no sample to follow domestically or internationally. Therefore, adopting the technique way of progressive prospect and development become the only way to get a stronger adaptability.

In recent years, it is with the way of progressive development while deepening the cognition of oil reservoir, developing the productivity while extending the reserves that engineering technologists engaged in the development have accumulated some experiences to the development of this kind of complicated oil deposit. They have supplied a gap in some extent in the development of this kind of reservoir in our country and enriched the related foundational theories. It is observed that progressive exploration and development mode establishes the solid foundation for the fleet and efficient increasing of reserves and production in Tahe Oil Field, and provide powerful guarantee for it.

This section has a detailed review of the history of Tahe Oil Field exploration and test production process, and a realistic summary for the achievement and shortages to be overcome in the development process, and bring forward the technique direction of tackling key problems. At the same time, it expatiates period characteristics in the development for this kind of oil reservoir.

一、油田的发现和初期试采史回顾

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摘要:塔河油田的发现是塔里木盆地油气勘探史上最为重要的里程碑。本文回顾了以奥陶系碳酸盐岩大型油藏为主体的塔河油田的发现和初期试采历史。作为世界级难题的深层非均质性极强的岩溶缝洞型碳酸盐岩油藏的开发,不可避免地会遇到许多困难,其中有的问题已在试采初期取得了一些认识和经验,但更多的则需要我们继续做出巨大的努力才有望解决。

新疆塔里木盆地是我国陆上最大的沉积盆地,面积约 $56 \times 10^4 \text{km}^2$ 。早在 20 世纪 50 年代,盆地的油气勘探工作即已开始。从那时起,广大石油地质工作者和从事勘探开发的工程技术人员就在这片多为戈壁沙漠覆盖的土地上风餐露宿,长年奋战,不断地为祖国石油工业的发展做出伟大无私的奉献。

迄今为止,这种艰难的奋战曾经有过 3 次里程碑式的重大突破。即:1977 年发现柯克亚凝析气田;1984 年发现雅克拉凝析气田;1997 年和 1999 年分别发现塔河大油田和克拉 2 大气田。在这 3 次突破中,尤以第 2 次和第 3 次的突破意义最为重大。因为其中雅克拉凝析气田和塔河大油田的发现使我国古生界海相克拉通盆地的油气勘探出现了重大转机,尤其是为古隆起、古斜坡不整合加岩溶缝洞型圈闭的油气勘探提供了可供借鉴的经验,它从根本上促进了我国“稳定东部、发展西部”石油战略的具体实施。

中国石化新星石油公司(原属地质矿产部)经过将近 20 年的努力,凭借着丰富的勘探经验和艰苦创业的精神,在地质条件极为复杂和生产环境极为恶劣的情况下,继雅克拉凝析气田之后,进一步在奥陶系(部分在石炭系和三叠系)中发现并探明了油气地质储量超亿吨的大型油气田——塔河油田。这是塔里木盆地发现的第一个整装大油田。在塔河油田发现以后,新星公司不断加大对该地区油气资源的勘探开发力度,积极地为增加油气接替资源和动用已探明储量做进一步努力。至 2001 年底,该油田已拥有探明地质储量 $1.97 \times 10^8 \text{t}$ 油当量,可采储量 $2931 \times 10^4 \text{t}$,剩余可采储量 $2391 \times 10^4 \text{t}$;原油年产量达到 $249.8 \times 10^4 \text{t}$ 。很显然,在西部地区,这一含有多套产层的亿吨级油田——塔河油田的发现,必将在我国石油工业史上占有重要的一页。

塔河地区勘探总面积近 6500km^2 ,属巴音郭楞蒙古自治州的轮台县和阿克苏地区的库车县管辖。工区地势平坦,为低缓沙丘和盐碱地。气候干燥,年平均温度为 $5 \sim 10^\circ\text{C}$ 。

油田的构造部位属塔里木盆地沙雅隆起阿克库勒凸起南斜坡。其南侧发育有寒武—奥陶系的满加尔生油拗陷。该构造部位在加里东、海西期发生过多期构造变动,故形成了令人瞩目的位于深部(一般大于 5300m)下奥陶统的不整合—岩溶缝洞型储集体。储集体上部发育有石炭系下统巴楚组等泥岩盖层,纵向上生、储、盖的组合条件良好。油气成藏始于海西晚期,其后受到印支—燕山运动的改造,喜马拉雅期得到进一步充注。除了下奥陶统碳酸盐岩油藏之外,塔河油田范围内还发育着三叠—石炭系的低幅度砂岩油藏。最近,又陆续发现了

中上奥陶统的碳酸盐岩油藏。

全油田目前划分为 10 个油区。在相对勘探程度较高的几个区中, 1 区和 2 区三叠系油藏的储量已探明, 3 区的石炭系砂岩油藏和奥陶系碳酸盐岩油藏的储量得到部分探明, 4 区、6 区、7 区奥陶系碳酸盐岩油藏的储量已基本探明。相对勘探程度较低的 8 区、9 区、和 10 区虽都已有油气突破, 且在小范围内试采, 但其储量尚未明确。

塔河油田最早的油气发现可追溯到 1990 年在艾协克构造(现称 3 区)的 S23 井。当时在石炭系和奥陶系发现了油气显示, 但奥陶系碳酸盐岩测试只获少量原油。其后, 在桑塔木构造(现称 1 区)的 S29 井三叠系中发现油气显示, 经测试获得工业油气流, 从而首先发现了 1 区三叠系油藏。接着, 于 1997 年在桑塔木南构造(现称 2 区)的 S56 井三叠系中也获得突破, 从而发现了 2 区三叠系油藏。经评价后, 分别向国家储委提交了 1 区、2 区的探明储量。1999 年, 根据新井资料, 对 1、2 区探明储量进行了复算。复算后 1 区和 2 区的含油气范围分别确定为 15 km^2 和 4.5 km^2 , 探明储量分别为 $1459 \times 10^4 \text{ t}$ 和 $423 \times 10^4 \text{ t}$ (油当量)。

由于不同系统的队伍早期在一起作业, 有关“桑塔木”等构造名称的地理位置概念有所混淆, 目前公司系统在塔河油田凡涉及地面的工作, 均以油区称谓。

作为目前原油生产的最主要油藏类型, 塔河油田的碳酸盐岩油藏虽然最早是在上述 S23 井发现的, 但从突破意义上来说, 应是 1997 年 3 区 S46 井的下奥陶统。当时, 测试获原油 $212.54 \text{ m}^3/\text{d}$, 天然气 $14.18 \times 10^4 \text{ m}^3/\text{d}$ 。随之即部署了 S47 井。该井测试获原油 $227 \text{ m}^3/\text{d}$, 天然气 $36.54 \times 10^4 \text{ m}^3/\text{d}$ 。根据这一情况, 1998 年又对位于该区的 S23 井奥陶系下统碳酸盐岩进行酸化压裂, 结果取得突破, 获天然工业油气流。当年, 国家储委批准该区奥陶系含油面积为 15 km^2 , 探明油气地质储量为 $651 \times 10^4 \text{ t}$, 天然气地质储量为 $28.4 \times 10^8 \text{ m}^3$ 。1999 年部署在该区东部的 S70 井奥陶统获工业油气流, 从而使该区含油气范围外扩了 8.5 km^2 。至此, 3 区的含油气范围和探明储量规模得以基本确立。截止 2001 年底, 探明的含油气面积为 23.5 km^2 , 探明原油储量为 $831 \times 10^4 \text{ t}$, 天然气为 $37.5 \times 10^8 \text{ m}^3$ 。

1997 年在 4 区部署了 S48 井。该井在钻遇奥陶系下统碳酸盐岩风化壳时, 曾发生严重井漏。经测试, 获原油 $570 \text{ m}^3/\text{d}$ 、天然气 $1.5 \times 10^4 \text{ m}^3/\text{d}$ 的高产工业油气流。值得一提的是, 该井连续 4 年保持着高产记录, 井口压力几乎不变, 至 2001 年底, 已累计生产原油 $62.089 \times 10^4 \text{ m}^3$, 成为该区乃至整个塔河油田的“王牌”产油井。它表明塔里木盆地北部奥陶系下统碳酸盐岩蕴藏着极为丰富的油气资源, 具有很高的产能, 标志着勘探和开发取得了重大突破。继 S48 井之后, 在该区的 T401、T402 井均试获工业油气流, 日产分别达到 291 m^3 和 350 m^3 。1999 年, 该区西部和南部一批评价井又相继获工业油流, 使该区的含油气面积进一步扩大。截止 2001 年底, 该区的含油气范围约为 56.7 km^2 , 探明储量原油为 $6345 \times 10^4 \text{ t}$, 天然气为 $38.7 \times 10^8 \text{ m}^3$, 成为塔河油田最重要的原油生产区。

随着塔河油田 3 区、4 区的发现, 为扩大勘探开发成果, 1999 年在塔河油田 6 区部署了 S66、S67 井, 同年分别试获 $111 \text{ m}^3/\text{d}$ 和 $476 \text{ m}^3/\text{d}$ 的工业油气流, 从而发现了塔河油田 6 区。截止 2001 年 1 月, 由 S74、S67、S80 等井控制的含油气面积约为 112.5 km^2 。探明储量为原油 $8657.7 \times 10^4 \text{ t}$, 天然气 $47.94 \times 10^8 \text{ m}^3$ 。现在该区已成为继 4 区之后的又一个重要的原油生产区。

1999 年同时在 7 区部署了 S76 井。该井在生物礁滩相灰岩段和裂缝—溶孔发育段均试获工业油气流, 日产原油 123 m^3 , 天然气 $1 \times 10^4 \text{ m}^3$ 。随之, S86 井等井也同样获得成功, 从而发现了 7 区奥陶系油气藏。根据现今 S76 井、S86 井以及位于 2 区的 T203 井(该区南部