

枣园油田孔缝型油藏单井产能地质控制因素研究

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摘要 枣园油田中生界孔缝型油藏岩性以安山岩为主, 探明地质储量 1355.87×10^4 t, 随着开发的不断深入, 已进入开发高含水阶段, 后续的进一步开发有着较大的难度。本文综合应用岩心、测井、地震等静态资料以及动态数据, 分析了枣园油田孔缝型油藏单井产能特征及其差异的控制因素, 并制定了研究区目的层产能评价标准。研究区储集空间主要以次生溶蚀孔隙为主, 裂缝则起到沟通孔隙的作用。经过分析表明, 研究区单井产能与岩相具有较好的相关关系, 其中爆发相和溢流相是主要储层; 除此以外, 产能与储层厚度以及裂缝发育呈正相关关系; 油柱高度和后期措施也对单井的产能有着较大影响。通过开展油藏单井产能特征研究, 总结研究区出3种单井产能类型及分类标准: I类产能稳定递减型、II类产能迅速递减型、III类低产或无产能型。I类单井钻遇储层厚度大于70 m, 岩相为爆发相和溢流相; 单井油柱高度大于150 m, 方差属性值大于0.6。II类单井钻遇储层厚度为35~70 m, 岩相为溢流相; 单井油柱高度为90~150 m, 方差属性值为0.15~0.6。III类单井钻遇储层厚度小于35 m, 岩相为溢流相; 单井油柱高度小于90 m, 对应方差属性小于0.15。单井产能差异的控制因素研究对油田确定储层有利区以及下一步油井的部署和开发具有一定的指导意义。

关键词 火山岩油气藏; 产能特征; 主控因素; 中生界; 岩相; 安山岩

Geological controlling factors of single well productivity in perforated and fractured reservoir in Zaoyuan oilfield

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Abstract The Mesozoic volcanic reservoir in Zaoyuan oilfield is mainly composed of andesite, with proven reserves of 1355.87×10^4 t. With the deepening of development, it has entered the high water-cut period, and the further development has great difficulty. Taking the Andesite reservoir of Zaoyuan oilfield as an example, this paper analyzes the productivity characteristics of single well and the controlling factors of its differences by comprehensively applying static and dynamic data such as core, well logging and seismic data, and establishes the productivity evaluation standard of the target layer in the study area. The volcanic reservoir space in this area is mainly dominated by secondary dissolution pores, and fractures play a role of communication pores. The analysis shows that there is a good

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correlation between the productivity of volcanic rock well and lithofacies in this area, in which the outburst phase and overflow phase are the main reservoirs. In addition, productivity is positively correlated with reservoir thickness and fracture development. Column height and post-production measures also have a significant impact on the productivity of a single well. Through the research on the productivity characteristics of single well in reservoir, this paper summarizes three types of single well productivity and classification standards in this area: class I stable declining productivity type, class II rapidly declining productivity type, and class III low production or proletarian productivity type. Class I single well was drilled with a reservoir thickness greater than 70 m, and the lithofacies was outburst phase and overflow phase. The height of single well oil column is greater than 150 m, and the variance attribute value is greater than 0.6. Class II single well is drilled with reservoir thickness of 35~70 m and the rock facies is overflow facies. The height of single well oil column is 90~150 m, and the value of variance attribute value is 0.15~0.6. Class III single well was drilled with reservoir thickness less than 35 m, and the rock facies was overflow facies. The height of single well oil column is less than 90 m, and the value of corresponding variance attribute is less than 0.15. The controlling factors of single well productivity difference in volcanic reservoir have certain guiding significance for oilfield to determine favorable reservoir area and oil well deployment and development in the next step.

Keywords volcanic rocks reservoirs; productivity characteristics; main controlling factors; Mesozoic; lithofacies; andesite

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0 引言

随着国内外油田勘探开发的不断深入,火山岩储层中发现了大量的油气藏^[1]。火山岩油气藏是目前世界上开发难度比较大的油气藏类型之一,具有储层厚度大、勘探潜力大、孔隙结构复杂、非均质性强、隔夹层发育以及裂缝发育等特点^[2-4]。前人对火山岩油藏的研究主要以储层为主要对象,对火山岩储层的岩性、岩相、孔隙特征、成岩作用等有效储层的主控因素进行了研究^[5-12],但忽略了单井产能差异的控制因素。针对枣园油田中生界火山岩油藏,仅做过火山岩储层分布和预测方面的相关研究^[13]:通过地震资料对火山岩相进行分析,结合多种属性信息反应岩相分布,以此预测火山岩储层分布。由于火山岩的特殊性,仅确定储层的分布是不全面的。

本文从岩性、岩相、储层厚度、油柱高度以及酸化措施等方面进行分析,落实了枣园油田中生界火山岩油藏单井高产的主要原因,对本区不同产能类型的单井进行了划分,即明确了单井的产能差异的控制因素,探讨造成本区火山岩油藏单井产能差异的控制因素。

1 区域地质概况

枣园油田中生界火山岩油藏地理位置上位于风化店构造带的南翼,西临沧东凹陷,东与孔东地区毗邻,北与自来屯构造带相接,南与沈家铺构造相连(图1)。构造上属于黄骅拗陷孔店凸起南部孔西断裂带,中部的孔西主断层以及南部大断层将该构造分割为枣北、枣南以及枣1508断块,3个断块均为富油聚集区。3

个断块钻遇安山岩79口井,所钻遇的火山岩储层具有孔隙结构复杂、非均质性强等特点;随着开发的深入,研究区单井产能差异较大。因此为了明确剩余油分布,进行进一步挖潜,通过静态、动态资料相结合,总结产能主控因素,为火山岩油藏新井部署提供依据。

2 油藏基本特征

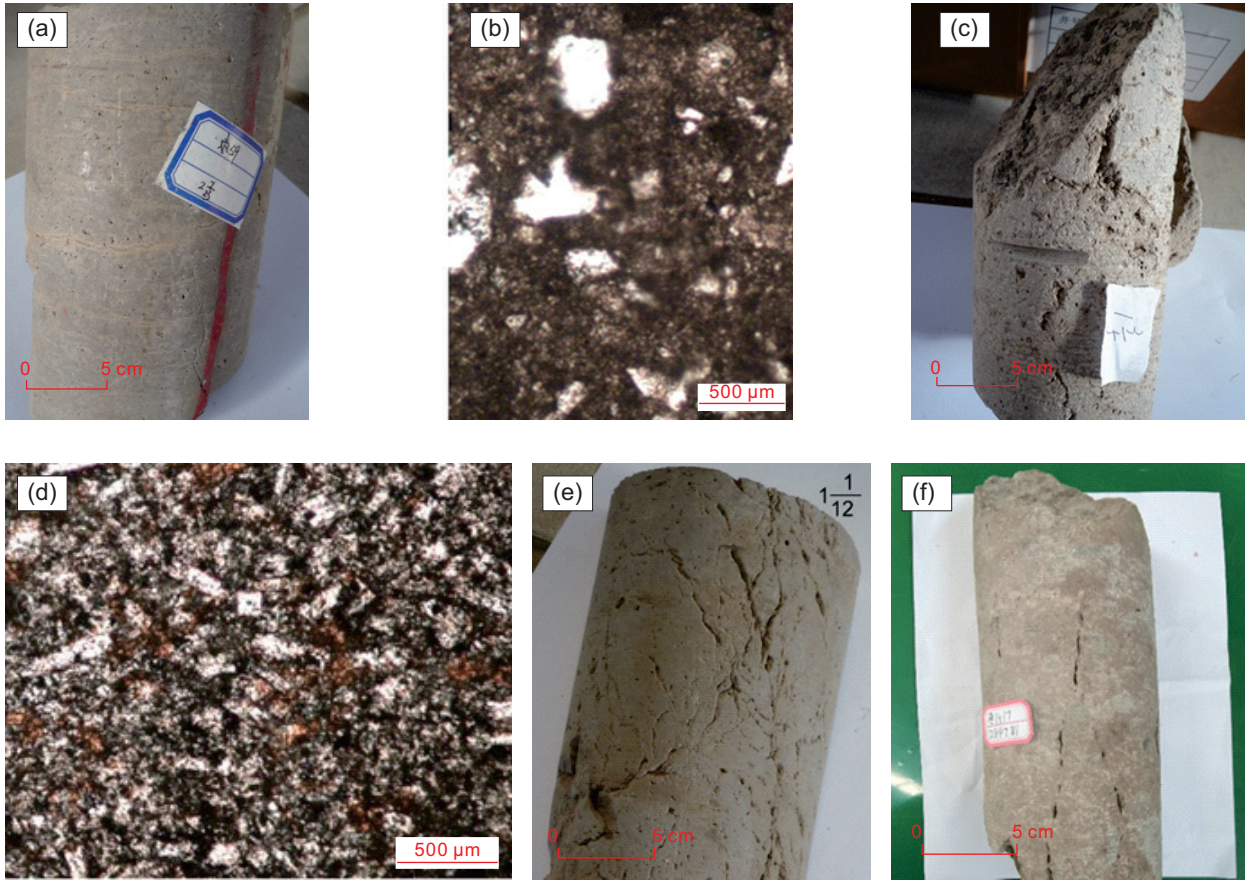
2.1 地层特征

枣园油田自上而下发育地层为第四系平原组、新近系明化镇组、馆陶组、古近系东营组、沙河街组、孔店组以及中生界的侏罗系地层。新近系的馆陶组和古近系的东营组之间、沙一段与沙三段之间、沙三段与孔一段之间、古近系的孔三段与中生界的侏罗系之间均为不整合接触。受构造影响,东营组、沙一段、沙三段地层剥失严重,只有部分地区有沉积。孔店组地层沉积比较稳定,孔一段地层主要为砂泥岩互层,孔二段、孔三段地层为湖相泥岩沉积。

研究区含油目的层为中生界安山岩储层,目前钻井钻遇安山岩地层厚度为7~309 m,平均151 m,总体发育6期火山岩。其中,北块火山岩厚度最大,南块次之,枣1508块厚度最薄。其中3、4期火山岩仅在北部发育且不含油,其他4个期次火山岩地层均为主力含油层段。

2.2 岩石学特征

根据录井资料以及薄片鉴定统计分析,火山熔岩主要发育安山岩、玄武岩。火山角砾岩、凝灰岩为主要的火山碎屑岩。本区主力储层的岩性为安山岩及火



(a)枣 59 井, 2913 m, 气孔, 微裂缝 (b)枣 1510 井, 3083 m, 粒内溶孔 (c)枣 116 井, 3012 m, 溶蚀缝洞 (d)枣 1510 井, 3101 m, 粒间溶孔 (e)风 22-15 井, 2860 m, 风化、构造裂缝 (f)枣 1517 井, 2847 m, 构造裂缝

图 2 枣园油田中生界火山岩储层孔隙裂缝岩心特征

Fig. 2 Characteristics of pore fractures and cores in Mesozoic volcano rock reservoir in Zaoyuan oilfield

个断块均存在多个高产井。根据产能特征, 研究区的单井可划分为产能稳定递减型、产能迅速递减型、低产或无产能型。

(1) I类(产能稳定递减型)。该类井生产初期具有很高的初产量, 随着时间的推移, 产量逐渐下降, 但仍能够维持一定的产能, 含水率逐渐上升, 可维持多年生产。该类井钻遇的储层裂缝发育, 沟通范围广, 该类型的井如枣 143 井(图 4a)。

(2) II类(产能迅速递减型)。该类井初始产量相对较高, 但产量下降较快。裂缝沟通性差, 仅能沟通井附近的一定范围内的储层, 产量快速下降, 仅能维持数年时间的生产, 该类型的井如枣 1528 井(图 4b)。

(3) III类(低产或无产能型)。该类井少量出油或少量出水, 只能维持数月生产, 相比II类井日产量更低, 且基质储层较为致密, 不发育裂缝或裂缝后期被充填。该类型的井如枣 59 井(图 4c)。

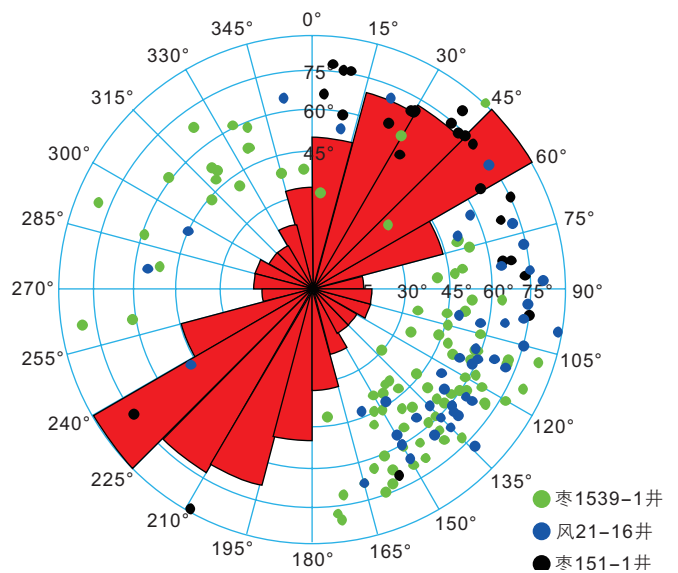


图 3 枣园油田中生界火山岩油藏单井裂缝走向玫瑰花状图
Fig. 3 Rose diagram of fractures strike in Mesozoic volcano rock reservoir in Zaoyuan oilfield

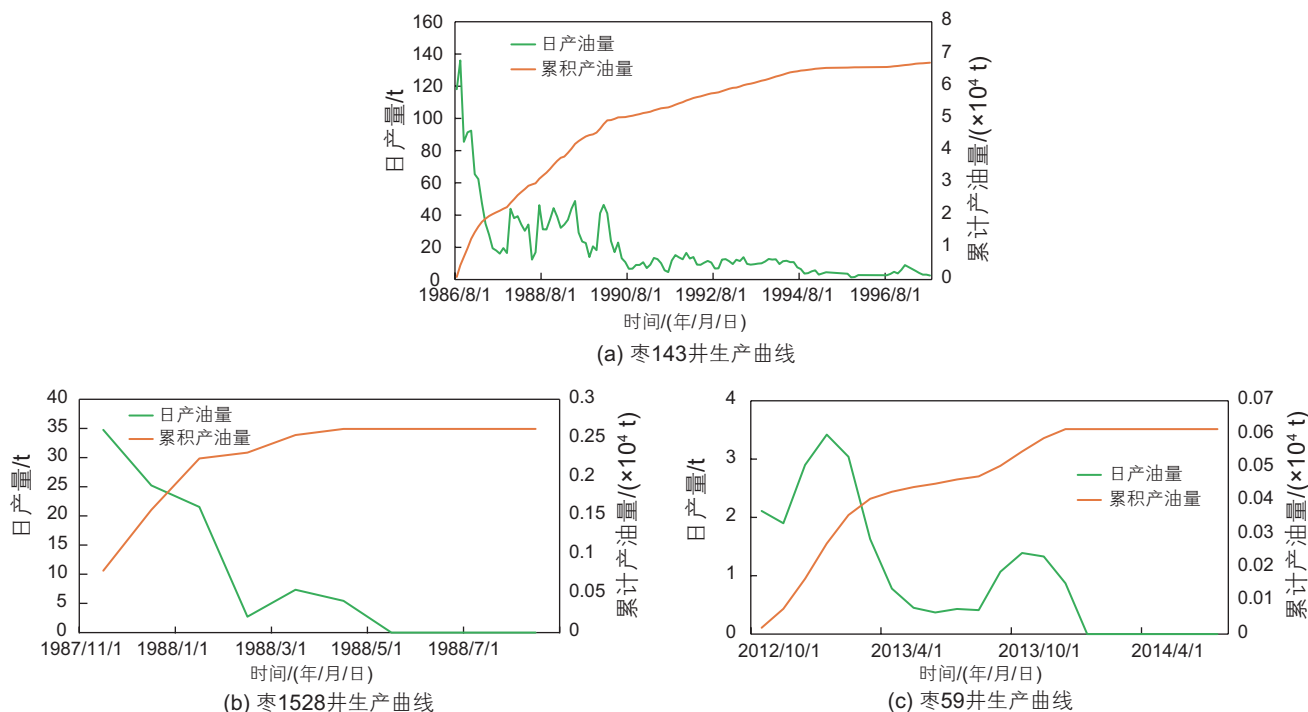


图4 枣143井、枣1528井和枣59井生产曲线

Fig. 4 Oil production curves of well zao55, zao1528 and zao 59

3.2 产能主控因素分析

前人对产能的主控因素进行过大量的统计研究, 产能的主控因素较为多样且相对复杂, 不同地区的主控因素有较大差异^[20-21]。针对研究区不同产能类型的单井, 通过动态、静态资料相结合, 主要从岩性岩相、储层厚度、裂缝发育程度、油柱高度以及生产措施5个方面对该区火山岩储层产能的主控因素进行分析。

3.2.1 岩性和岩相

火山岩岩性和岩相影响着火山岩储层的分布, 储层不同岩性的物性参数统计可以看出火山岩、角砾岩的物性最好, 安山岩和玄武岩次之, 凝灰岩物性最差

(图5)。根据本区的岩性—物性、岩性—含油性统计规律看, 本区爆发相的火山角砾岩和溢流相的安山岩为主力储层, 两种岩性及岩相均含油, 其他岩性分布范围小且不含油(图6)。本区以安山岩为主的溢流相最为发育, 因此本区的主要储层是裂缝发育的安山岩及火山角砾岩。结合岩相与累产量叠合图可以看出, 爆发相和溢流相为主要含油岩相(图7)。由此可以确定, 火山爆发相及溢流相发育于火山口附近, 因此会形成大量的火山角砾岩, 该岩性多发育粒间孔、杏仁孔、溶蚀缝等孔隙, 多种孔隙的发育使得该类型岩相的岩石更容易通过风化淋滤作用被沟通起来, 形成优质储层。因此在有油气供给的情况下, 在该类地区储量大, 产能效果好。

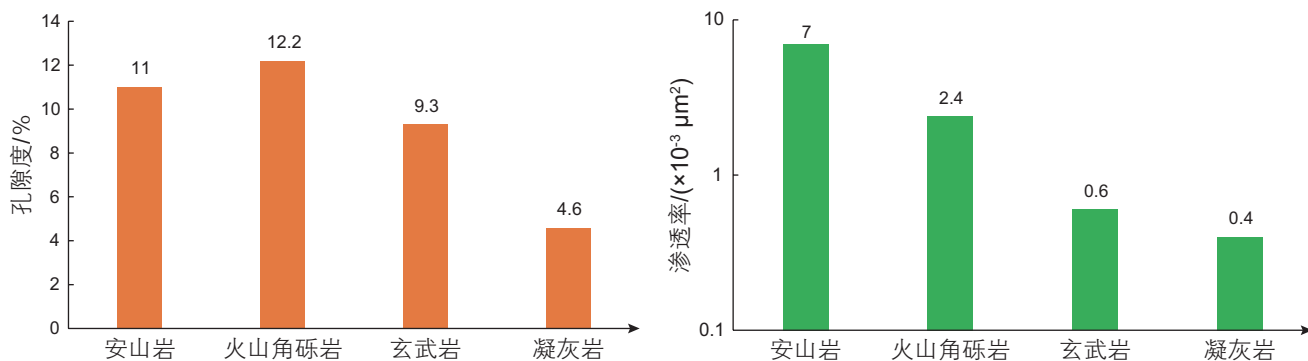


图5 枣园油田中生界安山岩块岩性—孔渗关系直方图

Fig. 5 Histogram of lithology-porosity and permeability of Mesozoic volcano rock reservoir in Zaoyuan oilfield

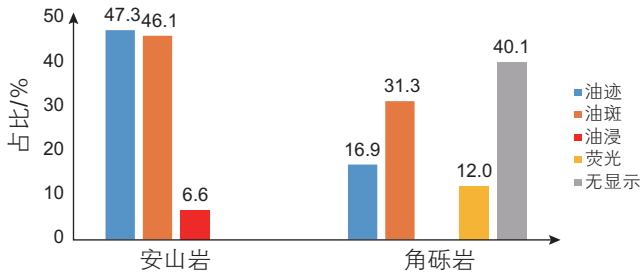


图 6 枣园油田安山岩块火山岩岩心含油性统计
Fig. 6 Oil-bearing properties of Mesozoic volcano rock reservoir in Zaoyuan oilfield

3.2.2 储层厚度

通过对研究区中生界开发井初期产能和累积产油的分析,可以看到单井产能有较大的差异。由单井累产油与储层厚度关系散点图可以看出研究区产能与储层厚度有一定正相关性,即随着储层厚度的增加,日产量和累产量均有所增大(图 8)。

3.2.3 裂缝发育程度

裂缝起到沟通储层内部孔隙的作用,是控制产能的关键因素^[22-25]。Sigma因子和方差属性能够体现裂缝的发育情况。Sigma因子代表着裂缝连通情况,其数值越大,连通的效果越好。结合本区几口高产井的裂缝发育模拟sigma剖面来看(图 9),枣 143 井位于裂缝发育带。而同样位于裂缝发育区域,但裂缝沟通距离较近,因此产能较差,如枣 1538-1 井。位于储层裂缝不发育的位置上,则低产或无产能,如枣 59 井。

方差属性值越大,裂缝发育的概率越大。本区方差属性对于裂缝的发育有较好的响应。本区的方差和单井产能分析结果表明,两者有着较好的正相关关系,单井产能高的位置对应方差属性高值区(图 10、图 11)。

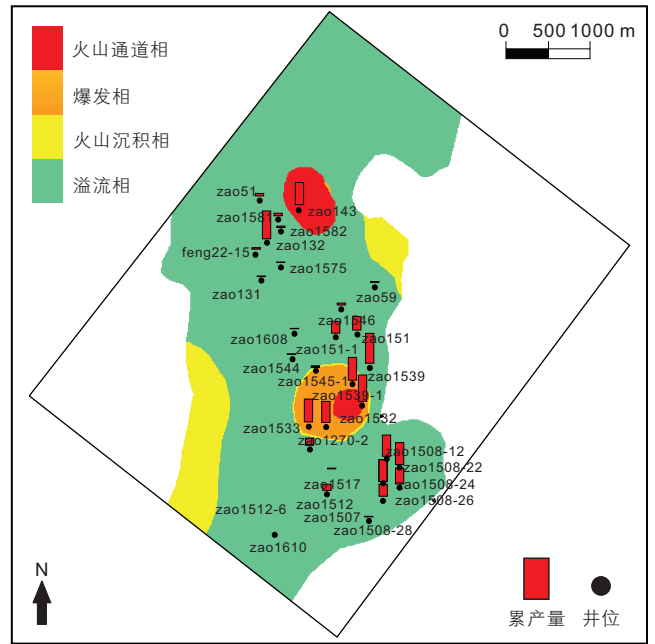


图 7 岩相与累产量叠合图
Fig. 7 Overlay map of lithofacies and cumulative production

3.2.4 油柱高度

油柱高度为油层顶面到油水界面之间的高程差。结合单井油柱高度和日产油、累计产油关系图,明确了油柱高度一定程度上和单井产量呈正相关。这是由于油柱高度越大,代表着单井控制储量越大,一旦被裂缝沟通,就会有较好的油气储量。除此以外,油柱高的井,多位于构造高点,受风化作用改善储层质量,因此产能较高(图 12)。

3.2.5 油井酸化措施

研究区中生界火山岩油藏受非均质性以及裂缝发育的影响,单井产能低,需要对储层进行酸化改造。主要针对产量较差的井进行了酸化处理,酸化前单井

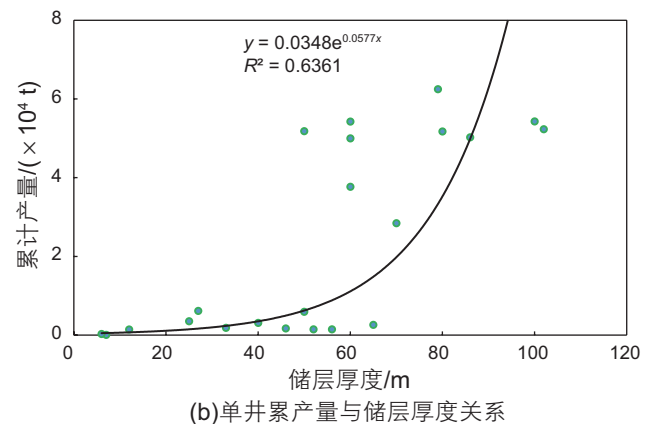
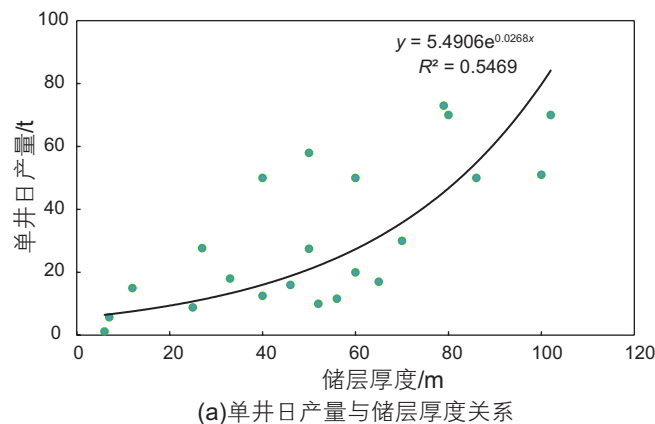


图 8 安山岩块单井产能与储层厚度关系
Fig. 8 Relationship between single well productivity and thickness of reservoirs

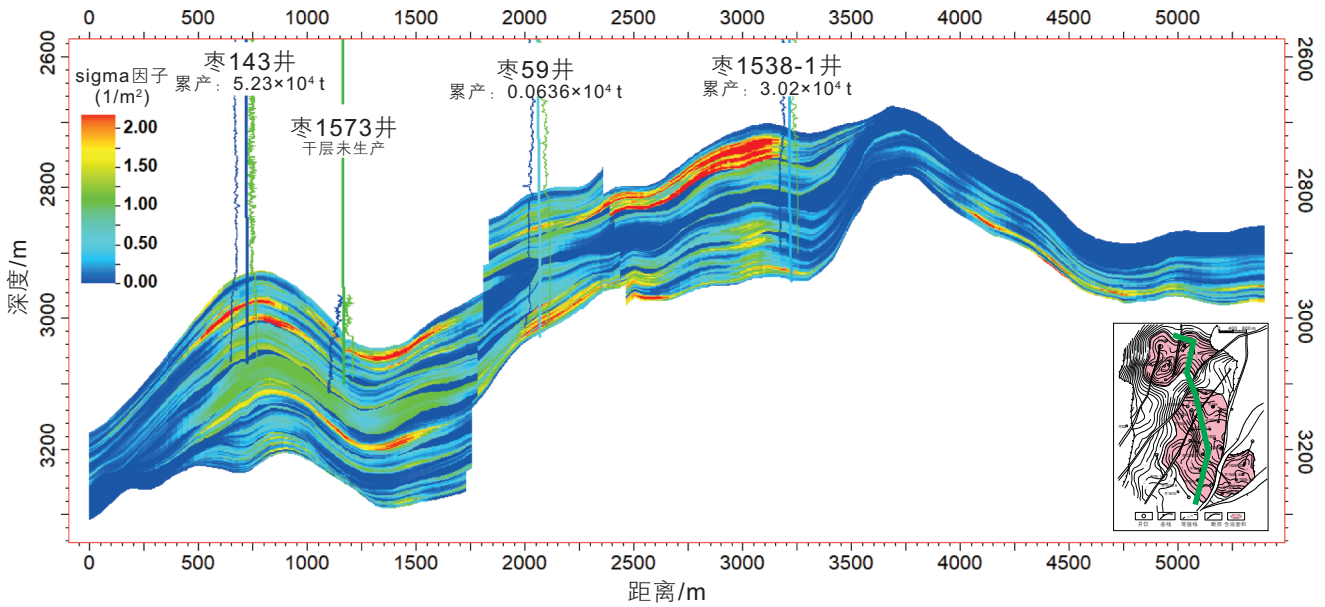


图9 枣园油田安山岩块井裂缝模拟sigma因子剖面

Fig. 9 Sigma factor profile of fracture simulation in Mesozoic volcano rock reservoir in Zaoyuan oilfield

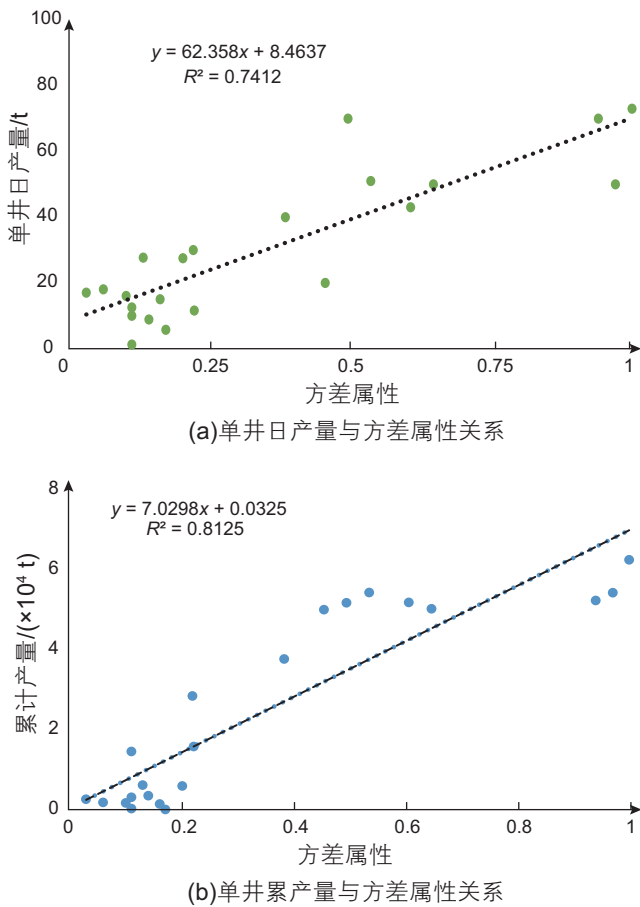


图10 安山岩块单井产能与方差属性关系散点图
Fig. 10 Scatter plot of relationship between single well productivity and variance attribute of andesite block in Mesozoic volcano rock reservoir in Zaoyuan Oilfield

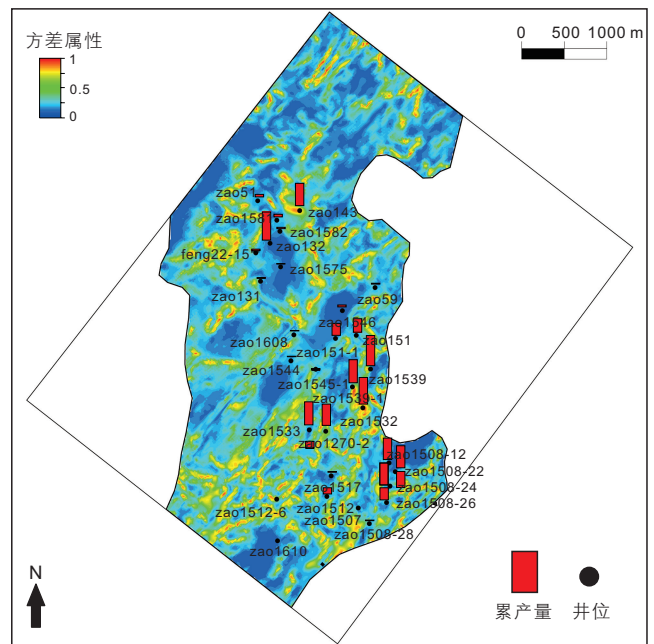


图11 枣园油田安山岩块方差属性与单井累计产量叠合平面图
Fig. 11 Overlay plan view of variance attributes and cumulative production of andesite blocks in Zaoyuan oilfield

日产油量为0~57 t, 平均单井日产量8.9 t。酸化后单井日产量为0.37~95.4 t, 平均单井日产量为20.2 t(表1)。酸化措施沟通了基质, 使产量上升。部分井由于边水能量较强, 导致产水量上升。

结合上述主控因素分析结果, 依据单井产量、钻遇储层厚度、岩性、岩相、油柱高度、裂缝情况以及

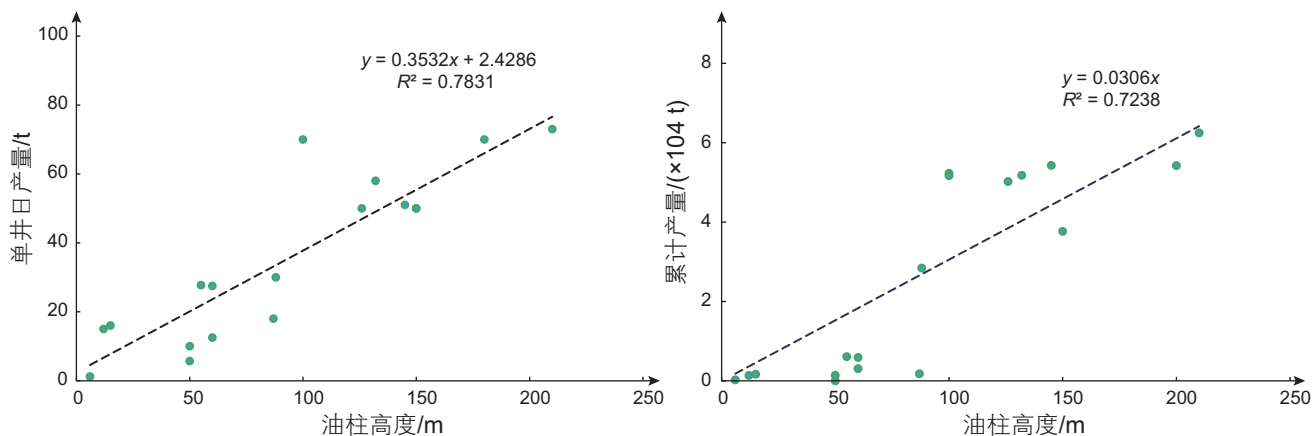


图 12 安山岩块单井产能与油柱高度关系散点图

Fig. 12 Scatter diagram of the relationship between single well productivity and oil column height in Mesozoic volcano rock reservoir in Zaoyuan Oilfield

油井措施情况将 3 类单井产能进行定量划分, 划分结果如表 2。

其中 I 类(产能稳定递减型)单井平均日产能大于 50 t, 最大可达到 100 t, 累产油大于 5×10^4 t。钻遇储层厚度大于 70 m, 火山岩性为安山岩和火山角砾岩, 岩相为爆发相和溢流相。单井油柱高度大于 150 m, 方差属性值大于 0.6, 对应裂缝发育, 储层沟通范围

大, 酸化措施效果好。

II 类(产能迅速递减型)钻遇储层厚度 35~70 m, 火山岩性为安山岩, 岩相为溢流相。单井油柱 90~150 m, 方差属性值介于 0.15 和 0.6 之间, 裂缝发育, 对该类井的酸化措施效果较好, 该类井钻遇裂缝数量相对较少, 裂缝沟通性差。

III 类(低产或无产能型)钻遇储层厚度小于 35 m,

表 1 枣园油田安山岩油藏单井酸化前/酸化后产量分析

Table 1 Production analysis of single well before/after acidification in andesite reservoir of Zaoyuan oilfield

井号	酸化井段/m	酸化前		酸化后		酸化效果
		日产油/t	日产水/m ³	日产油/t	日产水/m ³	
枣 1582	2980-2998.4	0	0.38	7.57	0	酸后见效、产量上升
枣 1546	2872-2880	0	0	3.91	3.46	酸后见效、产量上升
	2872-2880	3.91	3.46	7.38	0	酸后见效、产量上升
枣 1545	2714.65-2779.65	油花	1.3	4.3	16.1	酸后出水、产量上升
枣 1532	2718.0--2758.0	0.246	0	68.5	3.62	酸后见效、产量上升
枣 1517	2735.5-2793.0	20.6	13.2	21.1	2.07	酸后见效、产量上升
	2735.5-2793.0	5	0	15.4	0	酸后见效、产量上升
枣 1531	2786.0-2810.0	3.75	9.5	18.1	1.58	酸后见效、产量上升
枣 1270-2	2837.27-2863.0	0.124	0	15.7	1	酸后见效、产量上升
	2755.6-2863.0	57.6	0	95.4	0.96	酸后见效、产量上升
枣 1512	2840.0-2897.0	0	0	12.47	0.23	酸后见效、产量上升

表 2 枣园油田中生界火山岩油藏单井产能特征及分类标准

Table 2 Single well productivity characteristics and classification criteria of Mesozoic volcanic reservoirs in Zaoyuan oilfield

生产类型	产量		储层厚度/m	岩性	岩相	油柱高度/m	方差属性	措施效果
	日产油/t	累产油/10 ⁴ t						
I 类	>50	>5	>70	火山角砾岩、安山岩	爆发相、溢流相	>150	>0.6	好
II 类	10~50	0.1 ~5	35~70	安山岩	溢流相	90~150	0.15~0.6	好
III 类	<10	<0.1	<35	安山岩	溢流相	<90	<0.15	差

火山岩性为安山岩,岩相为溢流相。单井油柱小于90 m,对应方差属性小于0.15,裂缝不发育,单井油柱小于90 m,只能维持数月生产。

4 结论

(1)枣园油田中生界火山岩油藏储集空间以裂缝沟通的次生孔隙和原生孔隙为主;储层具有较强的非均质性,不同区域产能差异较大,受多种因素影响。

(2)产能主要受储层岩性、岩相、孔缝发育程度、油柱高度、开发措施等因素的影响。具体表现为溢流相中的安山岩以及爆发相中的火山角砾岩含油性最好;孔缝发育程度越高,单井产能相应的越高;油柱高度与单井产能有一定的正相关性,构造高部位的井产能相对较好;储层厚度也与产能有一定关系,储层较薄时受裂缝改造作用明显,产量随储层厚度增加而增大。酸化对于本区有较好的效果,能够将储层沟通起来,

可达到增产的目的。

(3)综合不同控制因素将研究区单井产能划分为3类:产能稳定递减型、产能迅速递减型及低产或无产能型。其中,产能稳定递减型的单井多位于火山岩体的构造高部位,该类型单井具有火山岩体内部裂缝发育、油柱高度高、酸化效果好的特点;产能迅速递减型井位于构造中部,裂缝相对发育较少,钻遇储量厚度中等且沟通能力相对较差,酸化效果差;低产或无产能型主要位于构造低部位,储层厚度小,储层致密且裂缝不发育。

(4)综合分析影响研究区单井产能的地质因素可以认为,火山岩储层自火山口出发向外随着岩相变化储层质量逐渐下降,后期风化改造作用以及构造裂缝的发育使构造高部位储层进一步变好。因此,火山岩中爆发相、溢流相的中高部位及构造裂缝多发区是单井高产地区,也是下一步开发的主力区。

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