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Evaluation of hydraulic fracturing results based on the analysis of geological field data

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Abstract. The relevance of the research is specified by the significant contribution of the oil produced as a result of hydraulic fracturing in the wells in its total production. A correct assessment of the results of actually carried out hydraulic fracturing will allow to develop clear recommendations on the further application of this method of oil production enhancement for the geological and physical conditions of specific fields. It was established that hydraulic fracturing in the well 221 of the Shershnevsky field (the Perm Territory, Russia) led to a change in interaction between wells within the entire element of the development system; it began to work as a single coordinated system. As a result of hydraulic fracturing, there was not just a redistribution of fluid drainage volumes. A synergistic effect arose when fracturing in one well led to an increase in fluid flow rates and coordinated operation of the entire element of the development system. It is likely that hydraulic fracturing in the well 221 led to a significant change in the geological and technological characteristics of the Bobrikovskian deposit of the Shershnevsky field to a greater extent than the volume of the drainage zone of this well. A whole system of channels with reduced filtration resistances appeared instead of a single crack, as is common in the classic representation of hydraulic fracturing.

It should be noted that the approach presented in the article is the first very important step in a comprehensive analysis of the effective reservoir development based on the results of field monitoring. In the future, it is necessary to attract more detailed information about the interaction of wells. Only such a multilevel analysis will allow to substantiate the general conclusion about the hydraulic fracturing on the development of a reservoir and to confirm conclusively the effect of wells on each other, which can be individual in different parts of the reservoir.

Keywords: hydraulic fracturing, terrigenous reservoir, interaction between wells, correlation of flow rates, method of enhanced oil recovery

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Introduction

Hydraulic fracturing (fracturing) is currently one of the most effective methods of stimulating oil production worldwide. An adequate assessment of the results of hydraulic fracturing allows, inter alia, evaluating the method prospects in certain geological and technological conditions (Cherepanov et al., 2015).

In the Perm Territory, a wide variety of hydraulic fracturing technologies are used, such as classic proppant fracturing in terrigenous reservoirs, acid proppant fracturing in carbonate reservoirs, acid fracturing with proppant fracturing, nitrogen foam fracturing, etc. (Cherepanov et al., 2015; Voevodkin et al., 2018).The effectiveness of these technologies is usually evaluated by the increase in oil production in wells – objects of exposure (Votinov et al., 2018; Tare A. Ganata et al., 2018). In addition to the increase in flow rate, in some cases technological efficiency indicators are also used such as additional oil production and the duration of the effect, calculating these indicators with respect to the wells where hydraulic fracturing was carried out (Valeev et al., 2018). This approach to assessing the results of hydraulic fracturing is due to the fact that this type of stimulation on the formation is usually attributed to the group of technologies for stimulating flow to wells. In particular, in the works (Kashnikov et al., 2018; Nurgaliev et al., 2017; Yakhina, 2018) it was shown that hydraulic fracturing is carried out in order to increase the reservoir permeability in the bottomhole zone and increase well productivity. However, some researchers (Nurgaliev et al., 2017; Tare A. Ganata et al., 2018; Debotyam Maity et al., 2019; Yuekun Xing et

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al., 2019) believe that hydraulic fracturing under certain conditions not only a way to increase the permeability of the bottom-hole zone, and, as a consequence, the productivity of a particular well, but also a deeply penetrating method of exposing the reservoirs in general.

The study of laws of fractures formation is one of the urgent tasks of monitoring hydraulic fracturing. Obtaining reliable information about the spatial position of the fracture(s) and its size will allow not only analyzing hydraulic fracturing in details, but also making justified decision on the appropriateness of replicating this technology to other wells in similar conditions (Jianming He et al., 2017; Voevodkin et al., 2018; Kulakov et al., 2018).

To date, a wide range of research methods and technologies exists and is used widely that allow controlling the process of creating fractures. The method for estimating hydraulic fracture parameters according to microseismic monitoring (MSM) has become widespread (Aleksandrov et al., 2007; Yew Kwang Yong et al., 2018; Lei Li et al., 2019). However, the support of all hydraulic fractures with microseismic monitoring is impractical for both economic and technological reasons (there are areas in which microseismic studies are inappropriate within the Perm Territory) (Alexandrov et al., 2007; Rastegaev et al., 2019).

Field geophysical survey and hydrodynamic well surveys hold a special place among other surveys. Their role is very significant, since these methods provide the predominant amount of information about hydraulic fracturing. It should be noted that the existing technologies for conducting and interpreting hydrodynamic well testing and field geophysical survey are of limited use for solving this problem and have a high potential for improvement and development (Ipatov et al., 2009).

In this regard, a technique seems to be relevant that allows us to solve this problem on the basis of a comprehensive analysis of field data (Tare A. Ganata et al., 2018; Chorny et al., 2019). The accumulated experience of hydraulic fracturing, accompanied by microseismic monitoring, made it possible to develop such a technique as applied to oil assets of the Perm Territory. The reliability of its results is confirmed by the materials of MSM (Rastegaev et al., 2019).

Thus, the availability of a reliable method for estimating hydraulic fracture parameters based on the integrated use of field data allows us to study the results of hydraulic fracturing even if the event was not accompanied by microseismic monitoring. The approach described further in the article is the first step in a comprehensive analysis of the effectiveness of reservoir development based on the results of field monitoring. This article presents the results of solving this problem in relation to the Shershnevsky field.

General information about the object of study

This article provides information on the results of hydraulic fracturing carried out at well 221 of the Shershnevsky oil field (the Perm Territory, Russia) (Fig.1). The well exploits the terrigenous Bobrikovskian deposit. The placement practically in the central part of the structure is its characteristic feature. The deposits of the Bobrikovskian horizon are mainly represented by quartz sandstones, sometimes with interbeds of mudstones and siltstones unevenly clayey, areas of very sandy before transition to sandstone. Sandstones, different-grained with various oil manifestations – from oil effusions in pores to complete oil saturation, can be attributed to channel alluvium, to which industrial oil content is confined. Brief information on the geological and physical characteristics of the operation of well 221 of the Shershnevsky field is presented in Table 1. Information on the other six oil producing wells participating in the assessment of hydraulic fracturing is presented in Table 2.

Standard approaches to determine technological efficiency made it possible to evaluate the results of hydraulic fracturing in this well as very high for the region. The well production rate increased almost three times, the effect persisted for more than 2000 days.

This article has conducted a study of hydraulic fracturing affecting not only on the performance of the well itself – the fracturing object, but also on the nearest surrounding wells, that is, on the element of the development system as a whole. So, in the immediate vicinity of well 221 considered in the article, there are six production wells (No. 64, 214, 215, 222, 228, and 229), which together form a "conditional" first annular row (Fig. 1).

Study of the interaction between wells before and after hydraulic fracturing

If hydraulic fracturing performed in well 221 had a deeply penetrating character, it should be manifested in a change in technological efficiency indicators, i.e. the nearest producing wells should "respond" by changing the values of their production indicators (Nurgaliev et al., 2017; Mukhametshin, 2018; Yudin et al., 2018). To test this hypothesis, field materials were studied and statistically analyzed – oil and liquid production rates, as well as accumulated oil and liquid production values for all wells of the selected development element (Galkin et al., 2017).

At the first stage, performance indicators were compared in the periods before and after hydraulic fracturing. In this case, the indicators before hydraulic fracturing are assigned to class 1 (the sample amounted to n = 69 values), after hydraulic fracturing – to class 2 (n = 81 values). Comparison of average fluid flow rates for grades 1 and 2, that is, before and after hydraulic

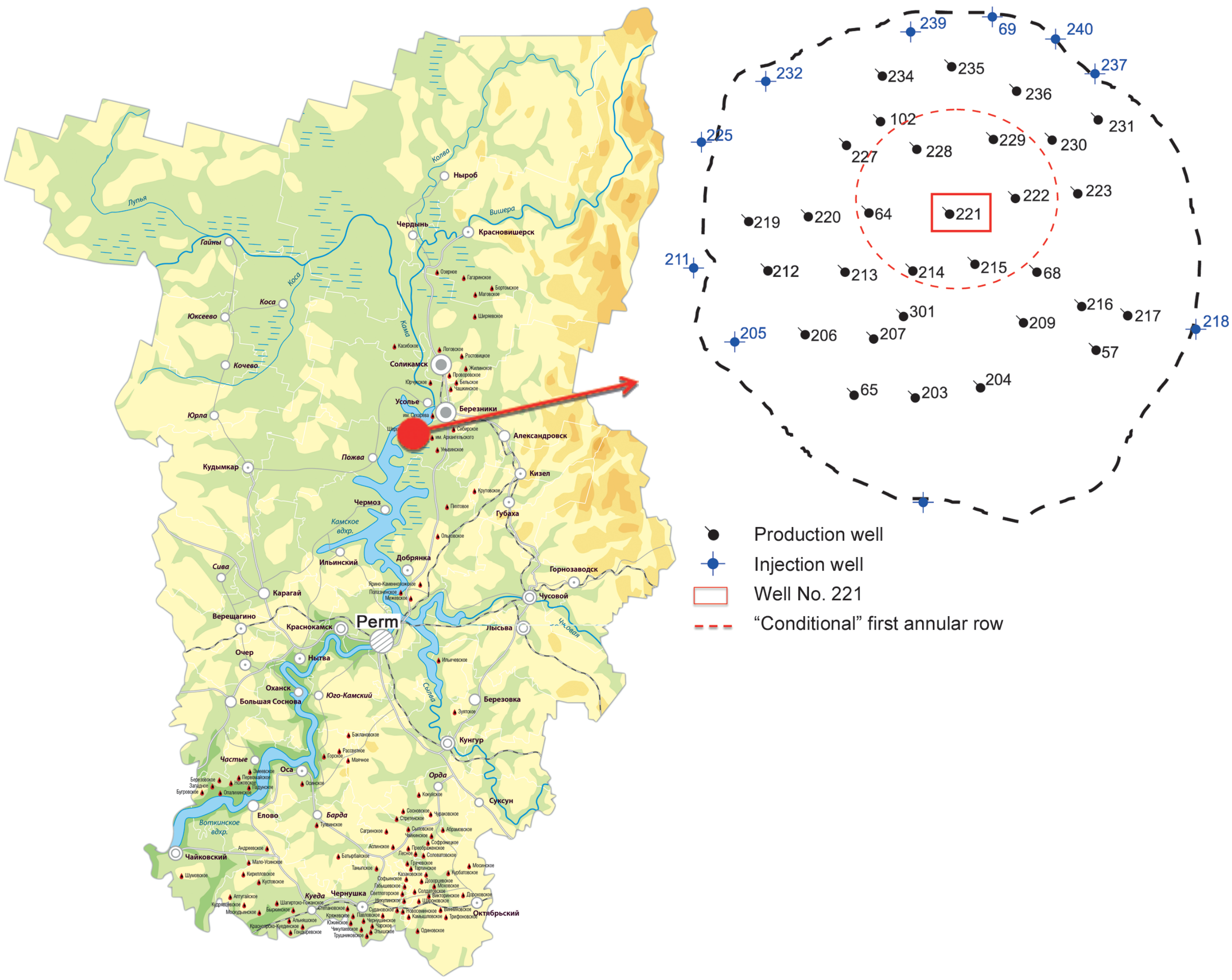

Fig. 1. Map of the location of the Shershnevsky field in the Perm Territory with scheme of the development system element of the Bobrikovskian deposit

fracturing, was performed using mathematical statistics tools (Student’s t-test and Pearson’s-χ^2 criterion), the comparison results are shown in Table 3.

It can be seen from the table that truly statistical criteria confirm a significant change (increase) in fluid flow rates after hydraulic fracturing for all wells of the selected element of the development system, and not just well 221, the object of the hydraulic fracturing.

As a graphic illustration, a combined graph of the dependence of Q_H on t for all wells was constructed (Fig. 2). It can be seen from the figure that after the hydraulic fracturing, well 221 underwent a restructuring of the system as a whole, which can be well confirmed using regression analysis. In the first case, the connection has the following form: $Q_H = -18.834 + 0.001158$ t, at r = 0.041, p = 0.3628; in the second: $Q_H = -212.265 + 0.006001$ t, with r = 0.3611, p = 0.0000. This shows that the change in the system of values of Q_H in time actually occurred.

A similar conclusion was also obtained by comparing oil production rates, cumulative oil and fluid production, typical for the periods of operation before and after hydraulic fracturing. That is, hydraulic fracturing at well 221 led not only to an increase in its production rate, but also to the production rates of all neighboring wells located in close proximity. That is, hydraulic fracturing of well 221 cannot be considered as a geological and technical measure aimed only at intensifying the inflow directly to this well.

It should also be noted that in all cases, the cause of the increase was not the conduct of any other geological and technical measures. That is, the assumption that as a result of hydraulic fracturing, a simple redistribution of drainage volumes between neighboring wells in favor of the well being affected is also not correct, since in this case there would be a decrease in the flow rates of neighboring wells.

For a more detailed analysis of the obtained data, a correlation analysis was used, the results of which are shown in Table 4.

In order to visualize the obtained results, we constructed schemes for changing the correlation

No.	Indicator name, units	Value
1	Absolute elevation of the roof, m	-1846
2	Net oil pay,m	9.9
3	Viscosity of formation oil, mPa*c	3.19
4	Gas saturation of reservoir oil, m^3/t	64.2
5	Bubble-point pressure, MPa	11.94
6	Porosity coefficient, unit fractions	0.17
7	Net-to-gross sand ratio, unit fractions	0.6
8	Average number of permeable intervals, unit fractions	3.21
9	Permeability coefficient (defined by field geophysical survey data), $micron^2$	0.096
10	Water cut before hydraulic fracturing, %	1.0
11	Bottom hole pressure before hydraulic fracturing, MPa	9.55
12	Reservoir pressure before hydraulic fracturing, MPa	12.97

Table 1. Brief information about the well – fracturing object

Well No.	Permeability coefficient, $micron^2$	Net oil pay,m	Reservoir pressure before hydraulic fracturing, MPa	Bottom hole pressure before hydraulic fracturing, MPa	Water cut before hydraulic fracturing, %
215	0.909	8.7	11.59	10.25	1.0
222	0.206	10.8	12.92	10.06	0
229	1.716	11.2	11.21	9.79	0
228	0.111	14.7	12.78	11.76	2.0
64	0.456	5.4	13.10	11.71	3.0
214	0.078	12.6	12.77	9.77	5.0

Table 2. Brief information about the operating parameters of adjoining wells participating in the hydraulic fracturing assessment

Well No.	Statistical performance indicators		Comparison criteria*	
	Class 1 (before HF)	Class 2 (after HF)	Student's t-test	Pearson's-χ^2 criterion
221	19.4±16.1	40.8±6.7	$\frac{-10.847}{0.000}$	$\frac{99.603}{0.000}$
64	21.9±17.6	48.1±12.1	$\frac{-10.724}{0.000}$	$\frac{85.483}{0.000}$
214	13.8±13.7	22.9±3.7	$\frac{-5.773}{0.000}$	$\frac{36.027}{0.000}$
215	29.1±14.4	37.4±5.0	$\frac{-4.833}{0.000}$	$\frac{29.127}{0.014}$
222	36.1±15.9	60.3±8.9	$\frac{-11.681}{0.000}$	$\frac{135.111}{0.014}$
228	30.5±6.6	43.7±3.9	$\frac{-14.997}{0.000}$	$\frac{134.260}{0.000}$
229	47.6±12.9	55.9±5.8	$\frac{-5.228}{0.000}$	$\frac{24.509}{0.014}$

*Table 3. Comparison of the average values of fluid flow rates (m^3/day) before and after hydraulic fracturing for wells of a selected element of the development system. *Note: the numerator shows the value of the criterion, the denominator shows the level of its significance.*

coefficients between oil production rates within the development element before (Fig. 3) and after hydraulic fracturing (Fig. 4).

The analysis of the diagram in Fig. 3 shows that for the period preceding the hydraulic fracturing, the maximum positive correlations are characteristic of a pair of wells 221-214, that is, these wells worked concertedly, they simultaneously responded to any events with a unidirectional change in their production rates. The eastern part of the development element is characterized by a rather strong negative correlation. That is, an increase in the flow rate of well 221 led to a decrease in the same indicator in wells 215 and 222.

It is likely that the increase in flow rate of well 221 was due to the redistribution of drainage volumes from the eastern part of the selected development element.

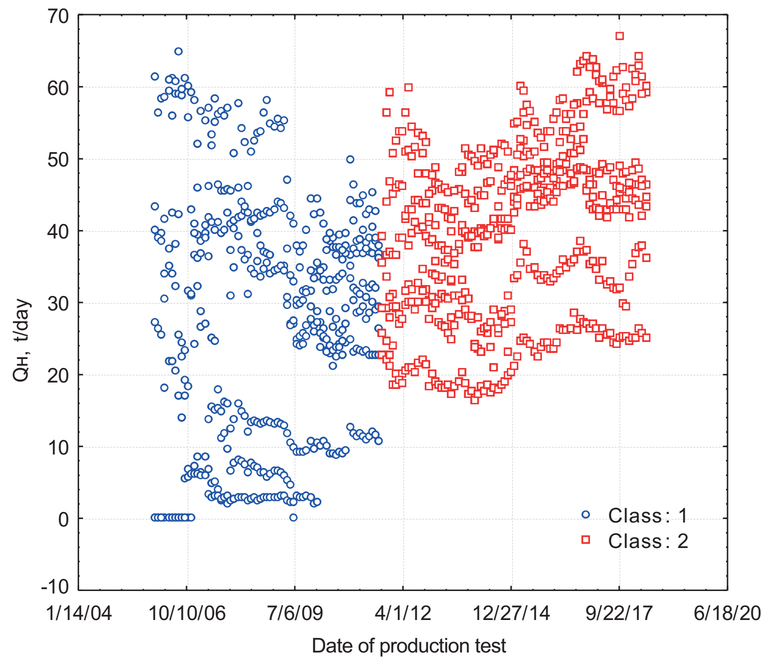

Fig. 2. The change in Q_H in time for producing wells before and after hydraulic fracturing

Well	221	64	214	215	222	228	229
221	1.00 / 1.00	-0.10 / 0.68*	0.65* / 0.63*	-0.72* / 0.69*	-0.81* / 0.64*	0.24* / 0.69*	-0.17 / 0.54*
64		1.00 / 1.00	0.57* / 0.93*	-0.29* / 0.83*	-0.23 / 0.67*	-0.05 / 0.72*	-0.52* / 0.73*
214			1.00 / 1.00	-0.74* / 0.82*	-0.74* / 0.72*	0.13 / 0.76*	-0.45* / 0.81*
215				1.00 / 1.00	0.82* / 0.75*	-0.02 / 0.69*	0.32* / 0.74*
222					1.00 / 1.00	-0.08 / 0.53*	0.38* / 0.74*
228						1.00 / 1.00	-0.13 / 0.79*
229							1.00 / 1.00

Table 4. The correlation matrix between the oil production rates of wells of the selected development element (the numerator is before hydraulic fracturing, the denominator is after hydraulic fracturing) Note: -0.65 – significant correlation*

Analysis of changes in the values of the correlation coefficients after hydraulic fracturing clearly demonstrates a significant change in the behavior of the entire selected element of the development system as a result of hydraulic fracturing in well 221. Significant positive correlations are noted within the first annular series between the flow rates of all wells. That is, the whole element began to work as a single unidirectionally coordinated system. The positive nature of the correlation indicates that as a result of hydraulic fracturing, there was not just a redistribution of drainage volumes, but a synergistic effect arose when an event in one well led to an increase in flow rates and coordination of the work of the development system entire element.

Conclusion

The conclusion obtained during the research indicates that the generally accepted model of the hydraulic fracturing result, which consists in visualizing the fracture within the drainage zone of the well – the fracturing object, and in some cases only within the bottom-hole zone of this well, does not reflect the picture that occurred on the Bobrikovskian deposit of Shershnevsky field. It is likely that hydraulic fracturing in well 221 led to a significant change in the filtration parameters of the Bobrikovskian deposit to a greater extent than the volume of the drainage zone of this well. Obviously, on a rather large section of the reservoir, a whole system of channels with reduced filtration resistances arose, rather than a single fracture, as is the

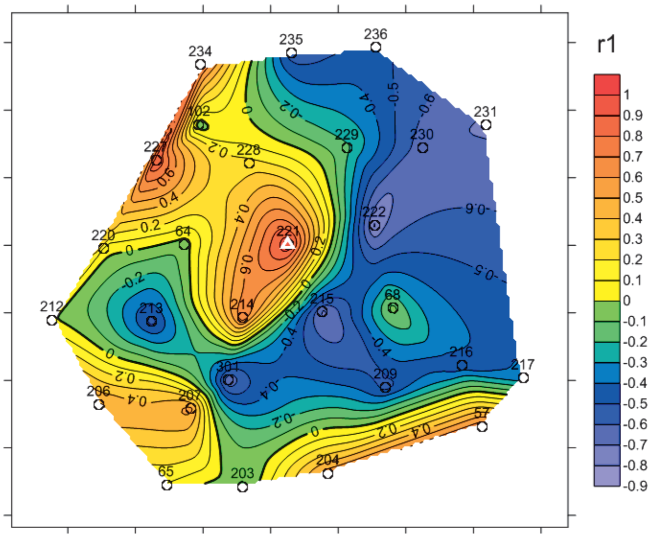

Fig. 3. Scheme for changing the values of the correlation coefficients between oil production rates within the development element before hydraulic fracturing

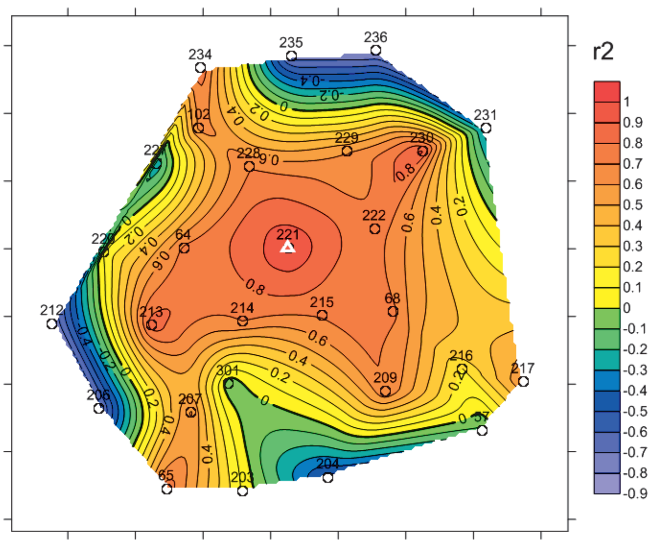

Fig. 4. Scheme of changes in the values of the correlation coefficients between oil production rates within the development element after hydraulic fracturing

case in the classical representation of the use of hydraulic fracturing data. In relation to the hydraulic fracturing field under consideration, it should be considered not as a single, point-based method of stimulating oil production due to an increase in the productivity of the well – the object of impact, but even, to some extent, as a method of increasing oil recovery. It should be noted that the approach described in the article is a very important first step in a comprehensive effectiveness analysis of the deposits development according to the results of the control. The next step in analyzing the effectiveness of hydraulic fracturing is to draw detailed information on the interaction of wells based on long-term monitoring of bottom-hole pressure and costs with the obligatory involvement of information on geological and technological measures carried out in each well. Such a multi-level analysis will allow not only to substantiate the general conclusion about the effect of hydraulic fracturing on the development of a reservoir, but also to confirm conclusively the effect of wells on each other, which can be individual in different parts of the reservoir.

Of course, the singularity of the study does not allow us to draw conclusions about the need to review approaches to assessing the results of hydraulic fracturing. It seems appropriate to conduct similar studies on other wells in this and other regions.

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