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Application of Self-Potential Method to a Vapor Dominated Reservoir, Matsukawa Geothermal System, Japan

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ABSTRACT

A set of repeat self-potential (SP) surveys was conducted at the Matsukawa geothermal field, Japan for the purpose of detecting the change of subsurface fluid flow system in a vapor dominated reservoir caused by well operations. Surface SP was measured around the reservoir range before and after shut-in of the wells for annual maintenance. As a result, change of SP at several measurement points, which may correspond to the phase change of subsurface fluid and the change of flowing direction of liquid phase, was observed near the main reservoir area. Thus SP monitoring can be applied for vapor-dominated reservoir to investigate the existence of liquid phase around the reservoir.

Introduction

Self-potential (SP) measurements have been conducted for geothermal field exploration and, recently, also for reservoir monitoring assuming that the main cause of the SP anomaly is streaming potential. Several authors have been reported the change of SP distribution after fluid production at liquid dominated geothermal reservoirs, such as Cerro Prieto (Goldstein et al., 1989), Mexico, Mori (Ishido and Pritchett, 2000), Sumikawa (Matsushima et al., 2000), and Yanaizu-Nishiyama, Japan (Tosha et al., 2000), etc. The application of continuous SP measurement on reservoir monitoring has been studied for Hachijojima (Nishino et al., 2000) and Mori (Yasukawa et al., 2001). Yasukawa et al. (2001) also introduces a practical procedure for interpretation of continuous SP data.

This paper presents the possibility of SP monitoring for vapor dominated geothermal reservoirs. It might be difficult to identify the changes of SP at steam reservoirs caused by well operations due to the fact that the streaming potential for steam is almost zero. Nevertheless, existence of small amount of liquid water may enable the use of SP observations to detect the movement and the phase change of the reservoir fluid caused by well operations.

Authors conducted repeat SP observations at the Matsukawa geothermal field, Iwate, Japan where geothermal steam has been produced for Matsukawa geothermal power station since 1966. In 2002, surface SP distribution was widely measured three times, before shut-in, after shut-in and after re-opening of the wells for annual maintenance of the power plant. The result shows the change of SP around the major production zones. The possible mechanism of SP change for vapor-dominated reservoirs will be discussed in this paper.

The Matsukawa Geothermal Area

The Matukawa geothermal field is located in the Hachimantai volcanic region in northeastern Honshu, Japan (Figure 1). The

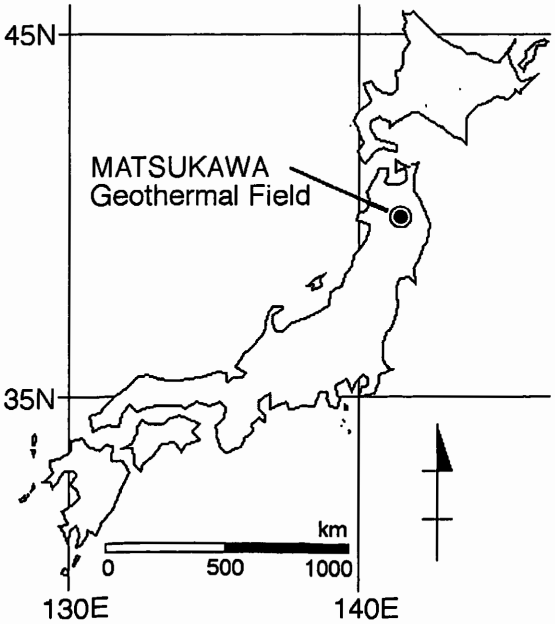

Figure 1. Location of the Matsukawa geothermal field.

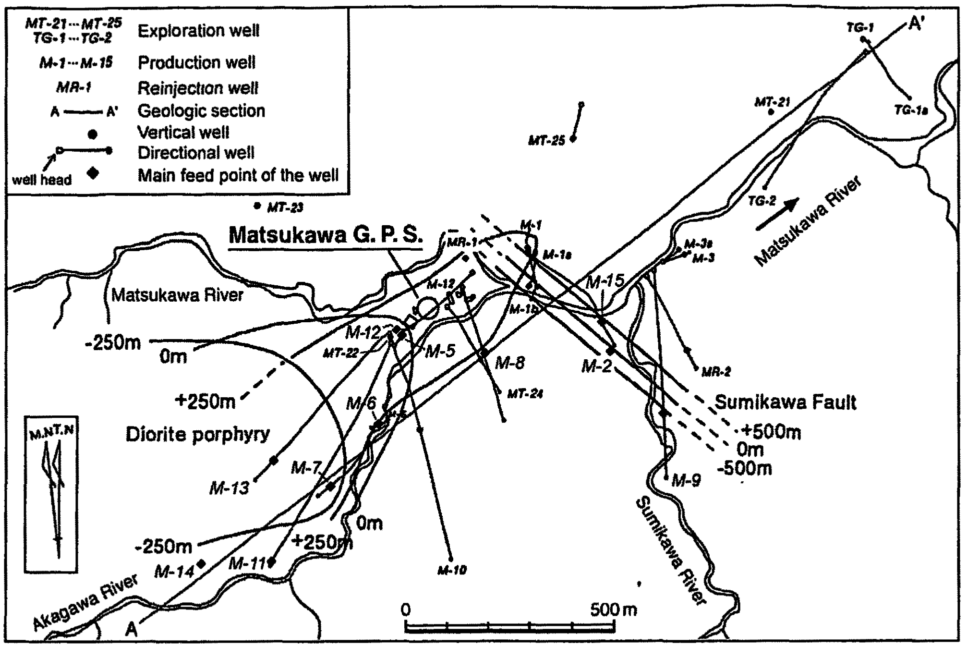

Figure 2. Location of the wells and geological structures of the Matsukawa area (Ozeki et al., 2000).

elevation of this field is about 850 m above sea level. In this area, geothermal exploration had been initiated by Japan Metals and Chemicals Co. LTD. (JMC) and Geological Survey of Japan (a part of present AIST, Institute of Advanced Industrial Science and Technology) since 1952. JMC has started power generation since 1966 as the first geothermal power station in Japan. Currently this system has the characteristics of a vapor-dominated reservoir, although it had two-phase zones at the beginning of fluid production. Water injection has been examined since 1988 to support reservoir pressure and to maintain steam production (Hanano et al. 1993, Hanano, 2003). The effect of injection has been evaluated through several monitoring methods including tracer tests.

The Matukawa geothermal field is located along the Matsukawa river (Figure 2) The Quaternary Matsukawa Andesite is widely exposed to the surface of the field. The Matsukawa geothermal reservoir consists of the Quaternary Matsukawa Andesite, the Pliocine to Pleistocine Tamagawa Welded Tuffs, the Miocine Takinoue-onsen Formation, the Kunimitoge Formation and the diorite porphyry (Figure 3). From central to southwestern part of the field, the reservoir is seated along the Akagawa river, while to the northeast is along the Matsukawa river.

SP Survey at Matsukawa

A repeat SP survey in Matsukawa was conducted in 2002 as follows:

1st SP survey;	27 May – 29 May
2nd SP survey;	17 June – 18 June
3rd SP survey;	9 July
Shut-in of the wells;	6 June – 28 June

The first survey was conducted before the shut-in of the wells. The second and third surveys are about 10 days after shut-in and opening of the wells, respectively. Note that not all production wells were shut-in during this period but only M-14, M-7, M-13, M-6, M-15 and M-9 were shut-in while the others were continuously open as shown in Figure 4 (no flow-rate change). Reinjection from MR-1, for which tracer returns are identified at wells M-12 and M-1, continued over the period at a flow rate of 15 – 30 tons/hour. The number of SP survey points is 74 (Figure 4). The survey line makes three loops, eastern, western and southern loops, so that the measurement errors can be corrected as enclosure errors. Central to southeastern points were not measured at the third survey because of the bad weather.

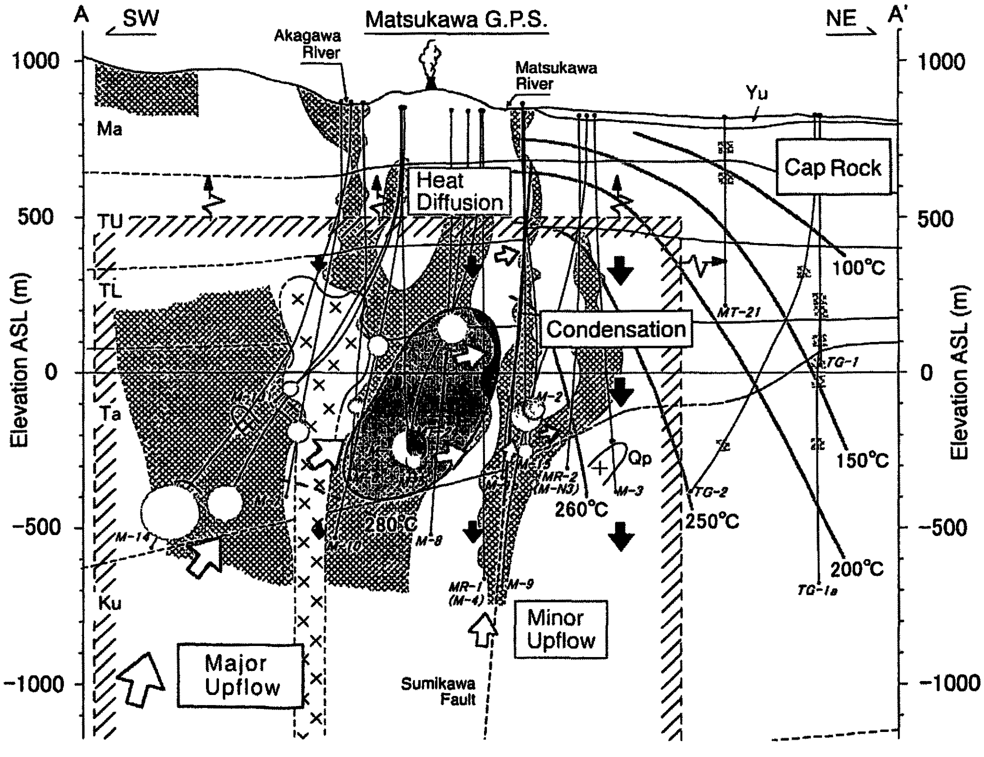

Figure 3. Geological cross-section and reservoir model of the current state of the Matsukawa area (Ozeki et al., 2000).

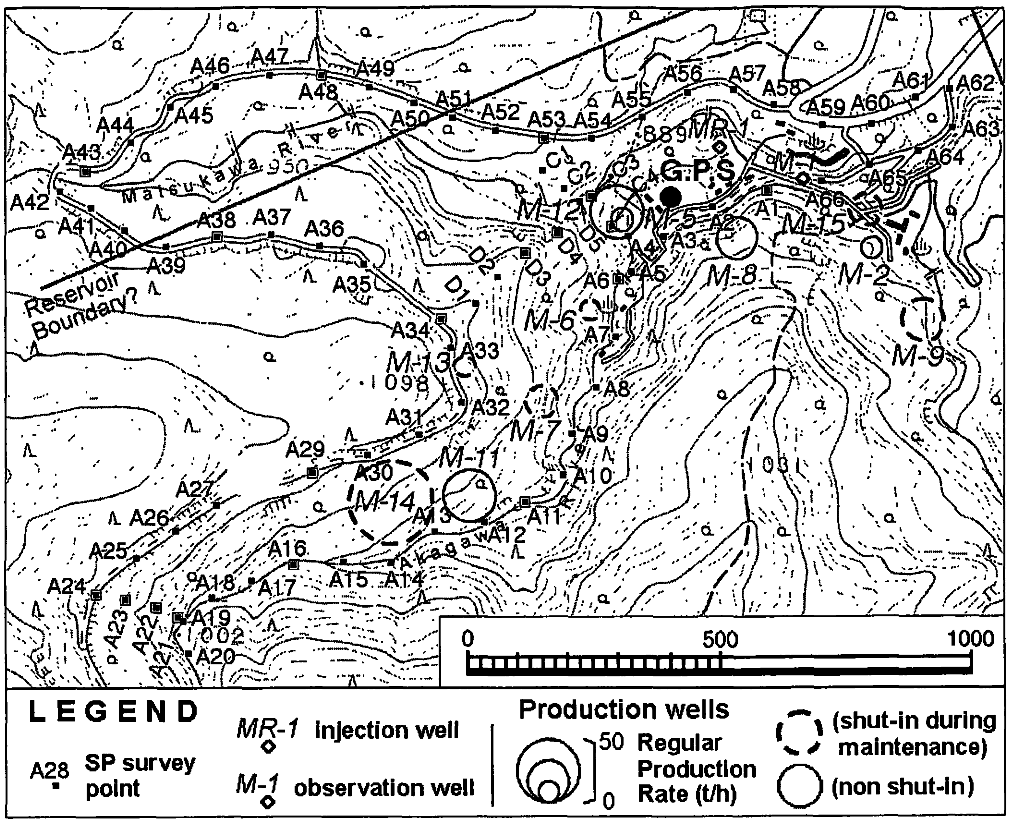

Figure 4. Locations of SP survey points (A0–A65, C1–C4 and D1–D5) and feed point of the production wells indicated by circles. Size of the circle indicates the production rate. The wells with dashed circles were shut-in during annual maintenance while solid ones were not shut-in. The reservoir boundary is suggested by Ozeki et al. (2000).

The resultant SP profiles of the loops are shown in Figures 5 to 7, respectively with elevations of the survey points. The zero point of the potential is set to the average of A43 – A50 since these points are considered to be outside the reservoir boundary and, as a result, the SP profile along these points was quite stable through the period. The maximum enclosure error of 50.9 mV, corresponding to an average error of 3.9 mV at each connection point, occurred for the south loop in May due to the time variation without well operation.

Distinctive spike-shaped SP anomalies at A2, A3 and A4 in Figure 5, A42 in Figure 6 are all because of artificial conductive structures such as bridges and pipelines. A34 and A35 in Figures 6 and 7 are also located beside a bridge. Extremely large negative anomalies from A26 to A32 and D1 in Figures 6 and 7 may be derived from volcanic intrusion shown in Figure 2 as diorite porphyry.

Although the time variation of SP is smaller than its spatial variation, notable time variations of SP are observed for some zones. Figure 8, overleaf, shows the change of SP distribution before and after the shut-in of the wells (SP_{June}-SP_{May}). Dark areas show the zones of positive SP change, where successive two or more survey points indicate positive change higher than 5 mV. The areas enclosed by dashed lines are the zones of negative SP change in the same manner as the positive ones. These positive and negative SP change zones are approximately aligned in NE-SW direction along Matsukawa and Akagawa rivers, where the

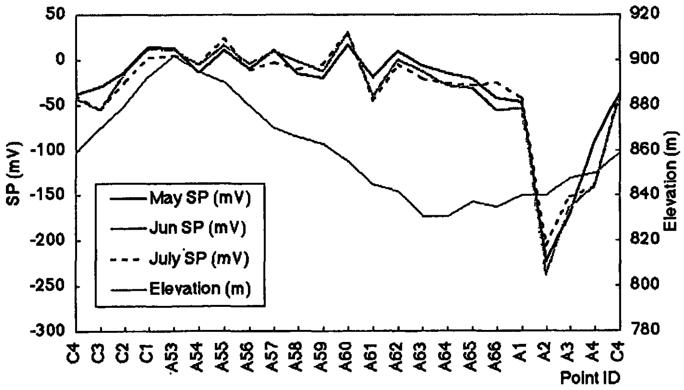

Figure 5. Observed SP profile for eastern loop.

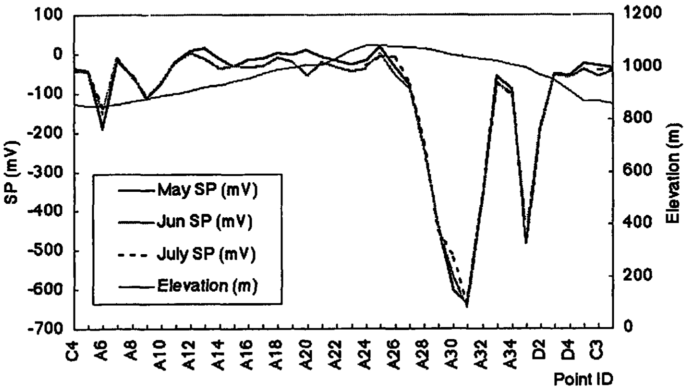

Figure 7. Observed SP profile for southern loop.

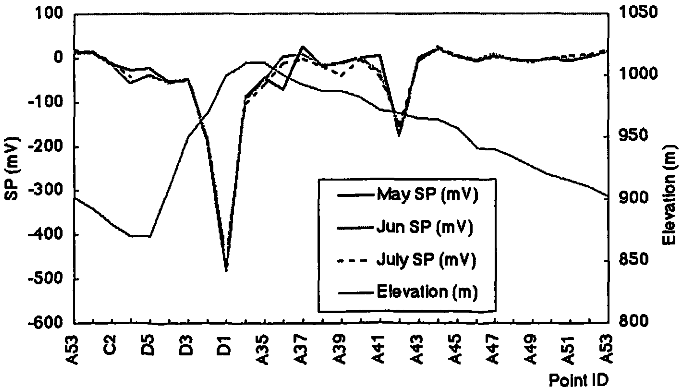

Figure 6. Observed SP profile for western loop.

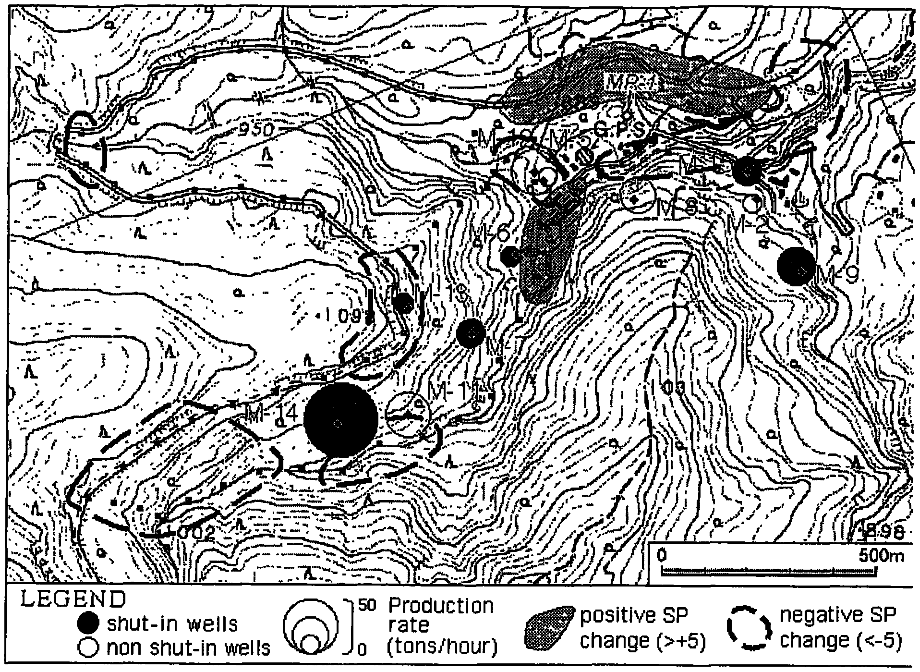

Figure 8. The change of SP distribution before and after the shut-in of the wells (June - May).

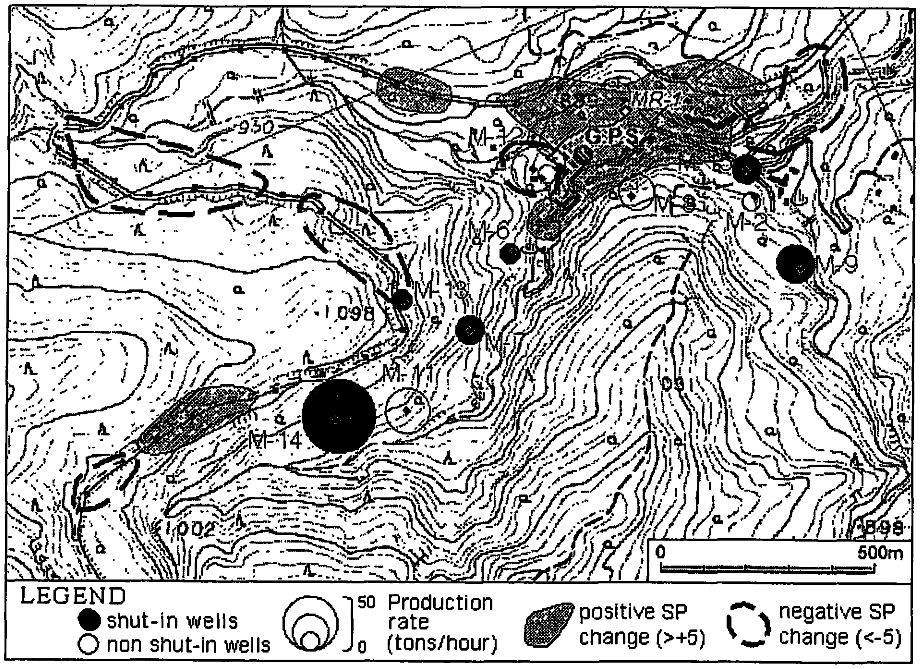

Figure 9. The change of SP distribution before shut-in and after the opening of the wells (July – May).

major reservoir is located. Near the shut-in wells M-14, M-13 and M-15, negative zones appear. Negative and positive zones appear around well MR-1, into which reinjection was continued over the period.

Figure 9 shows the change of SP distribution before shut-in and after re-opening of the wells (SP_{July}-SP_{May}). Compared to Figure 8, the negative zone at the northeastern end shrinks and the positive zones, separated by negative zone in Figure 8, emerge into one around the reinjection well MR-1. Also at the southwestern end, negative zone shrinks and positive zone appears. The negative zones at the north and southeast of M-14 disappear while negative zones appear in the northwestern part of the field.

Discussion

After shut-in of the wells, shown in Figure 8, negative SP changes were observed at the surroundings of shut-in wells M-14, M-13, and M-15. It can be interpreted that the subsurface pressure increase after shut-in pushed down the liquid phase, which causes negative streaming potential. However, since this reservoir is vapor dominated and no liquid phase exists in the very vicinity of the feed-point of the wells, the negative SP change appeared at the surroundings, a few hundred meters from the well. This phenomenon is quite clear in case of M-14 because its regular production rate is highest (70 tons/hour) and it is located in the southwestern end so that the interference from the other wells is small.

After re-opening of the wells, shown in Figure 9, positive SP changes were observed near M-14 and M-15. It may be the opposite phenomenon as the case of shut-in described above: pressure drop around the well pulls up the water level, which causes positive streaming potential. It is interesting that negative SP change was widely observed at the central to northwestern part. It may not be the effect of re-opening of the wells; but probably the effect of shut-in of wells M-14, M-13, M-7 and M-6 slowly traveled to this zone by this time, 30 days after shut-in. Existence of a two-phase zone might have delayed the pressure transmission. Thus this zone may have a weak hydrological connection with the main reservoir.

The mechanism of positive SP changes observed at northeastern part is not quite clear because there are interferences of many production wells and a injection well, some of which were not shut-in during the period. In addition, since streaming potential appears as a result of combination of both vertical and horizontal flows (Yasukawa et al., 2003), the mechanism explained above, which is based on vertical flows only, must be too simplified to describe the real phenomenon. Phase change is also an important factor for SP data interpretation for steam-dominated fields. Therefore, for more detailed interpretation, numerical modeling with proper physical parameters is essential.

Nevertheless, part of the observed data shows the result that seems reasonable to explain by the simplified mechanism of streaming potential. The fact that distinctive SP changes were observed at several zones of the reservoir range is also an important result of this study. It shows that some liquid phase still exist in the reservoir, which is consistent with Hanano et al. (1991), which describes the condensation in the reservoir. The result also suggests that SP monitoring can be applied to steam dominated reservoirs as well as liquid dominated reservoirs

Conclusions

Repeat SP surveys were conducted at the Matsukawa geothermal field, a steam dominated geothermal reservoir. As a result, distinctive SP changes from 5 to 30 mV were observed at several zones. It suggests that liquid phase still exists in the reservoir and SP monitoring can be applied also to steam dominated reservoirs.

After shut-in of the wells, negative SP changes were observed at the surroundings of shut-in wells. It might be because that the subsurface pressure increase pushed down the liquid phase. Since no liquid exists in the very vicinity of the wells, negative SP change appeared few hundred meters apart from the well.

After opening of the wells, positive SP changes were observed near shut-in wells, which probably because of the opposite mechanism as shut-in. Negative SP change was observed at the central-western part, probably because that the effect of shut-in slowly traveled to this zone. It suggests that this zone has a weak hydrological connection with the main reservoir.

For more detailed interpretation, numerical modeling with proper physical parameters is essential.

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