LESSONS LEARNT IN USAGE OF PRESSURE WHILE DRILLING (PWD) TO JUSTIFY DRILLING DECISIONS

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ABSTRACT

Pressure-While-Drilling (PWD) is a pressure sensor installed as part of the bore hole assembly (BHA) on the drill string. The PWD tool provides real time measurement of the pressure in the annulus at depth and can be used to monitor hole conditions such as the clearing of cuttings or used in early detection of well control issues. During Mercury's previous drilling campaign in 2016-2017, a methodology was developed by the reservoir engineering team to use the data obtained from PWD to quantitatively determine well capacity in real time. This information can then be used in lieu of the traditional stage test (which can induce additional cost for rig time) to drive drilling decisions such as side-tracking, deepening or early completion of the well. The PWD methodology yielded useful results during the 2016-2017 drilling campaign and therefore, the similar methodology was applied in the 2019-2020 campaign on two production wells and one injection well drilled.

This paper presents the lessons learnt from the usage of PWD in Mercury's 2019-2020 drilling campaign and provides specific examples of the drilling decisions that were made based on the PWD methodology. This paper also highlights the limitations of the PWD methodology and covers recommendations to improve the speed and accuracy to translate the PWD results into well capacity during a drilling campaign.

1. INTRODUCTION

Mercury's 2019-2020 drilling campaign consisted of two production wells and one injection well drilled in Kawerau and Rotokawa high temperature geothermal field (Figure 1) to fulfil fuel supply and injection requirements to the power plants.

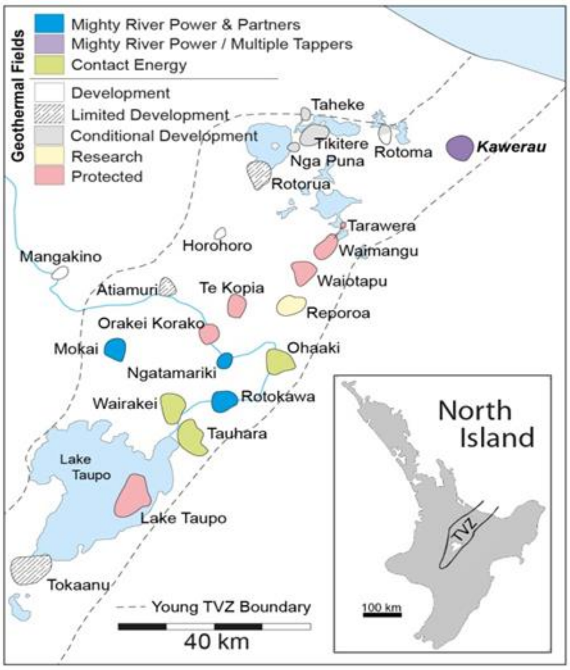

Figure 1: Geothermal Fields in the Taupo Volcanic Zone, North Island, New Zealand.

The PWD tool is a sensor placed within the BHA (Figure 2) and provides annular pressure data in real time during the drilling. The annular pressure measurement had been used previously to monitor hole conditions while drilling (an increase of annual pressure while drilling may indicate ineffective removal of cuttings). In the previous Mercury campaign in 2016-2017, a methodology was developed by the reservoir engineering team to continuously monitor the injectivity index (II) of the well using the annular pressure measurement and subsequently translating the II into a well capacity. While the results of the PWD methodology yielded conservative results of well capacities, it was found that information obtained was useful to aid the drilling decision process (Le Brun and Azwar, 2021).

Based on the learning and the methodology from the 2016-2017 drilling campaign, this method was applied in lieu of the standard stage testing method during the 2019-2020 drilling campaign to determine when the targeted permeability is reached and the well can be completed or alternatively, drilling to continue or side tracking is required.

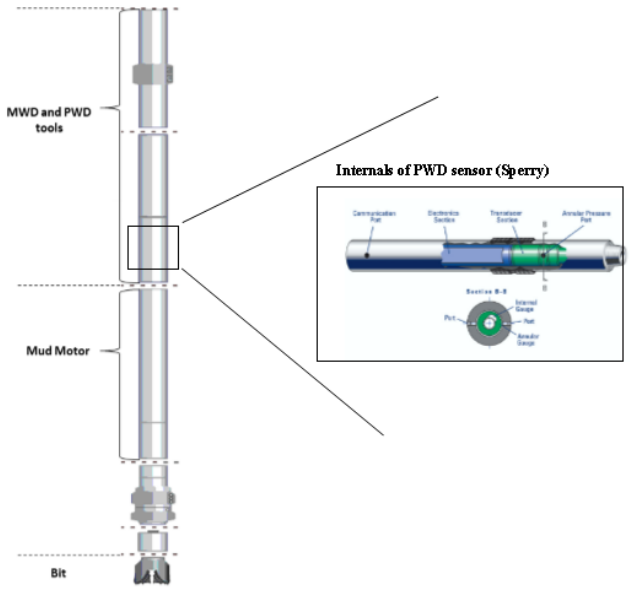

Figure 2: Schematic of the PWD tool and approximate location on the bore hole assembly (BHA).

2. METHODOLOGY

2.1 Setting Injectivity Index Drilling Targets and Drilling Decision Tree

In the planning for the drilling campaign, the production and injection capacity requirements were set for each well (i.e. mass flow and enthalpy for production well to provide fuel supply and injection flowrate requirements for injection wells). These requirements are then converted into equivalent II (t/h/bar) to produce a drilling decision tree (Figure 3). Le Brun and Azwar (2021) details the method of the conversion from production/injection requirements into II.

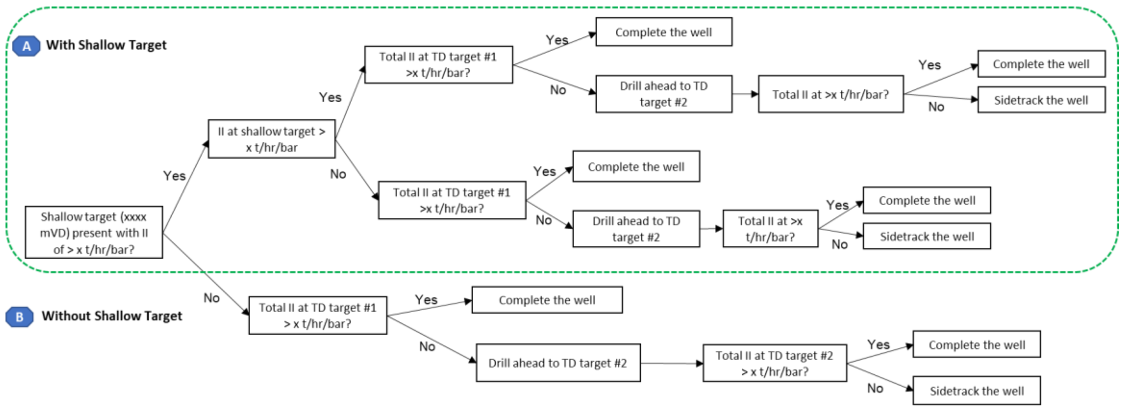

Figure 3: Decision tree example of a well drilled in the 2019-2020 drilling campaign.

The decision tree example in Figure 3 is for a production well drilled in the campaign. As there are information from the offset wells that have been producing for a number of years, the drilling target depths and target permeable zones can be determined. Therefore, the II requirements will differ depending on whether or not the permeable zone is encountered during drilling. Without the utilisation of PWD, the decision tree above would require up to three stage tests to determine if the target has been reached and this will increase the rig time required.

2.2 Analysing the PWD Data

The main parameters used for the computation of the II are the total flow in the well (Q_{in}), total flow out of the well (Q_{out}), total losses (Q_{loss}), pressure in the wellbore during drilling (P_{inj}) which is equivalent to the annular pressure measurements from the PWD tool and the reservoir pressure (P_{res}) at the depth drilled. These parameters are shown in Figure 4.

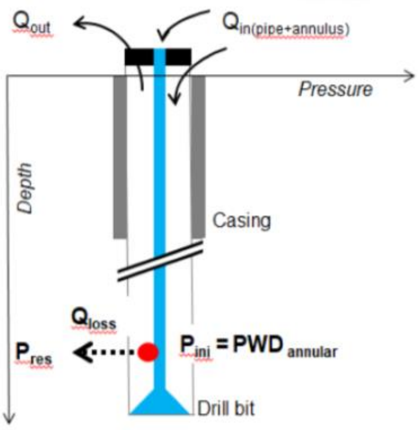

Figure 4: Elements Used in PWD II Calculation (Le Brun and Azwar, 2021)

Le Brun and Azwar (2021) details two methods in calculation of II using PWD data. For day-to-day monitoring of the II during the drilling, the first method used was to calculate the II from the flow measurements available on the rig (rig pumps and flow meters) and the estimated reservoir profile:

$$II = \left(\frac{Q_{loss}}{P_{inj} - P_{res}}\right) \text{ where } Q_{loss} = Q_{in} - Q_{out} \quad (1)$$

When there are only partial losses experienced, the loss calculation will then be verified against the losses measured by the mud loggers as the calculated MWD losses are always higher than what is measured by mud loggers. This error in loss calculation can cause the overestimation of II when there are only partial losses. The high uncertainty during partial loss measurement is caused by the flow measurement method of flow returns from the well (i.e. Q_{out}).

The second method used to calculate the II requires two different loss rates at the same depth (preferably near the bottom hole) and two wellbore pressure profiles and these can only be acquired during a trip out of the well. The II is defined using the following formula:

$$II = \frac{Q_1 - Q_2}{P_1 - P_2} \text{ where } Q_i = \text{loss rates and } P_i = \text{ annular pressure at the depth} \quad (2)$$

This method can be used as a sense check to the II calculated using flow measurements and/or mud logger losses to reduce the uncertainty in the results. In the comparison between the two methods, the pressure gradient measured during the tripping out of the well more accurately represents the near wellbore reservoir pressure during drilling.

The PWD II results are then converted to a range of estimated capacity and compared against drilling targets on the drilling decision tree.

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3. RESULTS AND DISCUSSION

This section evaluates the performance of PWD as a decision making aid for each well and where available, a comparison of the actual well performance against PWD II results.

3.1 Injection Well #1

Injection well #1 was drilled in a known injection area therefore the reservoir pressure could be constrained using a shut PTS from an offset well. The well encountered total losses shortly after commencing drilling into the reservoir section and this can be seen in the step change in annular pressure as measured by PWD (Figure 5a). The reservoir pressure gradient is also plotted against the annular pressure measured while tripping out for a bit change and shows that the gradient used in the II calculation was representative of nearby reservoir pressure. Based on the losses measured, the II calculated from the loss zone was found to have exceeded the target set for drilling completion (Figure 5b).

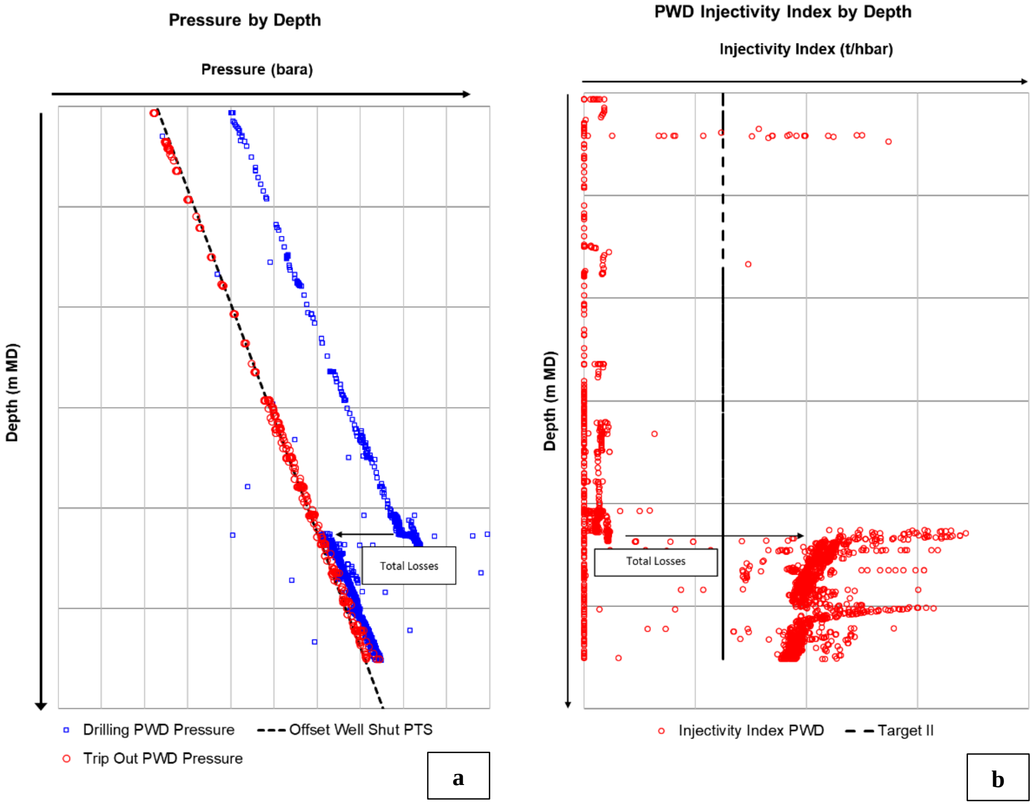

Figure 5: a) Annular pressure measured from PWD during drilling with total losses and reservoir pressure used. b) II calculated in the loss zone in comparison with target II.

There results from the PWD was enough to assure the well delivery team that the well capacity target had been achieved. Although the target capacity was achieved, the decision was made to step-down and continue drilling to secure more permeable zones. This was made in consideration with the experience of decline observed in offset wells and to reduce amount of potential interference during full injection. Despite the continued drilling, the well was able to be completed at a shallower TD than planned, saving on rig time.

Subsequent completion testing showed that the total capacity of the well exceeded the target capacity set during the drilling campaign. However, as the PWD tool was not used in the final hole section to reduce risk of losing tools in hole, the total II measured during the completion test could not be compared against the total II measured during drilling.

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3.2 Production Well #1

Production well #1 was drilled in an area that was considered a step-out of the known production area. During the drilling in the reservoir section, only partial losses were observed in the 12 ¼" hole section. This was made complicated by issues experienced with flow meter measurements (in particular return flow measurements and flows into the annulus) which caused an increased uncertainty in the II calculations (Figure 6). Where there are low partial losses, the II calculated from PWD can differ by a magnitude of 2-3 times if only the rig flow meters are used. The well experienced total losses after stepping down to the 8 ½" hole section however, subsequent drilling issues stopped the progress to TD. The completion test conducted indicated that the total injectivity was 2.5 times higher than the final PWD II calculated (Figure 6b).

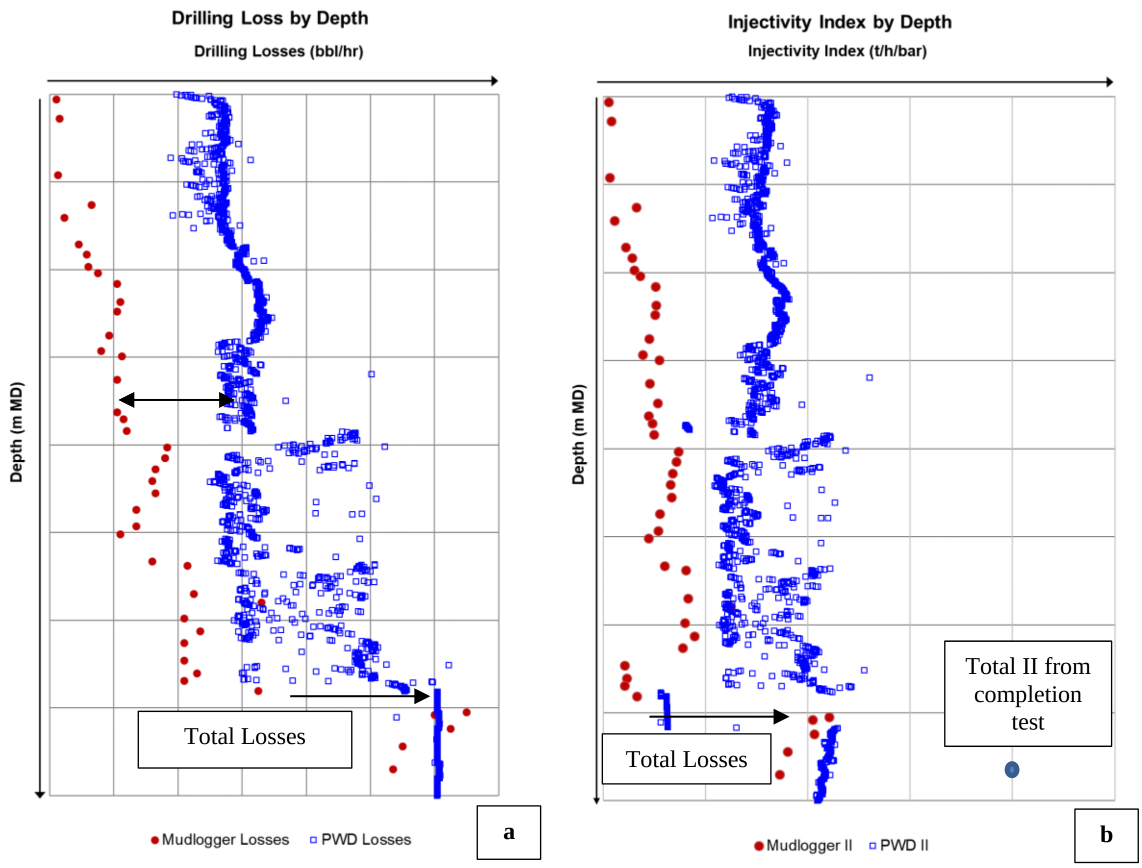

Figure 6: a) Drilling loses by depth calculated using flow meters in comparison with losses recorded by mud loggers through tank level. b) II calculated from mudlogger losses compared to II calculated from rig flow meters

Based on the experience with PWD while drilling production well #1, it is recommended if only partial losses are encountered in the reservoir section and issues with flow meter accuracy had not been resolved, doing a stage test with a downhole tool and rig pumps should be the preferred option to reduce uncertainty in the decision making.

3.2 Production Well #2

Production well #2 was drilled in a known production area to replicate the success from offset wells. There were two distinct feedzones observed in the offset wells, where the shallow feedzone has excess enthalpy compared to the liquid deep feedzones. Therefore, the drilling decision tree shown in Figure 3 is dependent on the PWD II of each feedzone. In this well, the main methodology applied to calculate the II is using the pressure gradient during the trip out as a proxy for reservoir pressure. This method reduces uncertainty between the effects of sustained injection during drilling (resulting in near wellbore temperature and pressure changes) and the known reservoir pressure.

Figure 7 shows the evolution of pressure and drilling losses by depth. The well encountered total losses after a few hundred metres into the reservoir section (permeable zone 1). Based on the drilling decision tree, the drilling continue until the total target II was achieved with the permeable zone 2 and plans were made to drill a rathole after TD target is reached. While drilling the rathole, another permeable zone (permeable zone 3) was encountered and to preserve the permeable zone, the programme was extended by another stand. As the drilling of the additional stand progressed, another permeable zone (permeable zone 4) was detected by the PWD. The total II measured with PWD was 1.5 times the II requirement for well completion.

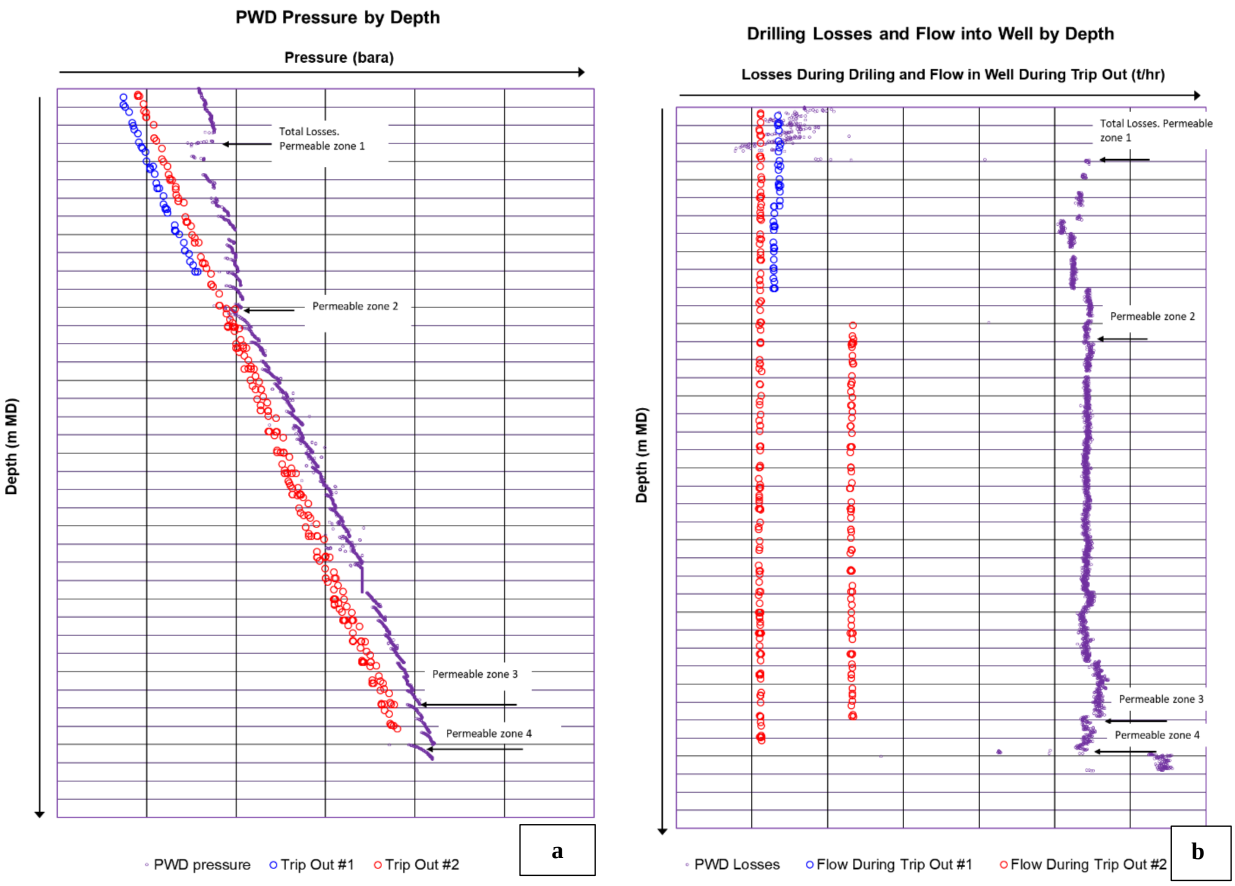

Figure 7: a) Annular pressure measured using PWD while drilling and tripping out. b)Drilling losses calculated by PWD and flows into the well during a trip out

The series of feedzones encountered indicated potential fracture network at a geological contact. The permeable zones were compared to offset wells and hole condition were evaluated to weigh the risk between drilling deeper to secure more potential feedzones or to complete the well as planned. In the end, the decision was made to step down in hole size and for drilling to continue to a new target TD to target the similar deep of an offset well. Confidence in the total II measurement from PWD was sufficient to avoid the additional cost of well testing. Drilling of the new hole section did not include PWD to reduce the risk of losing the tools in hole therefore no total II results are available for comparison.

4. CONCLUSION

The methodology and templates to analyse PWD data into well capacities continuously during the drilling was developed in the 2016-2017 campaign. Based on the success from the last campaign, the well delivery team in the 2019-2020 campaign adopted the same approach to assist in the decision making for well completion and deepening without the use of stage tests.

The main limitation of the PWD method (as with the previous campaign) is the accuracy of the return flow measurements which affects the drilling loss calculations. This is most pronounced during the drilling of the production well where only partial losses were encountered. In situations where results from PWD are marginal, it is highly recommended to run a traditional stage test using the wireline tool.

In terms of data processing, the current method for analysis and quality control manually intensive as it requires the processing of data every 30 seconds. The improvement scope for the analysis is to automate the quality control and plotting of the data to further improve the speed of decision making.

Despite the limitations, the methodology developed was proven again to be a valuable factor in the decisions that were made in the 2019-2020 drilling campaign. In one well, the II calculated from PWD was used to decide on the early on early completion of a well as capacity targets had been secured and in another, PWD data was used to justify the deepening of a well to secure more fuel supply. These proven results and potential payback should be considered against the cost of running and/or losing the tool for future drilling campaigns.

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