

BULALO WELL NO. 30 GEOTHERMAL RESIDUE SUBSURFACE INJECTION

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ABSTRACT

In 1999 and 2000 PGI finalized a plan and injected solid residues that had accumulated through continuous operation of the Bulalo geothermal field. The disposal process used was designed to be consistent with both UNOCAL environmental policy and that of the local environmental regulators, and was a direct application of the principles of solids injection and hydraulic fracturing. Over a period of seven months, a total of around 7,560,000 kilograms of solid residues was successfully injected into an injection well located at the south of Bulalo Geothermal Field. Bulalo Well No. 30 was chosen among other candidate injectors for this project. The well was selected through a process that considered various factors such as wellbore integrity, distance from nearby water sources and formation characteristics. The injection was carried out in batch modes where the solid residues were ground into finer particles, made into a slurry, and then injected into the well. The initial response of the well was characterized by low wellhead pressure injection. This is typical of natural fracture fill-up. During the latter stages of the injection project, higher injection pressures caused hydraulic fracturing which contributed to the success of the injection process.

1.0 INTRODUCTION

The development of Bulalo Geothermal Field, located at the southwest flank of Mt. Makiling, Laguna, Philippines (Figure 1), has resulted in an accumulation of significant volumes of solid residues in the form of silica scales as well as geothermal sludge.

Silica scales are recovered from pipelines and pressure vessels during routine maintenance shutdowns. Such residues are formed by precipitation of silica (SiO₂) from the

geothermal fluid when silica solubility decreases due to temperature reduction. Geothermal sludge mainly comes from the cooling tower basins as well as from the wellsite holding ponds.

A characterization of the residues in 1992 showed some samples containing heavy metals beyond background concentrations. Table 1 shows the result of the Maximum Leachate Load Test (MLLT), where levels of As, Cr and Pb exceed the standard for water. In the table, S1 and S2 are silica scale samples. S3 is a sample from a satellite station holding pond and S4 is a cooling tower sludge sample. In the absence of an established standard for water from the Philippine Regulatory Agencies, the US-EPA Limit was used as the standard.

A comprehensive approach to the problem required a program that would include collection, transport, storage and, finally, disposal of the residues.

Table 1. Residue Characterization Test (MLLT) Results

	S1, ppm	S2, ppm	S3, ppm	S4, ppm	Std, ppm
As	47	48	10	1.986	5.0
Ba	15.05	3.65	6.25	0.881	100
Cd	-	0.40		0.06	1.0
Cr	5.8	6.3	5.5	13.603	5.0
Hg	0.11	0.0145	0.014	0.004	0.2
Pb	2.8	26.25	3.8	15.705	5.0

Source: Cement Fixation Study of Geothermal Sludge and Silica Scales, UP-NEC, 1992

Philippine Geothermal, Inc. advocated subsurface injection to dispose the accumulated geothermal scales and sludge. The project had the approval of the Department of Environment and Natural Resources (DENR), as well as the Laguna Lake Development Authority (LLDA).

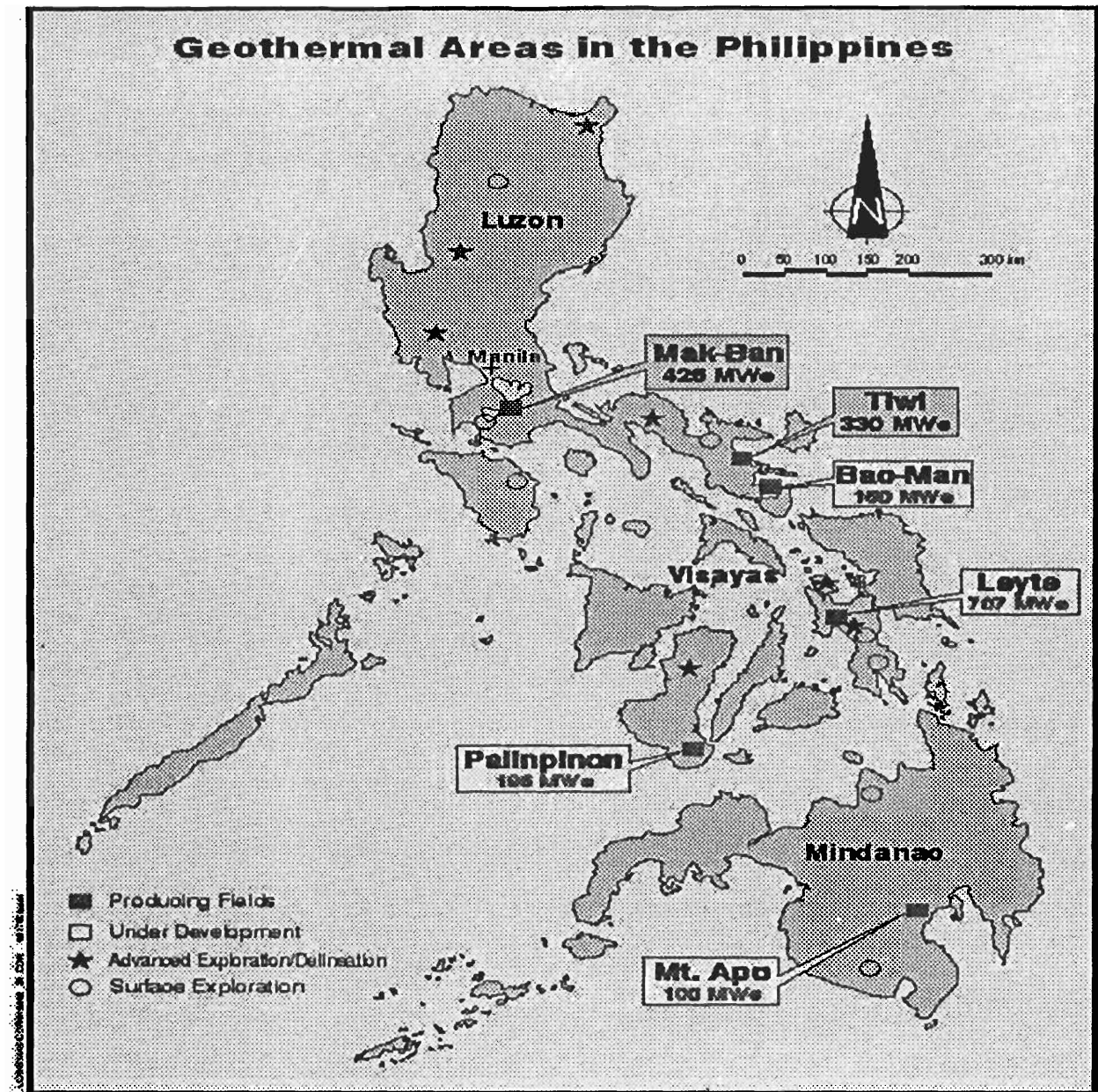


Figure 1. Location map of Bulalo Geothermal Field, Mak-Ban Contract Area

2.0 PROJECT SCOPE

The entire project was implemented following a comprehensive program which included the following:

- Development of a process for selecting the injection well.
- Development of a process for residue handling.

- Development of the grinding mixing and injection system.

2.1 Well Selection

Three existing wells were considered for the disposal of the geothermal residues in Bulalo Field. The main considerations that formed part of the criteria (PGI, 1997) in selecting the most appropriate well are:

- The well has structural integrity to withstand the expected injection pressures.
- The well is outside the production limit of the field to ensure that the injection process will not have an adverse effect on the production capacity of the geothermal reservoir.
- The well has sufficiently deep casing such that the possibility of contaminating the surface and/or groundwater resources is remote; and
- The well is not of economic or commercial importance.

Using the criteria listed above, Bulalo Well No. 30 was selected among the candidate wells. The well is located at the south of the Bulalo Field.

To further ensure that the well had the necessary integrity to perform this job, a workover was done prior to the start of the injection. New 5-1/2" injection tubing was installed and the wellhead was also upgraded to ANSI 1500 series. Figure 2 shows the schematic of the upgraded wellbore of Bulalo Well No. 2.

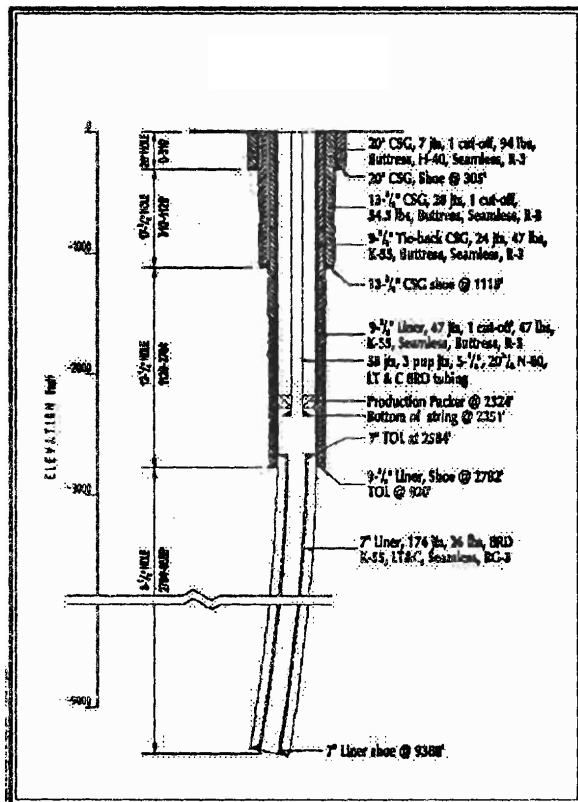


Figure 2. Bulalo Well No. 30 Wellbore Schematic

2.2 The Residue Management Process

Three main steps were included in the process of preparing the residues prior to grinding and actual injection:

- **Residue Collection** – Both the scales and sludge were collected from the various sources and stored in well-contained drums. Proper inventory and complete labeling were made to ensure control.
- **Hauling/Transport** – After containment in well-sealed drums, the residues were hauled to the sorting area at the Bul-30 wellsite. A transfer manifest system was implemented and proper measures were taken to contain possible spills during transport,
- **Residue Sorting** – The transported residues were unloaded into a sorting pad and a segregation process was done. All the non-residue materials, mostly metal scraps and plastics, were separated and power washed. They were later collected and transferred for surface disposal. The sorted residues were then stored inside a covered structure prior to grinding.

2.3 The Grinding, Mixing and Injection Process

The main processes involved in the preparation of the scales and sludge for injection were grinding and slurry mixing. The injection is carried out in batches, each batch consisting of around 64 m³ of slurry with densities that ranged from 1090.4 kg/m³ to 1138.4 kg/m³.

Grinding

All the sorted geothermal residues were passed through a weigh-bridge for mass monitoring. They were then made to pass through the grinding equipment, which mainly consisted of rolls crusher and centrifugal shear pumps. The time it takes to grind the residues to the desired particle size varies. It greatly depends on the hardness of the processed material for a particular batch. The desired particle size was maintained by the installed shale-shakers in the grinding system. Initially, the first shaker was set at mesh 48 (381 x 10⁻³ mm) and the final shaker was set at mesh 60 (234 x 10⁻³ mm). During the course of injecting the slurry batches, the final shaker screen was

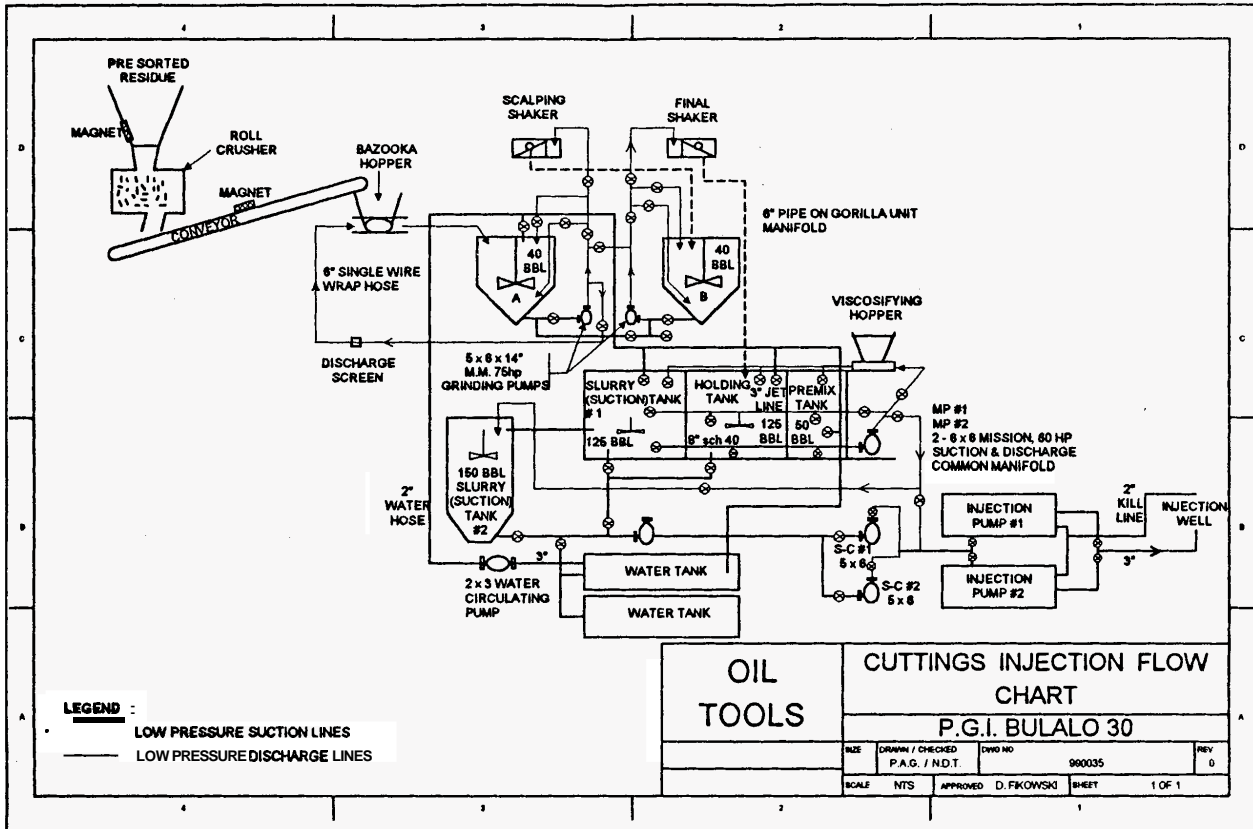


Figure 3. Bulalo Well No. 30 Injection Grinding Process Diagram

changed to mesh 45 (279×10^{-3} mm) to increase throughput.

Figure 3 shows the grinding process diagram.

Slurry Mixing

The processed residue slurry is stored in a 48 m^3 horizontal tank and a 24 m^3 vertical storage tank. Both tanks have agitators that keep the slurry to the desired consistency.

Two slurry types have been formulated over the entire duration of the project: the first slurry type was a simple mixture of residue and water. The second type had Guar gum as an added viscosifier. Guar gum was used primarily to raise the viscosity and thus increase the carrying capacity of the fluid. A viscosity of 40 sec/qt was achieved with the addition of Guar gum in the mix. The pH of the slurry was closely monitored to ensure effectiveness of the Guar gum.

Injection

Actual injection was carried out in batches. Each batch consisted of around 64 m^3 of processed slurry.

During the first stages of the injection, the slurry was prepared by mixing ground residue with water. The slurry density ranged from 1090.4 to 1102.4 kg/m^3 . After injecting each batch, a 175 m^3 water flush was pumped. The flush was intended to clean the wellbore and push the residue away from the wellbore vicinity.

A viscosified slurry made out of guar gum mix was adopted for the succeeding batches as soon as the injection wellhead pressure rose to around $8,274 \text{ KPa}$. The increasing injection wellhead pressure indicated that the natural fractures within the wellbore vicinity may have slowly filled up.

There were two main reasons for the shift to a viscosified slurry. First, each batch needed to have more residues to constantly keep the mass of injected material within the target. Guar gum

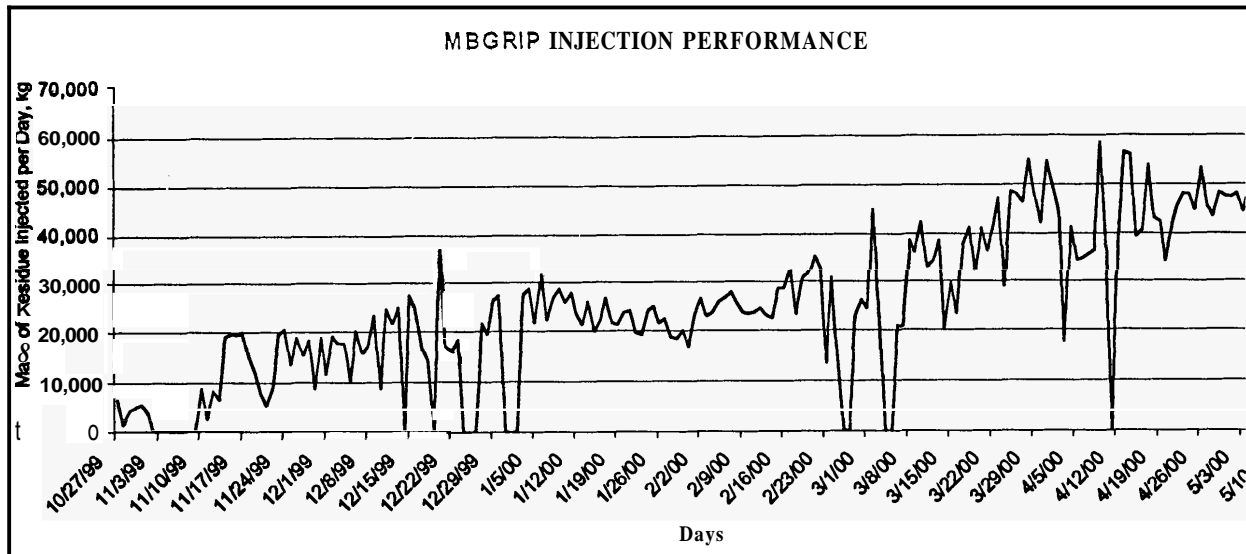


Figure 4. Injection Performance, Bulalo Well No. 30

raised the viscosity of the slurry, thus giving more carrying capacity to the fluid. Second, with the increase in the residue carrying capacity of the slurry, there was a better chance of pushing the residues further away from the wellbore and thus, maximizes the injection to a particular zone.

The viscous slurry had a density range of **1102.4** to **1138.4** kg/m³. At the top of the perforated liner, these would have equivalent bottomhole pressures of **8.25** to **8.52** MPa, respectively.

Process Measures

Specific measures were taken in order to prevent spillage and contamination of the crew from the heavy metals inherent in the geothermal residues. HDPE linings were also installed over the wellpad where the residues were processed.

3.0 RESULTS

3.1 Injection Performance

Figure 4 shows the overall injection performance in terms of kilograms of residues injected per day. The figure shows that there was a substantial increase in the injection performance. From a mere **7,258** kilograms of residues injected on the first day, the performance improved to a satisfactory average

of **45,360** kilograms per day towards the end of the project.

3.2 Response of the Well

The well's response to the injection could be characterized by two modes:

1. Low pressure response indicating natural fracture fill-up; and
2. High pressure response indicating hydraulic fracturing

During the early stages of the batch injection, the slurry mixes were injected at low wellhead pressures. A total of **478,086** kilograms of dry residue was injected below **6,895** KPa.

This surface injection pressure remained relatively constant until batch **85**. A total of **1,540,000** kgs of residue was injected below **8,274** KPa during each of these **85** batches.

Shortly after injecting this amount of residue, the average injection wellhead pressure rose to around **10,342** KPa and increased with every succeeding batch.

This prompted the shift to a viscosified slurry. It was hoped that with the guar gum mix, more residues could be squeezed into the fractures.

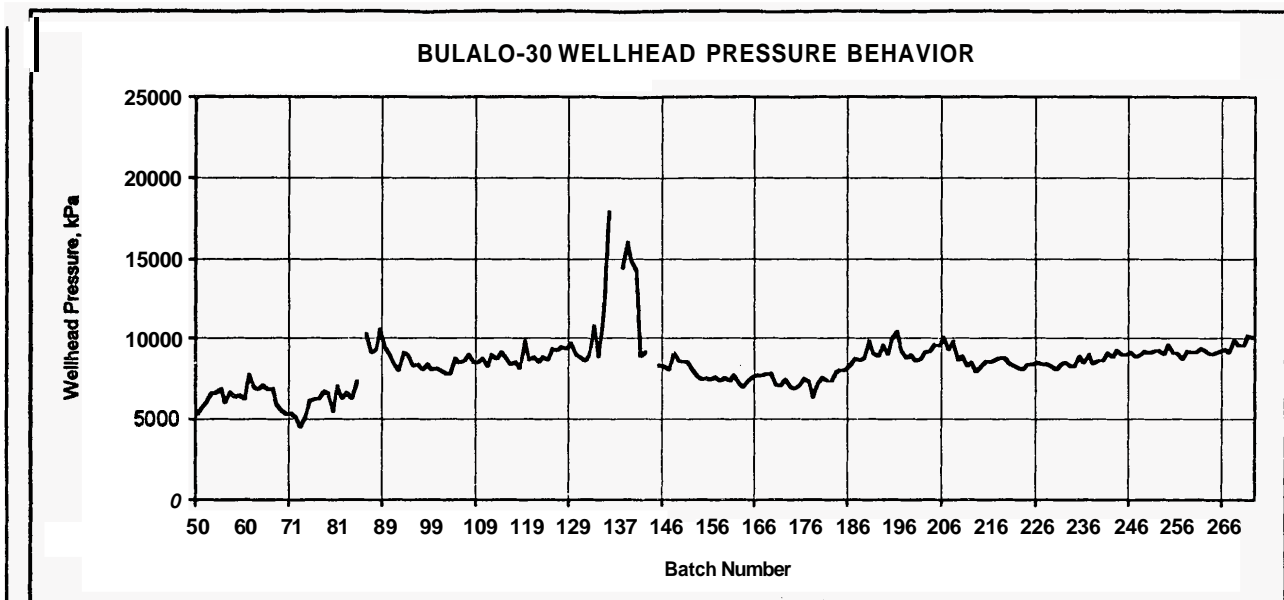


Figure 5. Bulalo Well No. 30 Injection Pressure Trend

Higher injection pressures characterized the succeeding batches. Wellhead pressure profile analyses of the succeeding batches indicated some hydraulic fracturing was induced.

Figure 5 shows the overall wellhead pressure trend during injection. The spike that occurred in batch 137 was due to plugging of the perforated liner. To reduce the injection pressure, the well was perforated shallower in the 9-5/8" casing to shift the injection to a shallower zone. The 9-5/8" casing was gun perforated at 774 meters MD. Another gun perforation was done at 770 meters MD because the first gun-perforated section became prematurely plugged when the injection pump broke down while pumping batch 140. The perforation jobs at shallow depths were part of the program and was duly approved by the local regulatory agencies.

At this stage in the injection process, the injecting wellhead pressures remained high. This prompted the shift to a viscosified slurry.

Following the perforating operations and the shift to a viscosified slurry, the wellhead pressure stabilized at batch 145 and remained constant until batch 180, where the pressure began to gradually increase again. The final maximum injecting wellhead pressure at the end of the project was recorded at 11,108 KPa.

4.0 CONCLUSIONS

The successful subsurface injection of the solid geothermal residues in the Bulalo project has proven to be both an environmentally and economically attractive disposal alternative.

The fractured nature of the geothermal reservoir may possibly serve as an advantage for solids disposal by increasing the storage space available in the formation. A significant volume of the solid residue slurry can be squeezed into the natural fractures and once filled up, hydraulic fracturing tends to open up additional space for accepting the solids.

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