East Java Mud Volcano (LUSI): Drilling Facts and Analysis*

Nurrochmat Sawolo[1], Edi Sutriono[1], Bambang P. Istadi[1], and Agung B. Darmoyo[1]

Search and Discovery Article #50186 (2009)
Posted June 10, 2009

*Adapted from extended abstract prepared for AAPG International Conference and Exhibition, Cape Town, Africa, October 26-29, 2008. Another article on this subject, with a different interpretation, is "Triggering of the Lusi Mud Eruption: Earthquake Versus Drilling Initiation," by Mark Tingay et al., 2008, Search and Discovery Article #50187 (2009).

[1]Energi Mega Persada, JI. Jend. Gatot Subroto 42, 12710, Jakarta Indonesia

Abstract

A sudden eruption of hot mud and steam began on May 29th, 2006, near the Banjarpanji-1 exploration well in Sidoarjo, East Java, Indonesia. In the early stages, the general public opinion speculated that the mud flows were caused by an underground blowout on the Banjarpanji well. But as the data was studied and analyzed, it quickly became clear that the mud flow was not triggered by the well, that an underground blowout did not occur. Firstly, the well-bore fluid pressure was too low to fracture the well bore. Secondly, there was no sustained pressure to propagate fractures. Thirdly and most importantly, the well bore was open and totally dead whilst mud was erupting at more than 300,000 bbl/day only 200 m away.

In the absence of the Underground Blowout, studies (e.g., Mazzini et al., 2007) suggest that tectonically reactivated faults provide the conduit for the water and overpressured shale to erupt and form the LUSI mud volcano. The presence of overpressured zone due to rapid subsidence and burial in the East Java Basin is evident. The high sedimentation rate of its maturing organic-rich sediments makes it an ideal setting for mud volcanism. Other mud volcanoes occur naturally in the area, and they are aligned with the LUSI mud volcano on the NNE-SSW Watukosek fault zone.

Introduction

On May 29, 2006, at around 05:00 hrs it was reported that Hot Water eruption intermittently with a maximum height of 25 ft and elapsed time of 5 minutes between the burst occurred around 200 meters from the well. This burst was very dramatic with a distinct geyser-like cycle of active and passive periods. This marks the formation of a new mud volcano known as LUSI in East Java, Indonesia. This new mud volcano adds to the many mud volcanoes existing in the area, such as the Porong collapse structure (NE of LUSI), Kalang Anyar & Pulungan (Sedati, Sidoarjo), Gunung Anyar (UPN campus, Surabaya), Bleduk Kuwu & Keradenan (Purwodadi), Wringin Anom / Pengangson (Gresik), Semolowaru (Unitomo campus, Surabaya), Dawar Blandong (Mojokerto), Sangiran (Central Java), Socah (Bangkalan, Madura) and others. LUSI however is special, as one can observe the ongoing geological processes from its controversial birth.

Three different hypotheses have been proposed as the trigger of LUSI; namely:
i). Underground Blowout (Davies et al., 2007; Tingay et al., 2008).
ii). Mud Volcanism due to remobilization of overpressured shale through a reactivated fault as the conduit (Mazzini et al., 2007).
iii). Geothermal activities where superheated hydrothermal fluids at high temperature and pressure are released through fault zone or fracture network as the conduit.

The objective of this paper is to clearly and transparently set out the drilling engineering data and analysis to correct the technical record and to provide a platform for further analysis. It focuses on key drilling pressure measurements and drilling facts to investigate the early speculation that drilling was the trigger of LUSI.

Underground Blowout As a Hypothesis

Several writers suggested that an Underground blowout triggered LUSI (Davies et.al, 2007; Tingay et al., 2008). However, the facts and pressure calculations clearly show that an underground blowout did not happen in the Banjarpanji-1 well. Several conditions must be met for an underground blowout to occur. The most important is that pressure in the wellbore must be sufficiently high to break the weakest formation (typically the casing shoe). Secondly, sustained fracture propagation pressure is required to extend the fracture to surface. Davies et al. (2007) suggested that the casing shoe was fractured and breached. However, calculations based on proper data obtained from the well and related facts clearly show the opposite; the shoe was still intact and not breached.

An investigation was carried out to determine if there was a connection between the well and the mud eruption. If an underground blowout did occur, then it was expected that a temperature anomaly and noise would be recorded in the Banjarpanji-1 wellbore. Temperature and Sonan logging were carried out during the relief well campaign to determine if such phenomena occurred. The temperature logs did not record any anomaly within the Banjarpanji-1 well (Figure 1). The sonan log did not indicate any unusual noise, indicating there was no flow behind casing (Figure 2).

Other facts that do not support the underground blowout hypothesis include:

- From the time after the well kick was killed on May 28, 2006, until the mud eruption, the Blow Out Preventer (BOP) was kept in the open position and numerous activities were conducted in the wellbore, such as fishing, cementing, and circulating. If the well was fractured, in order to propagate the fracture to surface, it would require sustained high pressure and for the BOP to be kept closed.
- No mud or gas or steam came out of the well despite the BOP being in the open position. It would have been easier for the mud to come out of the well instead of having to fracture the formation (Figure 3-I/D). If caused by drilling, the well should at the least be surging and flowing itself as the path of least resistance to surface and there would definitely be some gas and steam coming from the wellhead. It seems totally impossible for 300,000 bbl/day of mud and steam and gas at the beginning to flow through a well that is totally dead at surface.
- Noting this nearby eruption, the first information required was evidence for any connection or channel between the eruption and the well. This assessment was done by closing the well and pumping into it on May 29, 2006. After pumping two batches of mud the well did not experience any losses and the pressure was holding at 900 psi. Another injection test was done on May 30, 2006, prior to placing the cement plug with an injection pressure at 370 psi with a rate of 2.5 bbl/minute. Pumping into the well confirmed no connection between the well and the mud eruption.
- The unprotected wellbore was expected to enlarge due to erosion from the very high mud rates. Such erosion was expected to result in the dropping of the fish and cement (Figure 3-II/H); however this did not happen and the fish remained intact as reported in Daily Drilling Report on July16, 2006, 1.5 months after the eruption.
- The mud eruption occurred along lines of weakness aligned with the Watukosek fault zones; this is not typical of underground blowouts. The crack that formed at the rig site on June 2, 2006, was not followed by extrusion of fluid nor mud, suggesting they were not due to hydro-fracturing. Other fractures parallel with the Watukosek fault were observed at the same time as the initial mud eruption. The movements suggest sinistral reactivation of the faults. Second-order dextral movements were observed several times in the railway line movements in September, 2006 (Figure 4).

Banjarpanji-1 Casing Shoe Strength Analysis

The following data is used to calculate the pressure at the casing shoe and determine if an underground blowout occurred in the well.

Shut In Casing Pressure

The maximum Casing Pressure of 1,054 psi is used based on the Real Time Data (RTD) of May 28th, 2006. This casing pressure of 1,054 psi is considered as more reliable pressure measurement where stabilized maximum pressure is reached 36 minutes after shut in, and remained constant until it was bled off as part of the well control procedure, as shown in Figure 5.

Note that the normal reading of ISICP (Initial Shut In Casing Pressure) is not applicable here since the casing pressure was not stable throughout the shut in period. Similarly the drill pipe pressure cannot be used to calculate well pressure in this instance because of a flapper valve at the bottom of the drill string that prevented wellbore pressure reading.

Fluid Density at the Top of the Well

The well took a fluid influx of over 300 bbls. During the kill process, the well was bled off and found water instead of gas or mud. After the well was killed, this influx was circulated out with a density of 8.9 ppg as shown in the well's IADC report and Morning Report dated May 29, 2006 (Figure 6). The influx represents approximately 30% of the hole volume. This large influx of water, due to its lighter density found its way to the top and occupied the upper portion of the well.

Bottom Hole Pressure

The bottom hole pressure is calculated to be 12.8 ppg based on the fill-up volume of the well (Real Time Data of May 27, 2006). The common practice for calculating bottom hole pressure when a loss circulation occurs is by measuring the amount of mud needed to fill the hole (Fill Up method). It took 220 bbl to fill-up the hole, equivalent to 6200 psi (12.8 ppg) of bottom hole pressure (Figure 7).

This calculated BHP value of 12.8 ppg was checked using other theoretical bottom hole pressure calculations using the drilling Dc-exponent and Resistivity log which shows that the value is within the correct range (Figure 8). Other evidence that supports the correctness of this Bottom Hole Pressure includes:

- The well lost mud twice on May 27, 2006, indicating that the BHP is less than the mud weight of 14.7 ppg (Figure 11).

- The Static Influx Test conducted at 9010 ft on May 27, 2006, was used to check the Bottom Hole Pressure. This test was negative with no increase in gas reading meaning that the pore pressure was less than the Mud Weight used, which was 14.7 ppg.

Leak Off Test

The leak off test done at the 13 3/8” casing shoe is shown in Figure 9. The LOT was 16.4 ppg at a depth of 3580 ft. The LOT result is consistent with the LOT of Wunut 2, an offset well approximately 2 km away which had a LOT of 16.6 ppg at a shallower depth of 3160 ft. It should be noted that the shallow section of Banjarpanji-1 is within the Wunut anticlinal structure.

Pressure Analysis at the Casing Shoe

This analysis showed that it is intact.

Using the basic data above, the pressure analysis is as follows:
1. Maximum Casing Pressure = 1,054 psi.
2. Fluid in the upper part of the hole = 8.9 ppg. Maximum mud weight = 14.7 ppg.
3. Bottom Hole Pressure = 12.8 ppg.
4. Leak Off Test at the casing shoe (3,580’) = 16.4 ppg.

The resulting graph is shown in Figure 10. The pressure at the shoe exerted by the fluid is 2710 psi which is lower than the strength of the rock (LOT) of 3053 psi. This proves that the weakest point in the well, which is the shoe, was still intact and was not fractured.

Underground Blowout Arguments

Observers were quick to assume that the mud eruption was caused by an Underground Blowout because of its proximity to the well. Arguments on Underground Blowout, however, are not supported by facts.

These include:
1. Davies et al. (2007) showed the bottom hole pressure of 48 MPa (14.4 ppg) and proposed a kick occurred while drilling into the Kujung Formation. However, in fact well had a loss, not a kick, when drilling using 14.7 ppg drilling mud on May 27, 2006. The well suffered a partial loss of 20 bbls of drilling mud less than 10 minutes after May 27, 2006, earthquake recorded at the Tretes BMG

Station (Figure 11). The total loss of circulation of 130 bbls occurred in the well after 2 major aftershocks around midday of the same day.

2. Tingay et al. (2008) quoted pore pressures which are unrealistically high (Figure 3). Pore pressure in BJP-1 was reported as 17.84 MPa/km (15.2 ppg) at 2130 m depth and 17.1 MPa/km (14.5 ppg) at 2800 m depth. These pressures are higher than the mud weight and the Static Influx Test that shows the actual pore pressure to be much lower than 14.7 ppg.

3. Claims made by Davies et al. (2007) that hydrofracturing occurred and by Tingay et al. (2008) that the fluid pressures inside the well exceeded 19.5 MPa/km (16.4 ppg) shortly after the blowout preventer was closed. Contrary to claims, as shown on Figure 10 and by calculations below, the pressure at the casing shoe, which is the weakest point of the wellbore, was lower than the fracture pressure.

Pressure at casing shoe = Maximum casing pressure + hydrostatic pressure of fluid

$$P@3580 = 1054 + (0.052 \times 8.9 \times 3580)$$
$$= 2710 \text{ psi} < 3053 \text{ psi (fracture pressure)}$$

Conclusion

A number of papers hypothesized that the birth of the LUSI mud volcano was related to drilling of the Banjarpanji-1 well.

This article presents drilling data, facts, analysis, and investigation during the re-entry and relief well campaign, which show that the well casing shoe did not breach. The well bore pressure was too low to fracture the well. Supporting this conclusion, field data demonstrated that the well was still intact and indicated no communication between the well and the mud eruption. Therefore it is concluded that an Underground Blowout as a trigger of the LUSI mud volcano is a hypothesis not supported by drilling data and facts.

In the absence of any evidence supporting an underground blow out hypothesis, reactivation of the Watukosek Fault is seen as the most likely and natural trigger for the mud volcano, as there was a clear connection between the timing of earthquake and after-shocks, and mud losses in the well.

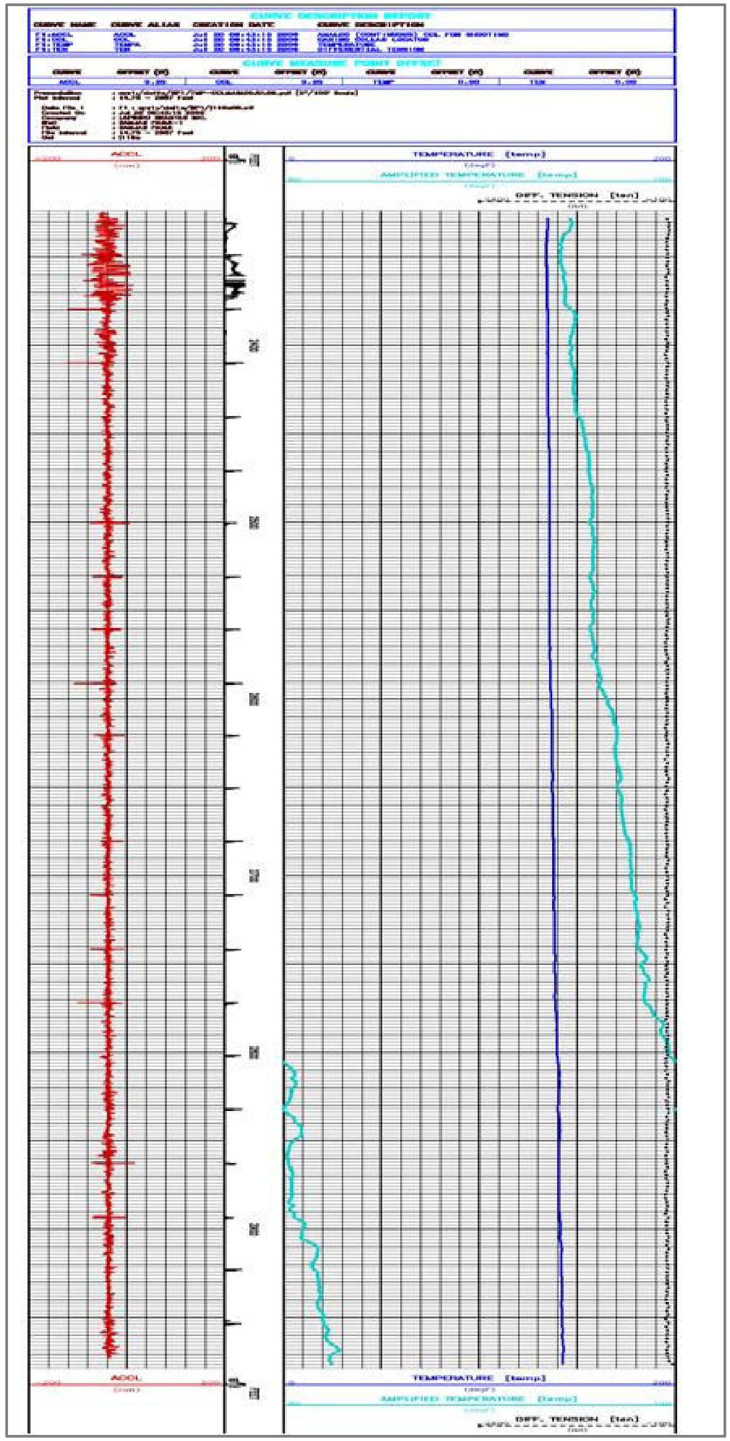


Figure 1. Temperature log does not indicate any temperature anomaly.

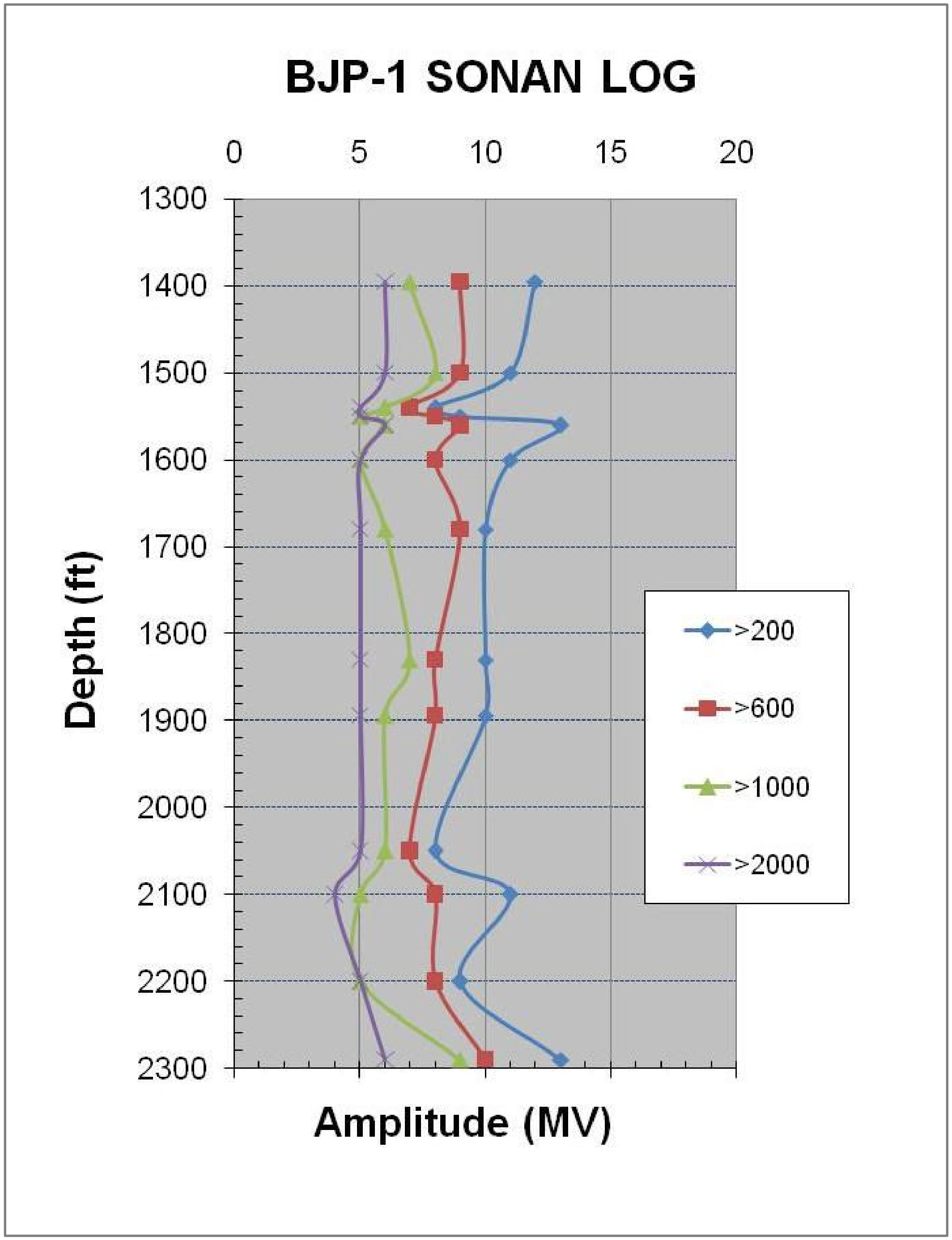


Figure 2. Sonan log taken during re-entry operations, 2 months after eruption did not show any noise indicating no flow behind casing.

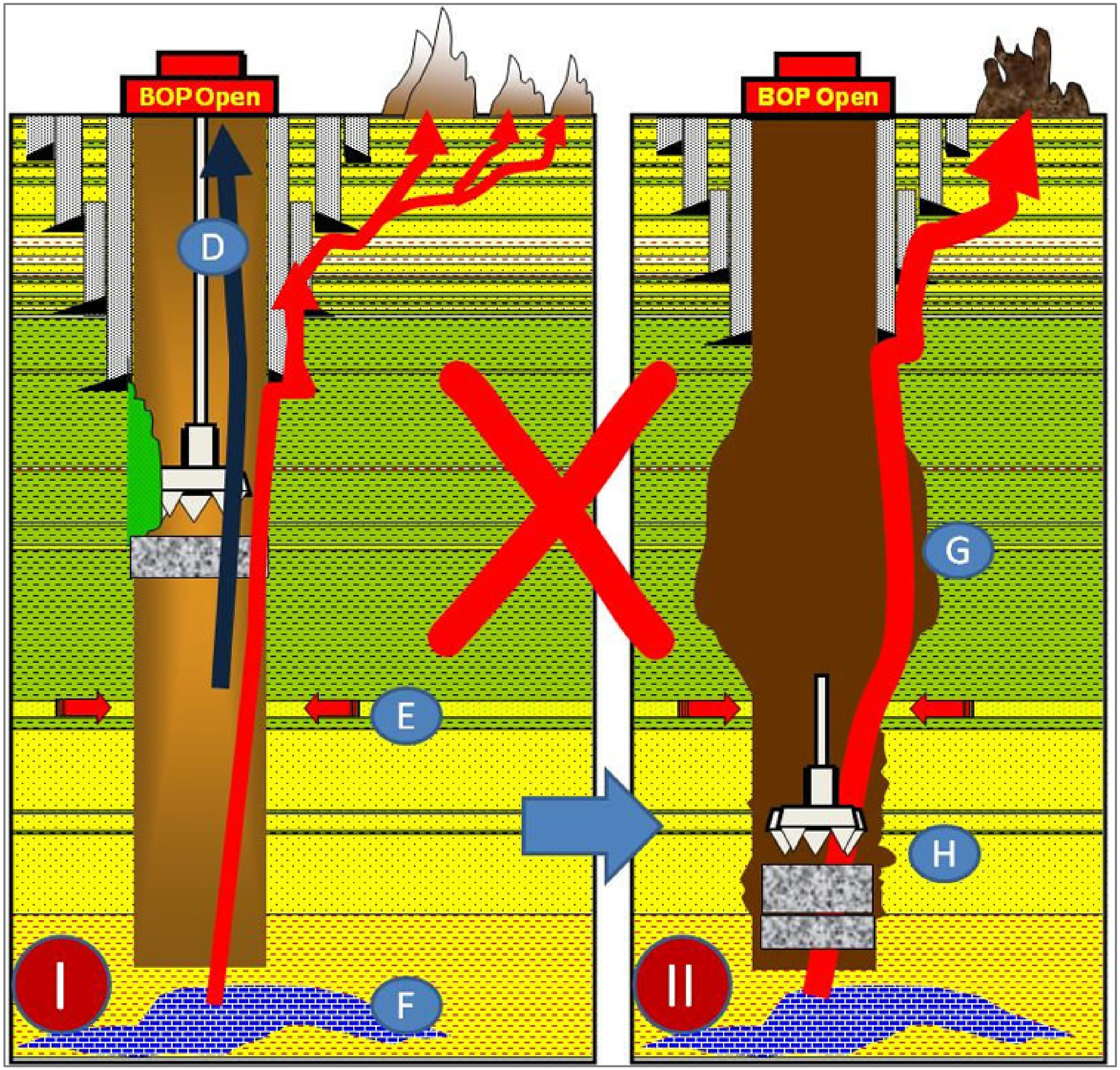


Figure 3. Illustration of underground blowout scenario of what would be expected.

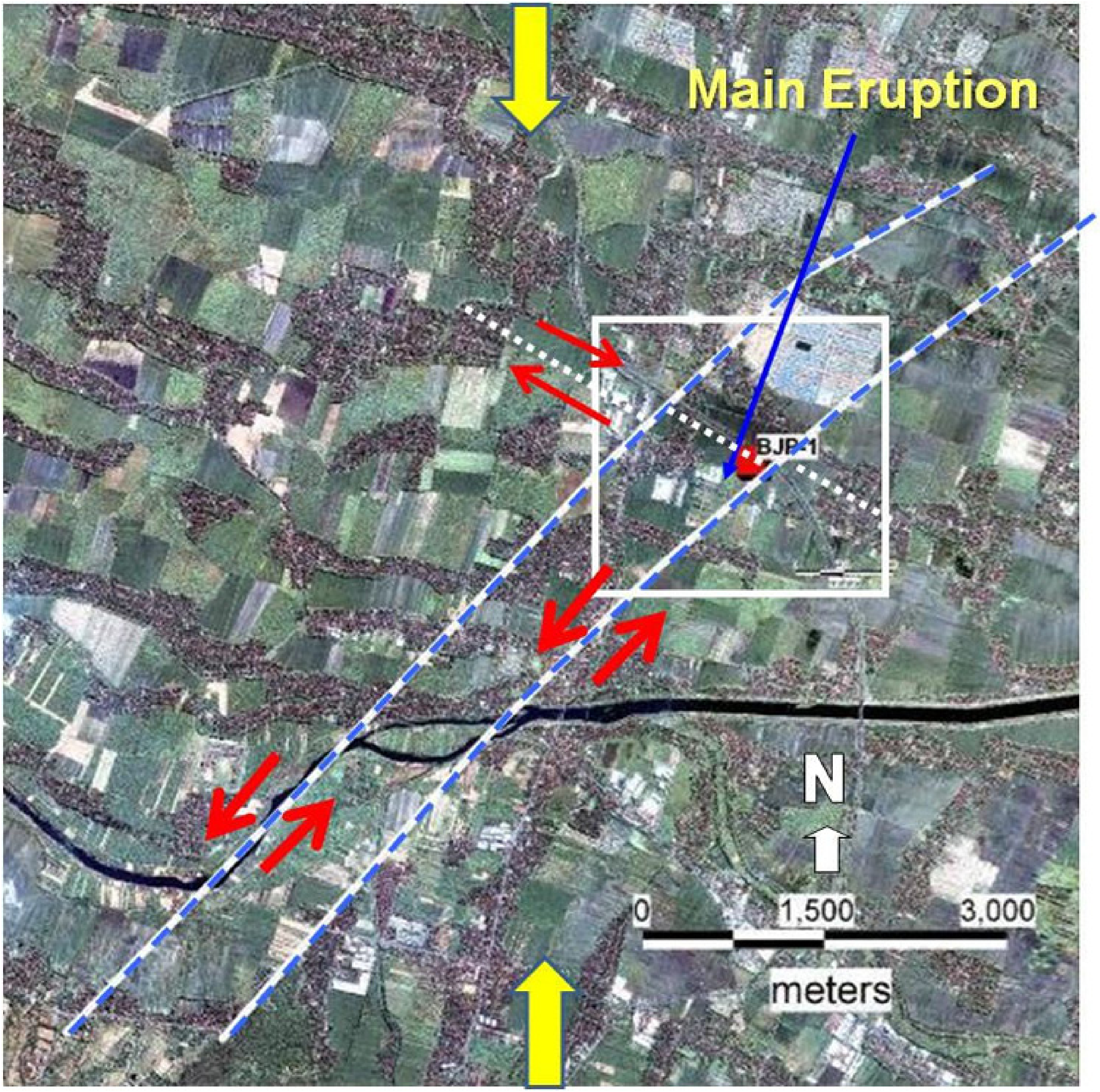


Figure 4. Location of the mud eruption, major stress directions, fault zones and their relative movements.

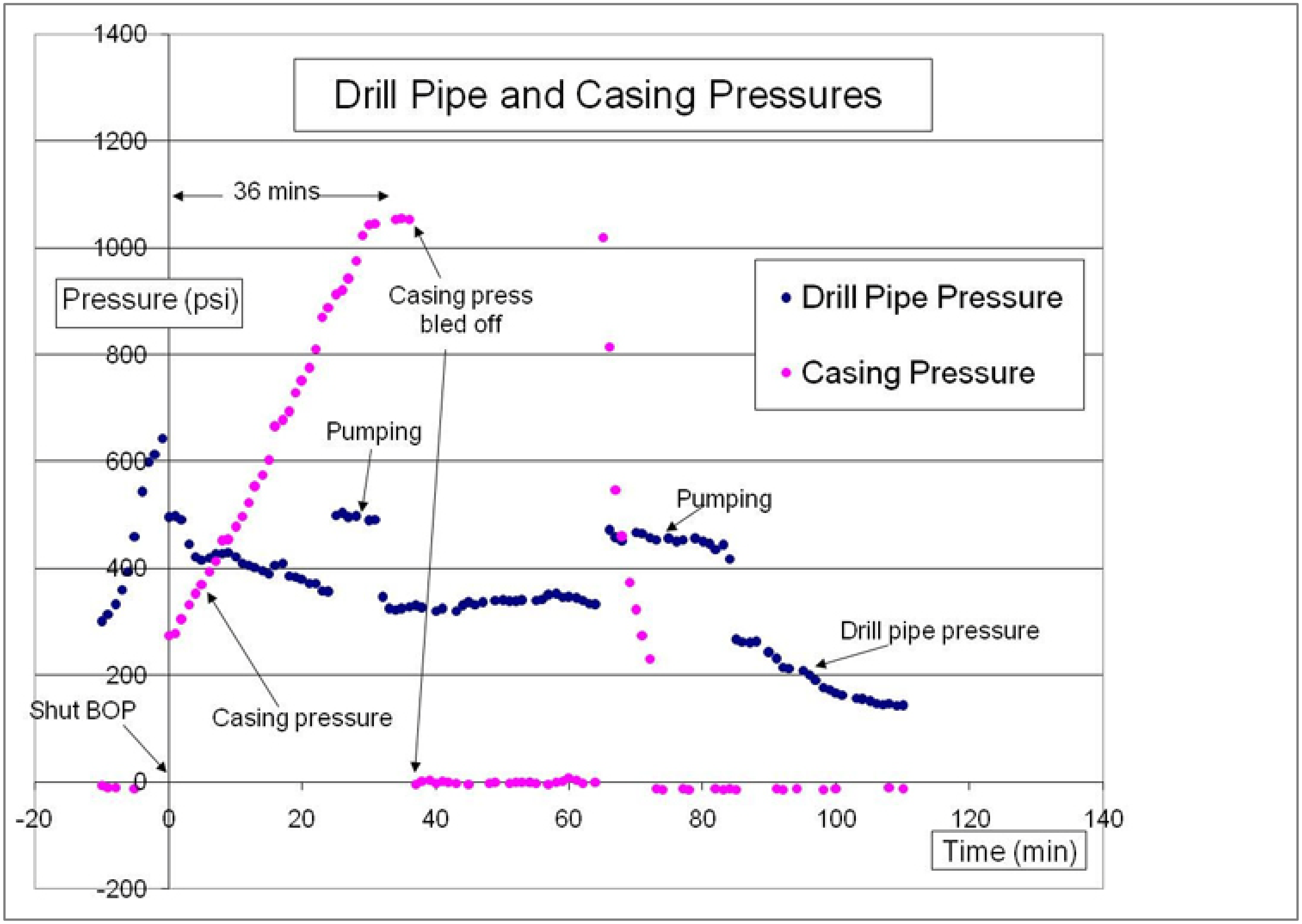
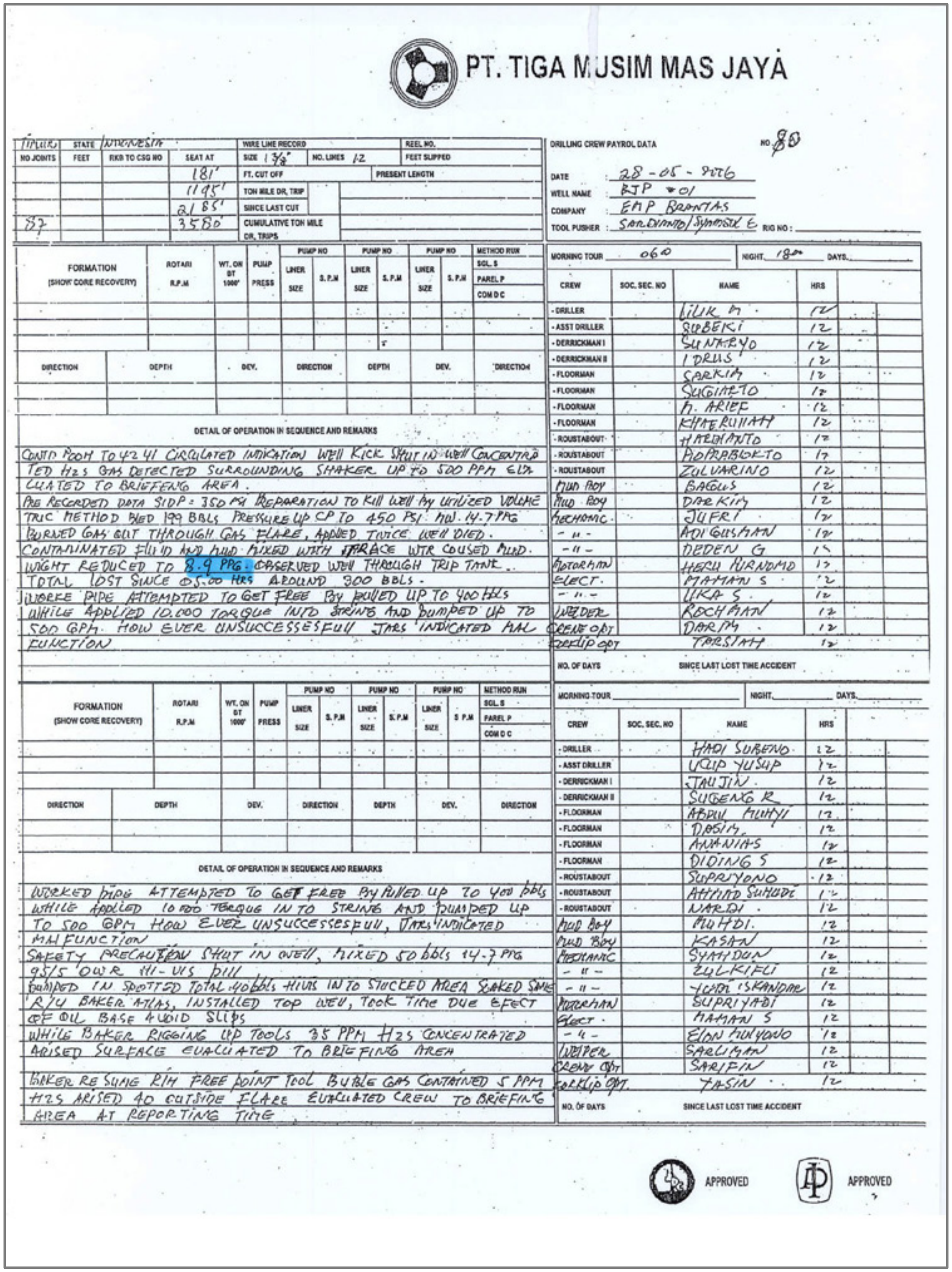


Figure 5. BJP-1 Real time data dated May 28, 2006. The maximum casing pressure was 1054 psi, pressure reading 30 min after shut in. Well was dead and BOP was opened at 10:00 hrs, May 28, 2006.



PT. TIGA MUSIM MAS JAYA

DRILLING CREW PAYROLL DATA NO. 80

DATE: 28-05-2006
WELL NAME: BJP #01
COMPANY: EMP BRANTAS
TOOL PUSHER: SARDIANTO/SYAMSUL E RIG NO.:

NO JOINTS	FEET	RKB TO CSG HD	SEAT AT
			181'
			1195'
			2185'
87			3580'

WIRE LINE RECORD — SIZE 1 3/8" — NO. LINES 12

MORNING TOUR 060 — NIGHT 1800

CREW	SOC. SEC. NO	NAME	HRS
DRILLER		LILIK M	12
ASST DRILLER		SUBEKI	12
DERRICKMAN I		SUNARYO	12
DERRICKMAN II		IDRUS	12
FLOORMAN		SARKIM	12
FLOORMAN		SUGIARTO	12
FLOORMAN		M. ARIEF	12
FLOORMAN		KHAERULLAH	12
ROUSTABOUT		HARDIANTO	12
ROUSTABOUT		ADRABBOTO	12
ROUSTABOUT		ZULVARINO	12
MUD BOY		BAGUS	12
MUD BOY		DARKIM	12
MECHANIC		JUFRI	12
- " -		ADI GUSMAN	12
- " -		DEDEN G	12
MOTORMAN		HERU PURNOMO	12
ELECT.		MAMAN S	12
- " -		UKA S.	12
WELDER		ROCHMAN	12
CRANE OPT		DARIM	12
FORKLIP OPT		TARSIAH	12

DETAIL OF OPERATION IN SEQUENCE AND REMARKS

CONTD POOH TO 4241 CIRCULATED INDICATION WELL KICK SHUT IN WELL CONCENTRATED H2S GAS DETECTED SURROUNDING SHAKER UP TO 500 PPM EVACUATED TO BRIEFFENG AREA.
PRE RECORDED DATA SIDP = 350 PSI PREPARATION TO KILL WELL BY UTILIZED VOLUMETRIC METHOD BLED 199 BBLS PRESSURE UP CP TO 450 PSI MW. 14.7 PPG BURNED GAS OUT THROUGH GAS FLARE, APPLIED TWICE WELL DIED.
CONTAMINATED FLUID AND MUD MIXED WITH TRACE WTR COUSED MUD WIGHT REDUCED TO 8.9 PPG. OBSERVED WELL THROUGH TRIP TANK. TOTAL LOST SINCE 05.00 HRS AROUND 300 BBLS.
WORKE PIPE ATTEMPTED TO GET FREE BY PULLED UP TO 400 KLBS WHILE APPLIED 10.000 TORQUE INTO STRING AND PUMPED UP TO 500 GPM. HOW EVER UNSUCCESSESFULL JARS INDICATED MALFUNCTION

MORNING TOUR — NIGHT — DAYS

CREW	SOC. SEC. NO	NAME	HRS
DRILLER		HADI SUBENO	12
ASST DRILLER		UCUP YUSUP	12
DERRICKMAN I		JAUJIN	12
DERRICKMAN II		SUGENG R	12
FLOORMAN		ABDUL MUHYI	12
FLOORMAN		DASIM	12
FLOORMAN		ANANIAS	12
FLOORMAN		DIDING S	12
ROUSTABOUT		SUPRIYONO	12
ROUSTABOUT		AHMAD SUHUDI	12
ROUSTABOUT		NARDI	12
MUD BOY		MUHDI.	12
MUD BOY		KASAN	12
MECHANIC		SYAMDUN	12
- " -		ZULKIFLI	12
- " -		YUDI ISKANDAR	12
MOTORMAN		SUPRIYADI	12
ELECT.		MAMAN S	12
- " -		ELAN MULYONO	12
WELDER		SARLIMAN	12
CRANE OPT		SARIFIN	12
FORKLIP OPT.		YASIN	12

DETAIL OF OPERATION IN SEQUENCE AND REMARKS

WORKED PIPE ATTEMPTED TO GET FREE BY PULLED UP TO 400 KLBS WHILE APPLIED 10 000 TORQUE INTO STRING AND PUMPED UP TO 500 GPM HOW EVER UNSUCCESSESFULL, JARS INDICATED MALFUNCTION
SAFETY PRECAUTION SHUT IN WELL, MIXED 50 BBLS 14.7 PPG 95/5 OWR HI-VIS PILL
PUMPED IN SPOTTED TOTAL 40 BBLS HIVIS INTO STUCKED AREA SOAKED SAME
R/U BAKER ATLAS, INSTALLED TOP WELL, TOOK TIME DUE EFECT OF OIL BASE FLUID SLIPS
WHILE BAKER RIGGING UP TOOLS 35 PPM H2S CONCENTRATED ARISED SURFACE EVACUATED TO BRIEFING AREA
BAKER RESUME RIH FREE POINT TOOL BUBLE GAS CONTAINED 5 PPM H2S ARISED AO OUTSIDE FLARE EVACUATED CREW TO BRIEFING AREA AT REPORTING TIME

APPROVED APPROVED

Figure 6. BJP-1 IADC report dated May 29, 2006. Note the 8.9 ppg fluid influx into the wellbore that was circulated out after a kick.

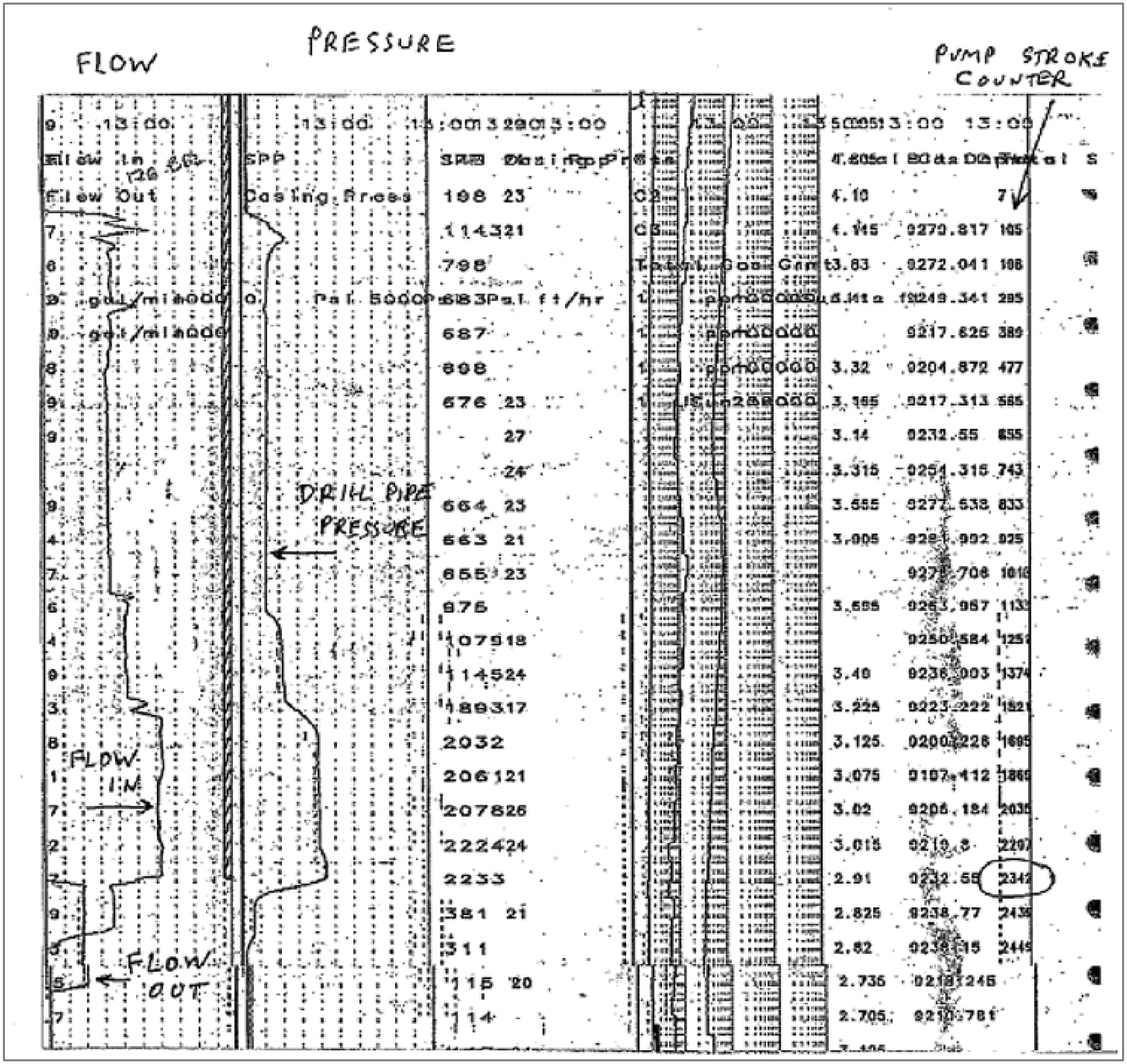


Figure 7. Real time data May 27, 2006, shows 220 bbls to fill the hole.

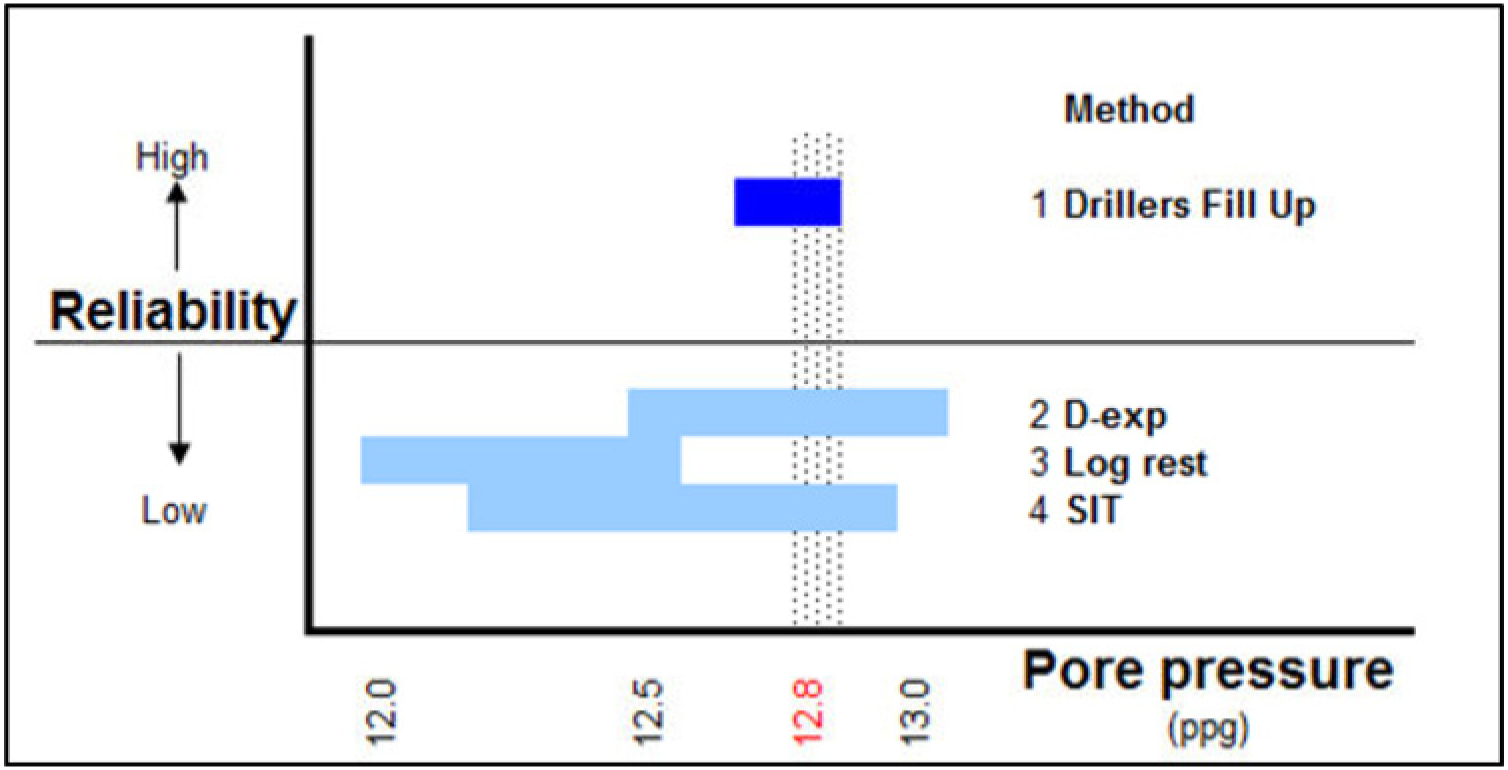


Figure 8. Range of bottom hole pore pressures. The pore pressures are derived from a number of pressure prediction methods with different reliability. The ‘Fill Up’ method is considered the most reliable and widely used in drilling.

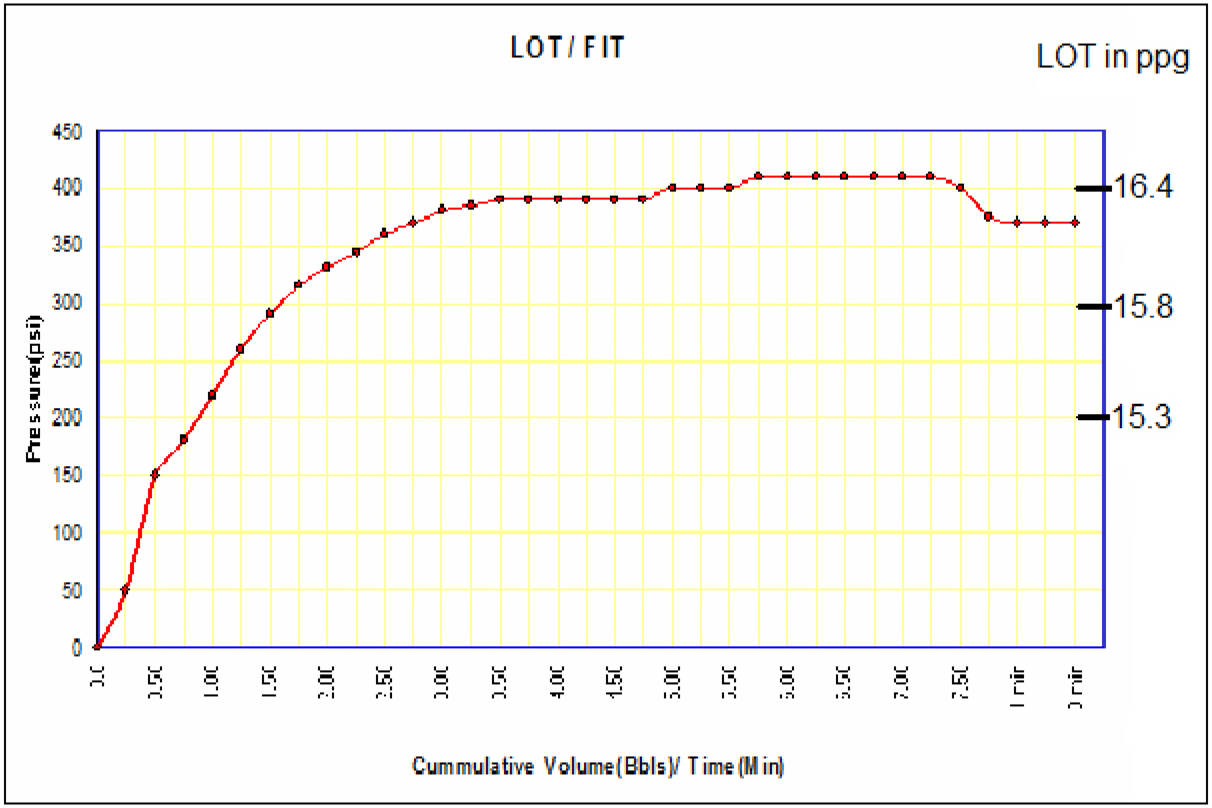


Figure 9. Banjarpanji-1 Leak off test result of 16.4 ppg at the 13-3/8” casing shoe at a depth of 3580 ft.
The result is consistent with the nearest offset Wunut-2 well which had 16.6 ppg LOT from a shallower depth of 3160 ft.

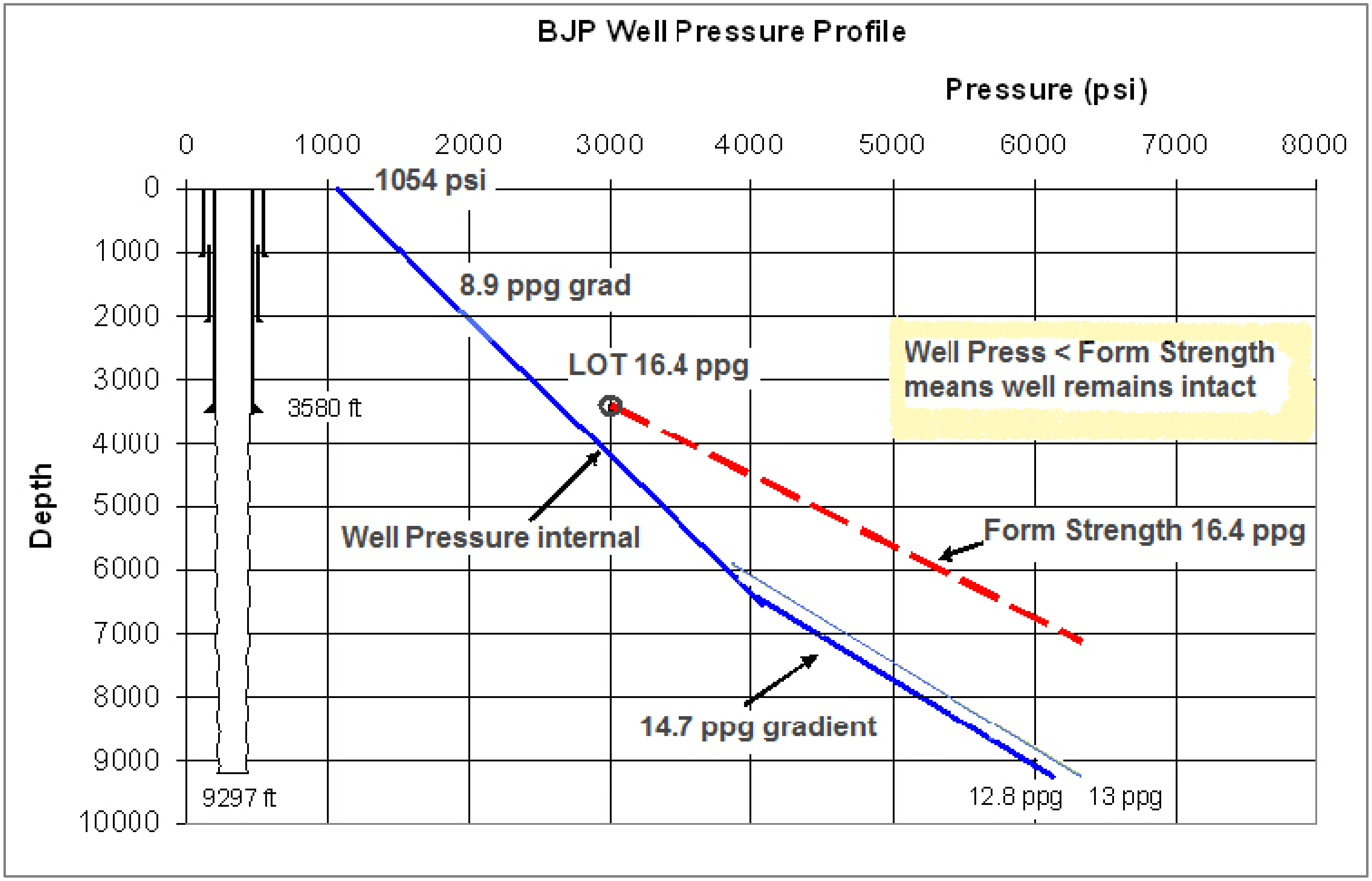


Figure 10. BJP-1 Pressure profile shows that the pressure within the wellbore is still lower than the strength of the rock at its weakest point; i.e., lower than the LOT.

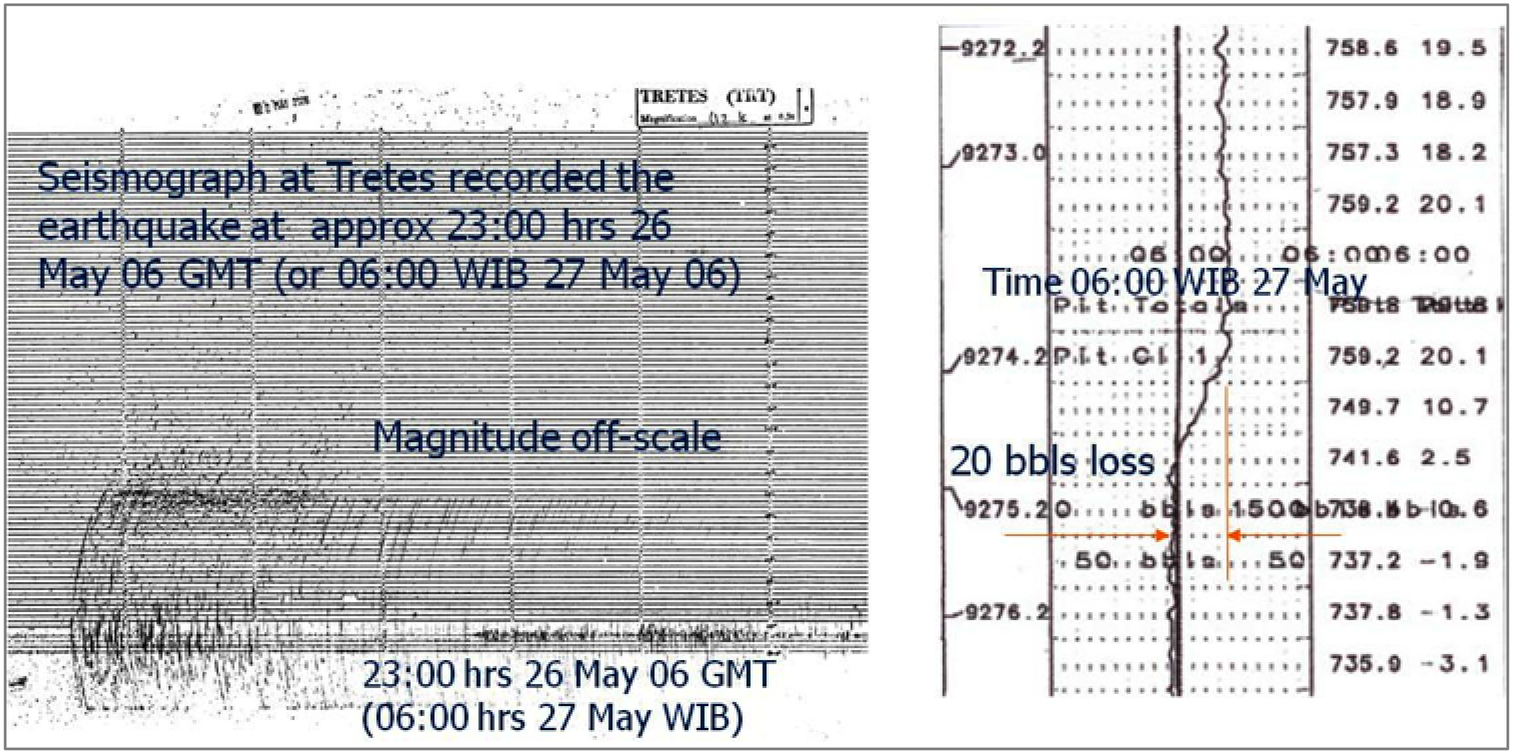


Figure 11. BJP-1 RTD showing drilling mud losses less than 10 minutes after May 27, 2006, recorded in Tretes BMG Station (10 km away from LUSI.

References

Davies, R.J., R.E. Swarbrick, R.J. Evans, M. Huuse, 2007, Birth of a mud volcano, east Java, 29 May 2006: GSA Today, v. 17/2, p. 4-9. http://dx.doi.org/10.1130/GSAT01702A.1

Mazzini, A., H. Svensen, G.G. Akhmanov, G. Aloisi, S. Plante, A. Malthe-Sorenssen, and B. Istadi, 2007, Triggering and dynamic evolution of the LUSI mud volcano, Indonesia: Earth and Planetary Science Letters, v. 261/3-4, p. 375-388. http://dx.doi.org/10.1016/j.epsl.2007.07.001

Tingay, M., O. Heidbach, R. Davies, and R. Swarbrick, 2008, Triggering of the Lusi mud eruption; earthquake versus drilling initiation: Geology Boulder, v. 36/8, p. 639-642. http://dx.doi.org/10.1130/G24697A.1

Tingay, M., O. Heidbach, R. Davies, and R. Swarbrick, 2008, The Lusi mud eruption of East Java (abstract): Search and Discovery Article #90082 (2009) http://searchanddiscovery.net/abstracts/html/2008/intl_capetown/abstracts/469863.htm