DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

In-Situ Stress Project

Technical Report Number 7: The Use of Mechanical Pressure and Temperature Gauges in Hydraulic Fracturing at the Cajon Pass Well, California.

By

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U.S. Geological Survey

Open File Report 87-629

Menlo Park, California

1987

FIGURES

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

THE USE OF MECHANICAL PRESSURE AND TEMPERATURE GAUGES IN HYDRAULIC FRACTURING AT CAJON PASS WELL, CALIFORNIA.

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ABSTRACT

Eight hydraulic fracturing experiments were conducted to calculate in-situ stress in the Cajon Pass Well, starting on March 9, 1987, and finishing on April 2, 1987. Four mechanical pressure gauges and one mechanical temperature gauge were used. These gauges measured pressure in the test interval, packer elements and open-hole, the temperature gauge measured temperature in the open-hole. These gauges were all used downhole while electronic gauges were used at the surface. The gauges record the pressure and temperature on coated metal charts that were removed after the test and digitized. The charts were digitized using a Kuster 2-way reader with encoder, PBR interface, and an IBM Personal Computer. A single 5 1/4 inch disc was used to store all the digitized data. Along with the data, calibration information was also stored on the disc. These calibrations were used to convert the pressure/time deflections from inches of deflection into actual pressure in psi and time in minutes.

A total of twenty-five records were digitized. Two of the charts contain records at two different depths, because the packers were moved to a second test interval and reset.

The records that were digitized are used to determine the least principal in-situ stress, monitor status of the packer/bundle carrier assembly during the test, and reconstruct any unusual events or malfunctions that occurred downhole, while conducting the tests (see fig. 1).

Figure 1.

CAJON PASS
HYDROFRAC SCHEDULE

FRAC#	DEPTH:	DATE:	REMARKS:
1	6216'	3/09/87	PACKERS WOULD NOT SET, TUBING BACKED OFF. FISHING TRIP.
2,3	6110', 6216'	3/10/87	GOOD TEST
4,5	6859', 6839'	3/28/87	GOOD TEST
6	6732'	3/29/87	TUBING SEPARATED GOOD TEST GOOD IMPRESSION
7	6719'	4/01/87	WIRELINE DEPTH TIE PROBLEMS, NO TEST TRIP OUT
8	6719'	4/02/87	GOOD TEST

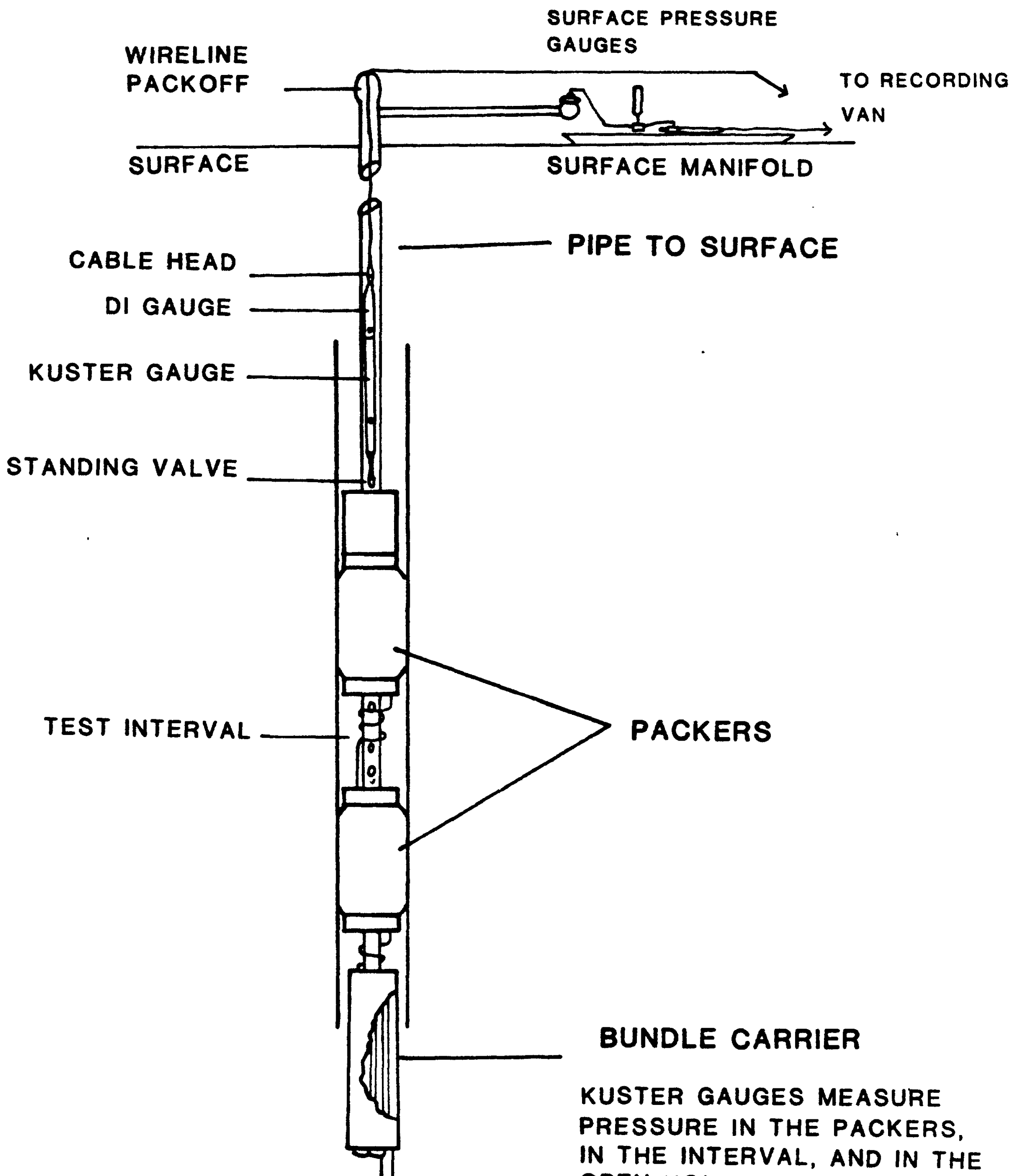
INTRODUCTION

During hydraulic fracturing stress measurements at the Cajon Pass well, five Kuster gauges were used to measure pressure and temperature in the system. The tests were conducted in the open hole using a straddle packer assembly (fig. 2). Four of the Kuster gauges measure pressure (KPG), and one measures temperature (KT). The temperature and three of the pressure gauges were carried in a bundle carrier attached to the bottom of the packer assembly. The fourth Kuster pressure gauge was suspended on the wireline just above the packers inside the tubing string.

The Kuster pressure and temperature gauges are Amerada type mechanical gauges that record pressure and temperature using an expandable Bourdon tube which rotates a shaft connected to a stylus. The stylus makes a trace on a moving coated metal chart.

After hydraulic fracturing tests are completed and the packer assembly is recovered, the Kuster records are removed from the gauges and digitized. The digitized information is stored on floppy discs. Each test is stored into a separate directory. Time-deflection curves are converted into time-pressure and time-temperature curves then plotted.

FIGURE 2.



STRADDLE PACKER ASSEMBLY

THE PRESSURE AND TEMPERATURE GAUGES

The Kuster gauges are used in conjunction with electronic gauges at the surface. These Kuster gauges, being self-contained, are started at the surface, tripped downhole, and let run uninterrupted for the full duration of the test. The 1.5 inch (38 mm) KPG and KT are chosen because of their extended heat and pressure ranges. These gauges record pressure up to 30,000 psi and temperatures up to 500 degrees F (260 degrees C). Their length is 74 inches (188 cm). The gauges weigh 19 lbs (8.6 kg) and have an accuracy of .2% of full scale. Clocks are available with run times of 2, 3, 4, 6, 12, 24, 48, 72, 120, 144, 168, 180, and 360 hours. The principle advantage for using this type of gauge is that it can accurately measure downhole pressure in an adverse environment (see Daneshy etal., 1986).

GAUGE OPERATING DESCRIPTION

The gauge communicates with ambient pressure through a port in the bellows housing (Fig. 3). This housing may be filled with oil to prevent the sensitive bellows material from being pierced by small sand particles or exposed to corrosive fluids. Some housings have more ports to allow better fluid and pressure migration through them.

The bellows itself is filled with a high temperature, high pressure oil. As pressure increases, the bellows compresses sending fluid up to the bourdon tube. The bourdon tube is a coiled metal tube, fixed at the bottom and connected to a rotating pin at the top. As pressure in the tube increases, it uncoils, causing a deflection of the stylus. The stylus rotates, scribing a line on a black coated chart in the recording section.

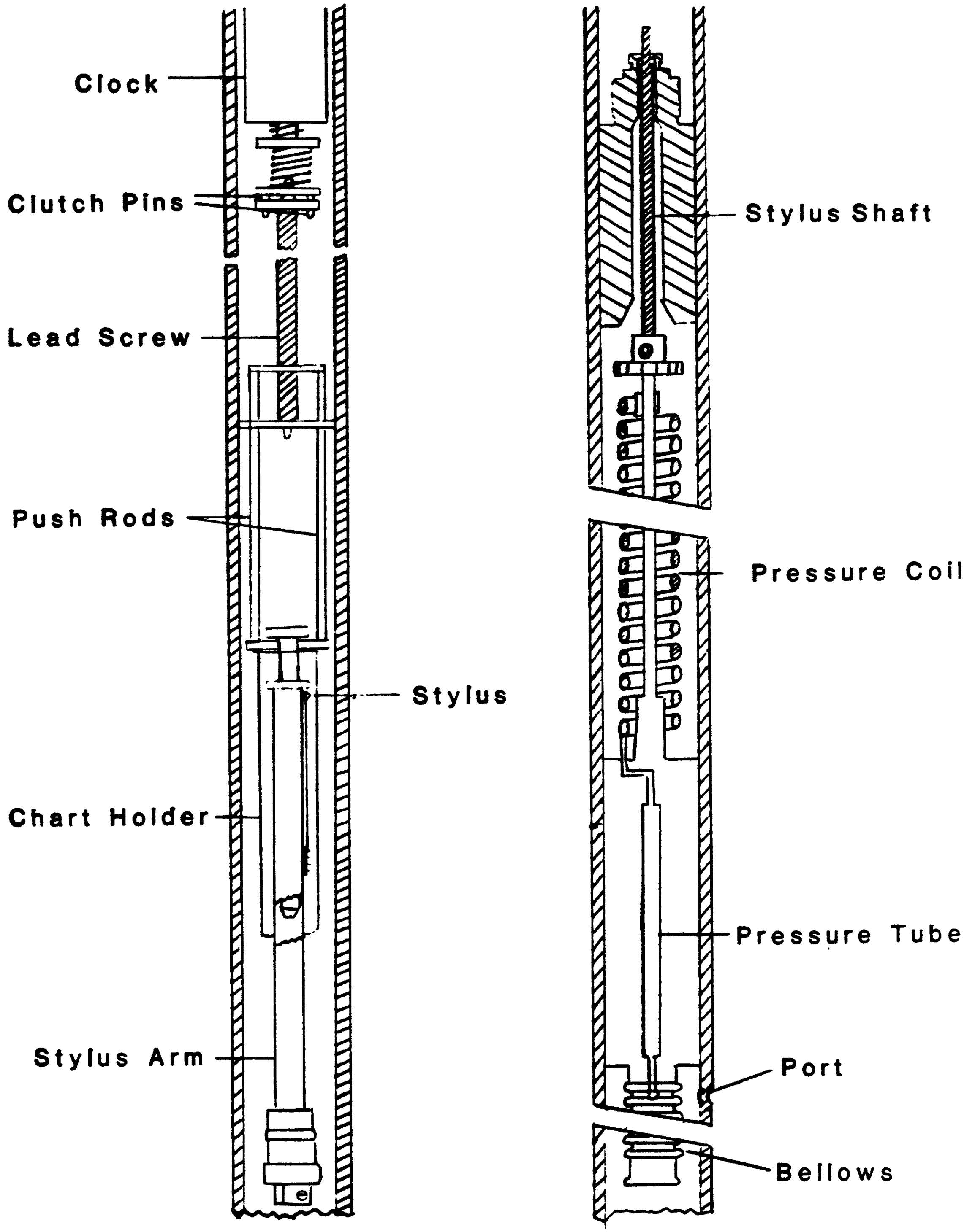
A chart is inserted into the chart holder before a survey begins. The chart holder is suspended by two parallel rods which are in turn connected to a lead screw. The lead screw, aided by the clock, controls the fall of the chart recorder. Two different lead screws may be installed; a standard lead screw with a .333 pitch, and a double lead screw with a .666 pitch. The latter cuts the clock time in half. The lead screw and clock are connected by a spring loaded clutch. To start recording, the clocks are wound and engaged to the lead screw at the surface.

KUSTER SURVEY START-UP PROCEDURE

The procedure for conducting a survey with the KPG's is as follows (fig. 3): (1) Remove recorder housing exposing the recording section. (2) Lay the gauge on a horizontal surface and remove the inner housing cover. (3) Move the chart holder toward the top, to the limit of motion. Remove the chart holder. (4) Insert a new chart into chart holder with a mandrel. (5) Wind the clock with clutch pins disengaged. (6) Insert the loaded chart

FIGURE 3.

CUT-AWAY of KUSTER PRESSURE GAUGE



holder back into gauge. (7) Move the chart holder over the stylus arm assembly to the outer limit of motion, away from clock. (8) Replace the inner housing cover. (9) Move the stylus to the "on" position. Place gauge in the vertical position while holding chart holder. Let the chart holder freefall to run a baseline at ambient pressure. (10) Engage clock clutch pins and record the start time. (11) Inspect the O-rings on the recording section before replacing the outer housing (see GRC manual, 1983).

Repeat this procedure for each pressure gauge.

The temperature gauge follows a similar procedure as above, excluding drawing of the zero base line. Instead, manually turn the stylus arm in a clock-wise direction until it hits the stop pin. Engage the stylus arm to the "on" position and hold the gauge in a vertical position to allow a free fall of the recording section. A line will be scribed at zero temperature. Then proceed to engage clutch pins.

THE BUNDLE CARRIER

The bundle carrier (Fig. 4) is used to hold and protect the Kuster gauges during handling of the drill string. It also serves to isolate individual gauges to the particular parameter that is to be recorded.

PARAMETERS MEASURED BY THE KUSTER GAUGES

The pressure gauges in the bundle carrier measure three different parameters. One of the gauges is isolated in a sealed chamber that communicates pressure with the packer elements, through a 1/4" steel tube. The second gauge is isolated in another chamber that only allows communication to the test interval between the packer elements. The third and fourth Kuster gauges are situated in chambers that are opened to the borehole below the packer assembly to record downhole pressure and temperature. Recording downhole temperature is an important parameter allowing for proper temperature correction to be applied to calibrations of the pressure records. These four gauges have 12-hour clocks that are started at the surface before they are lowered into the borehole. The start times are recorded as well as other basic specifications (Fig. 5).

FIGURE 4.

BUNDLE CARRIER SCHEMATIC

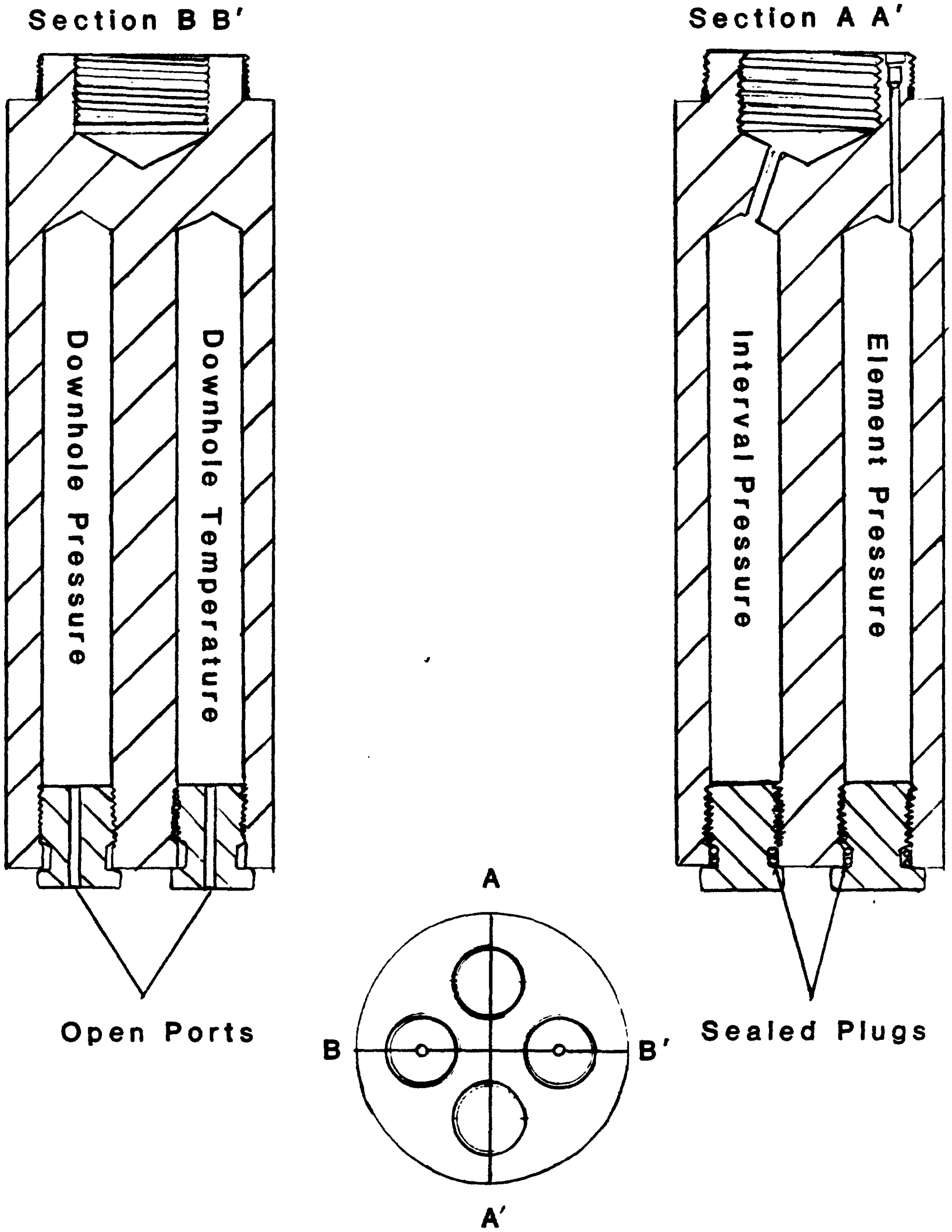


Figure 5.

KUSTER SPECIFICATIONS

SITE: CAJON PASS DATE: 4/2/87
DEPTH: 6719 FT. FRAC #: 8
BAROMETRIC PRESSURE: 27.002 GEORGE A.F.B 2877' ABOVE SEA LEVEL

BUNDLE CARRIER ASSEMBLY

```
1) 30,125 PRESSURE GAUGE     S/N 850710
    -12 HOUR CLOCK           S/N 863340       >ELEMENT PRESSURE
    -RECORDING SECTION       S/N 856215
     STARTED CLOCK: 22:13:47
2) 10,675 PRESSURE GAUGE     S/N 29750
    -12 HOUR CLOCK           S/N 32825        >DOWNHOLE PRESSURE
    -RECORDING SECTION       S/N 856214
     STARTED CLOCK: 22:14:00
3) 30,400 PRESSURE GAUGE     S/N 850711
    -12 HOUR CLOCK           S/N 863344       >INTERVAL PRESSURE
    -RECORDING SECTION       S/N 856219
     STARTED CLOCK: 22:14:49
4) KT-B TEMPERATURE GAUGE    S/N 27796
    -12 HOUR CLOCK           S/N 863331
    -RECORDING SECTION       S/N 856215       >DOWNHOLE TEMP.
     STARTED CLOCK: 22:15:49
```

WIRELINE ASSEMBLY

```
5) DI 10 K PRESSURE TRANSMITTER ABOVE ON WIRELINE
     -S/N 93388
     -SWITCHED HOUSINGS FROM #3 TO #1 SAME 10K S/N 93388
6) 29,875 PSI GAUGE          S/N 850729
    -6 HOUR CLOCK            S/N 18917
    -RECORDING SECTION       S/N 856217
    -CLOCK STARTED: 05:57:16
```

BUNDLE CARRIER

```
                                         ---------------------------------
                                    -      -
PACKER ELEMENT (10)              -    (1)    -   --------
                               -               -
                              -                 -
BOTTOM T/P (96)     (50) - (4)          (2) -             ----------
                             -                  -
                              -                -
INTERVAL PRESS. (11)           -    (3)      -    --------
                                -          -
                                  -      -
                                         ---------------------------------
```

WIRELINE ASSEMBLY

The pressure gauge on the wireline records two events; inflation of the packers to set them, and pumping on and or pressuring up of the test interval between the packers.

The Kuster gauge and a Data Instruments (DI) pressure transmitter are run together on the wireline. The DI gauge is read at the surface in the logging truck (see Updegrove and Springer, 1987). The Kuster gauge screws onto the bottom of this gauge and a standing valve is connected to the bottom of the entire assembly. The Data Instruments gauge and the Kuster gauge record the same pressures (fig. 6). The Data Instruments gauge delivers instantaneous pressure readings during testing.

The packer/bundle carrier assembly is tripped to the test depth. Since the wireline gauge is tripped later and can be replaced during the operation, it has a 6-hour clock. The standing valve and wireline assembly sits on top of the packer assembly inside the tubing while the packers are being inflated and set. After setting the packer, the wireline assembly with the dart attached is pulled ten feet above the packer assembly, opening the interval for testing.

The interval is subjected to several pumping cycles in order to determine the maximum and minimum horizontal principle stresses (see Hubbert and Willis, 1957; Zoback and Haimson, 1983). After the test is completed, the wireline must be lowered again for the unsetting procedure. The wireline is then pulled completely out of the hole. The gauge is taken off the wireline and the chart removed.

The chart is marked as follows: The parameter measured, the gauge serial number, date, and the clock run time (ie. WIRELINE, S/N 850729, 4-2-87, 6-HOUR CLOCK). The packer assembly can either be moved to another testing depth or pulled completely out of the hole. This decision is determined by the time remaining on the 12-hour clocks inside the bundle carrier gauges.

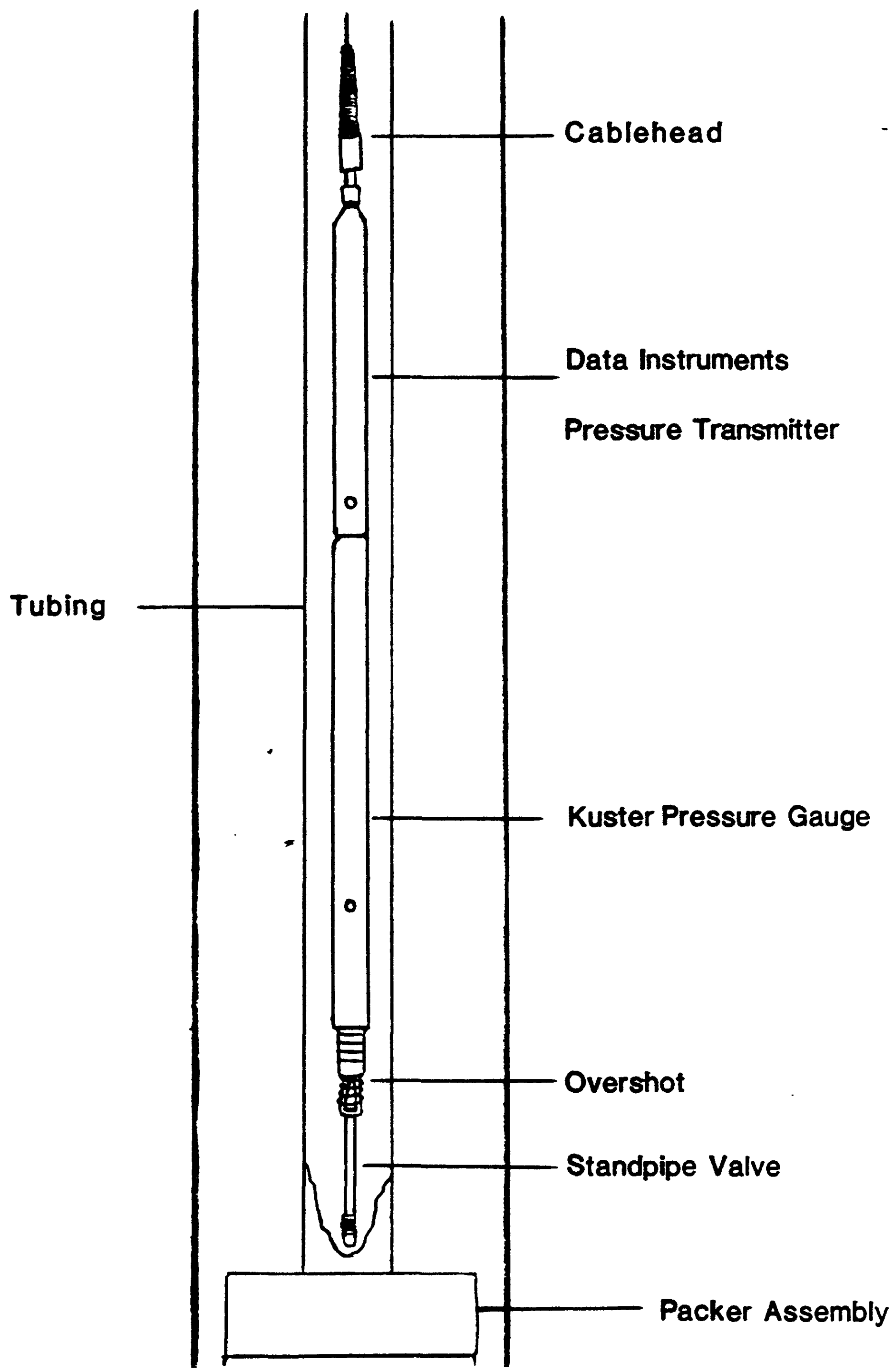
If the downhole gauges have sufficient time remaining, the packer/bundle carrier assembly is moved, a fresh chart is put into the wireline gauge, and it is run down to the top of the assembly again. The hydraulic fracturing test procedure is then repeated.

When the packer/bundle carrier assembly is pulled, the gauges are removed from the bundle carrier, cleaned, and the charts are removed. These charts are labeled similar to the wireline chart and placed into a envelope with the: test name, test date, number of charts, and the frac number marked. (ie. CAJON PASS, 4-2-87, 5 CHARTS, FRAC 8).

This envelope is brought back to the field office for digitization.

FIGURE 6.

WIRELINE ASSEMBLY SCHEMATIC



DIGITIZING SYSTEM

The pressure and temperature information is recorded in real time by the gauges. To process the information, the records are first digitized.

The charts are read with a Kuster 2-way reader fitted with a 20X microscope (fig. 7). The operator looks through the microscope and follows the trace, as recorded by the stylus, by turning micrometer dials on the x- and y- axes, keeping it centered on the cross-hairs in the scope. A foot pedal is pushed each time a point is entered. The signal from the encoder is fed through a Kuster PBR interface to a IBM Personal Computer which records the points as they are digitized.

KUSTER DATA FILING SYSTEM

A separate disc is used for every site. In this case the label "CAJON PASS DATA AND CALIBRATIONS" is written onto the disc. This disc contains the digitized chart records and the calibration charts at actual temperature (ie. DATA.CAT).

The filing system for the digitized Kuster charts is done on an IBM PC. After the chart has been retrieved from the KPG, and brought back to the field office, a separate file has to be created for that specific chart. These files are called "data", and are listed under subdirectories according to which gauge they were recorded in. These subdirectories are listed under directories according to frac number. The directories are specified as to which disc drive they are stored in.

B:\FRAC1\INTERVAL\DATA.CAT

B:............the disc drive the directories are stored in.

FRAC1..........the first Hydrofrac at this particular site.

INTERVAL.......the parameter this gauge was surveying.

DATA...........the digitized coordinates in inches.

CAT............the calibration of the data at actual temperature.

CALIBRATION PROCEDURES

Kuster company calibrates each gauge using temperature and pressure controls to produce a unique table. A hot oil bath is used to achieve the temperature for calibration. The pressure is controlled using a dead weight tester which is graduated in 2400 psi increments.

To obtain greater control, a calibration sub is connected in place of the bellows housing and an encoder replaces the recorder section. The calibration sub is then connected to the tester via

DIGITIZING SYSTEM

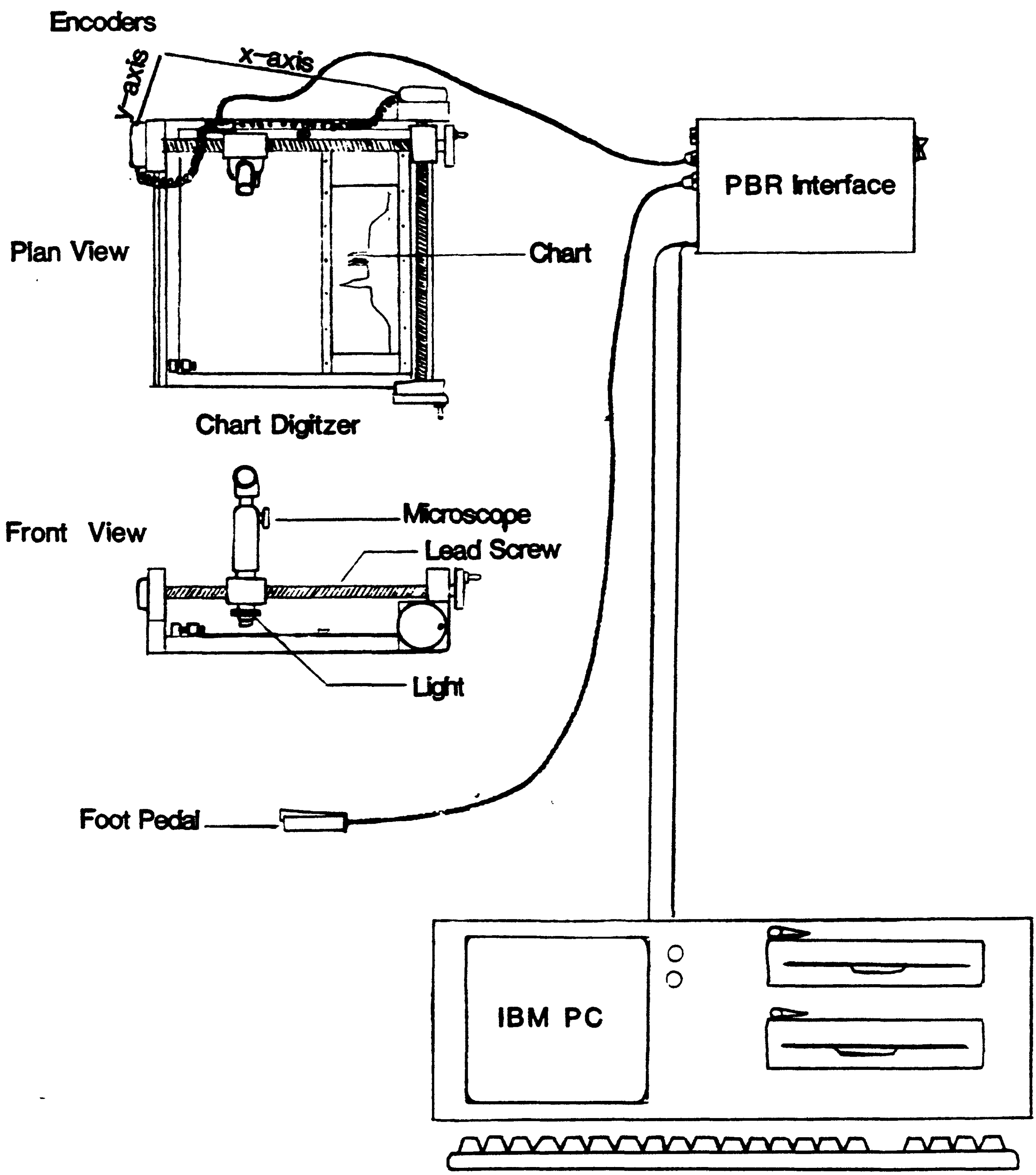


FIGURE 7.

a 1/4 inch stainless steel high pressure tube. This forms a closed pressure system. The pressure element is connected to the encoder which produces a four-digit readout.

This readout is recorded at each 2400 psi graduation throughout the gauge's range. The recorded values are multiplied by a constant (.000461344) to calculate the deflection in inches. This process is done on an IBM XT in BASIC menu driven programs. The tables received have one column containing pressure values (in psi) and a corresponding column giving the deflection values (in inches) at each of the 2400 psi increments, at the specified temperature. From this table, a second table is generated using linear interpolation between points. This table contains deflections in inches from .001 inches to 2.00 inches in increments of .001 inch. Full scale pressure is determined by the number that corresponds to 2.00 inches, rounded to the nearest 25 psi.

The gauges are calibrated at set temperatures (Fig. 8), one above and one below the expected operating temperature range. The actual temperature recorded by the temperature gauge is interpolated linearly between the two calibrated temperatures and recorded into the file with the data.

Figure 8.

CALIBRATION TEMPERATURES AND DATES

NO.	GAUGE RANGE:	DIAMETER INCHES:	S/N:	CALIBRATED TEMP: DEGREES F	DATE:
1	10 K PSI	1 1/4"	22350	175, 250	1/06/86
1	10 K PSI	1 1/2"	29750	350, 500	12/01/86
3	10 K PSI	1 1/2"	29751 29752 29753	350, 500	12/02/86
3	30 K PSI	1 1/2"	850710 850711 850730	350, 500	12/18/86
1	TEMP GAUGE	1 1/4"	27796	1-257 DEGREES C	2/13/87
1	TEMP GAUGE	1 1/4"	852427	0-260 DEGREES C	2/13/87

NO.	GAUGE RANGE:	DIAMETER INCHES:	S/N:	CALIBRATED TEMP: DEGREES F	DATE:
3	30 K PSI	1 1/2"	850729 850710 850711	70, 175, & 350	3/05/87
1	10 K PSI	1 1/2"	29750	70, 175, & 350	3/05/87
1	10 K PSI	1 1/4"	22350	70, 130	3/04/87
3	30 K PSI	1 1/2"	850710 850711 850729	175, 250 *	3/23/87
2	10 K PSI	1 1/2"	29750 29751	175, 250 *	3/23/87
1	TEMP	1 1/4"	27796	4-267 DEGREES C	3/23/87

* GAUGES WERE CALIBRATED ASCENDING TO AND DESCENDING FROM FULL SCALE.

The last calibration of the gauges was done ascending to and descending from the maximum pressure. This was done because the gauges show hysteresis when climbing to and falling from high pressure peaks. Since most of the data interpretation is taken with pressure falling from the peaks, the descending calibration is used in final interpretation. Time/Pressure plots are generated using the temperature calibrations (fig. 9).

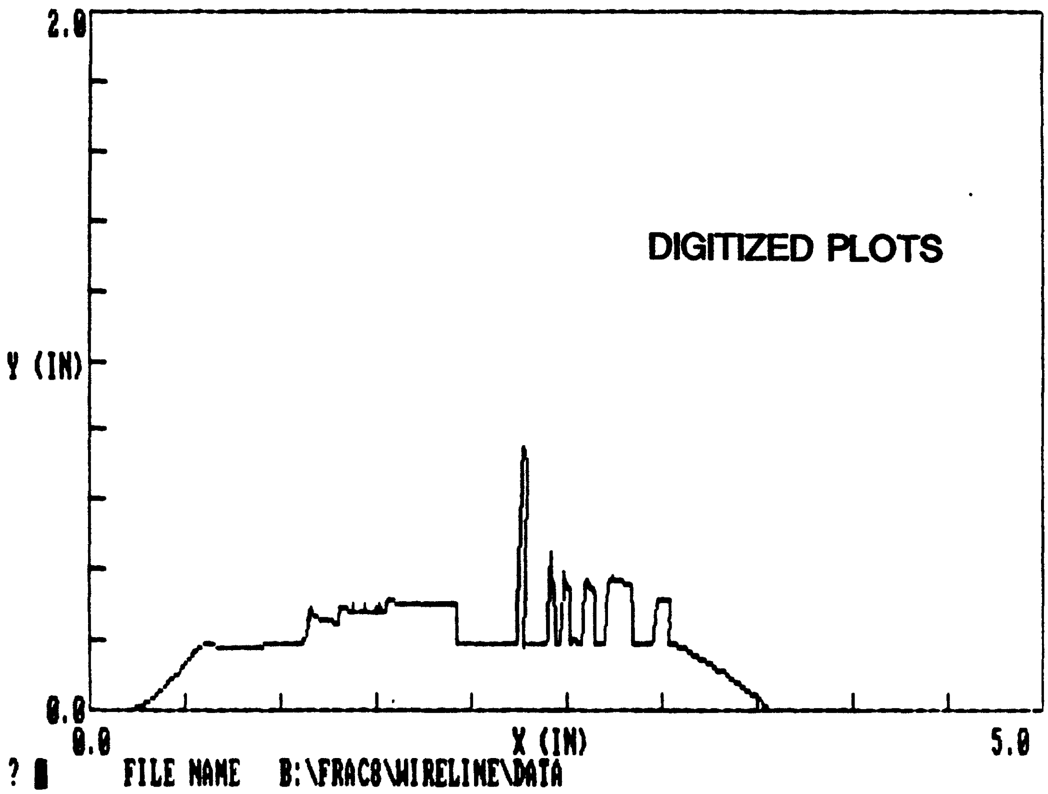
ACCURACY of the SYSTEM

The digitizer is capable of reading to the nearest one ten-thousandths (0.0001) of an inch. The trace is as much as 0.0008 inches wide, so when digitizing, the crosshairs are centered within the trace.

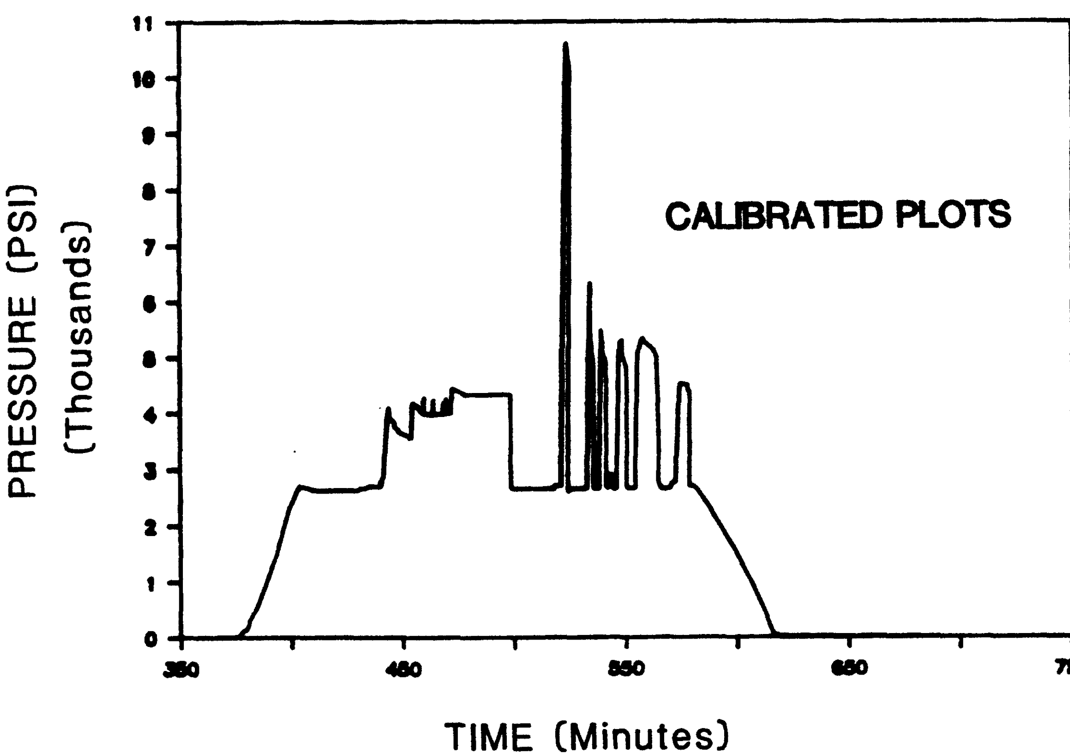
Vibrations are often seen on the records. They characteristically appear in two places on the charts. As the packer assembly is tripped in and out of the borehole, the system is subjected to quite a bit of jarring and bumping. This source of noise is restricted to the part of trace that is not critical to interpretation.

The other area where vibration shows up is in the peaks and troughs of pumping cycles. It appears as an extension of the pressure peak or trough, followed by an increasing-decreasing

FIGURE 9.



WIRELINE, FRAC 8



pressure vibration, whose amplitude decreases with time. This form of noise does show up during critical portions of the test and can cause inaccurate high and low pressure peaks to be digitized. The vibration shows up when the interval is pumped on at a fast rate and then shut-in. This could cause an inaccurate reading of the breakdown, or peak pressure. Vibrations also show up in the trough of a pressure dump, or a rapid decrease in pressure, within an isolated system. This vibration could be caused by air within the Kuster gauge's pressure housing or an elastic response of the bourdon tube. During rapid pressure changes, the air responds by changing volume. When the pressure change ceases the air responds by a series of compressions and dilations until it equalizes with the pressure within the system.

Other errors can occur in the digitization itself. Because the reading of the charts is done by eye and at the digitizer's discretion, human error is always possible. Furthermore, point density is another factor that may cause error. Some parts of the trace may be digitized more densely than others causing the trace to look smoother in places, as opposed to appearing squared off. In order to minimize this problem, two or more people may digitize the same trace. The two different traces are then compared statistically to see how close they are to each other. The traces are compared until agreement is reached. If they vary by a great amount, then a third person is called in to digitize until two traces match.

SUMMARY

Five downhole mechanical gauges were used for each of the eight hydraulic fracturing tests performed at Cajon Pass. These gauges were used in conjunction with electronic strain gauges at the surface. Each mechanical gauge measured a different parameter; four measured pressure, and one measured temperature. Each gauge produced a chart with a trace of the pressure parameter it measured. The chart has time on the X-axis and pressure or temperature on the Y-axis.

After the charts were removed from the gauges, they were brought back to the field office and digitized. This was done by a Kuster two-way reader through a PBR interface box. They were synthesized using an IBM Personal computer. Eight hydrofracs were attempted, and of these, 25 charts were digitized. These charts were first digitized in inches with 5 being the maximum x-value and 2 being the maximum y-value. Applying temperature-compensated calibrations to the digitized data allowed inches of deflection to be converted to actual pressure and temperature.

The problems that were found with the digitization accuracy were due to mechanical vibrations, air volume pressure fluctuations, or errors induced by the person digitizing. All of these errors can be eliminated or decreased by careful observation and practices and/or by use of statistical methods of evaluation.

The performance of these gauges was quite remarkable, since only three minor malfunctions were recorded. Not only did they render very valuable information, but they hold promise for deeper measurements at higher temperatures and pressures, where other gauges will not survive.

ACKNOWLEDGMENTS

Thanks to all the members of the project; Jack Healy, Joe Svitek, Jim Springer, and Bill Updegrove for without their help and support this paper would not be possible. Thanks to Thomas Moses for reviewing this paper. Thanks to John Jacobson, Stephen Ficken and Ron Smith of the Kuster Company for their advice, "Doc" Stokely of Tam International Inc. for his consulting, and the entire USGS drill crew for the testing and re-testing of the equipment.

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