DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

In-Situ Stress Project, Technical Report Number 9: Interpretation of Hydraulic Fracturing Data from Yongping, Western Yunnan, China

by

Springer, J.E.[1], Zhai Qingshan[2], Haimson, B.C.[3], Zoback, M.D.[1,4], Lee, M.Y.[3], and Li Fangquan[2]

U.S. Geological Survey

Open-File Report 87-491

Prepared in cooperation with the State Seismological Bureau of China, the University of Wisconsin, and Stanford University.

[1] Menlo Park, CA [2] Inst. of Crustal Dynamics, Beijing, China [3] Univ. of Wisconsin, Madison

[4] Stanford Univ.

1987

CONTENTS (continued)

TABLES

INTERPRETATION OF HYDRAULIC FRACTURING DATA FROM YONGPING, WESTERN YUNNAN, CHINA

by

James Springer, Zhai Qingshan, Bezalel Haimson, Mark Zoback, Moo Lee, and Li Fangquan

ABSTRACT

Hydraulic fracturing stress measurements were performed in a 500 m-deep well at Yongping in western Yunnan, a region of high seismicity and active normal and strike-slip faulting. The well was drilled in an alkali syenite intrusion. Five methods were used to determine the instantaneous shut-in pressure. These were: (1) the inflection point method (IP), (2) the dP/dT vs Pressure method, (3) a nonlinear regression method for isolating the negative exponential part of the decay curve (NLR), (4) minimal flow-rate pumping pressure (LF), and (5) flow-rate vs pressure (FR). These methods were compared and upper and lower bounds were placed on the value of Shmin. The criterion for chosing or rejecting a method was its internal consitency and its consistency compared to other methods. The most successful methods was the inflection point method, which is the most subjective and the nonlinear regression method which is relatively objective.

Rubber impressions of the test intervals were taken after the tests. These provided evidence that hydraulic fractures had been created, although clear breakdown pressures were not always seen during the tests. Because of poorly controlled pumping rates, fracture reopening pressures were hard to pick accurately and are presented as ranges of possible values. These ranges yielded uncertainties for the value of the maximum horizontal stress that varied from 7% up to 40%.

The vertical stress is intermediate in value between the maximum and minimum horizontal stress, indicating a strike-slip stress regime. Orientations of hydraulic fractures are consistent with a maximum horizontal stress of direction of N20-40E.

INTRODUCTION

The joint Sino-U.S. in-situ stress program was undertaken in an effort to understand the tectonic stress field in a seismically active area of northwestern Yunnan, China (fig. 1). The hydraulic fracturing method was chosen because of the advantage of being able to make deep measurements (Haimson and Fairhurst, 1970). The first two sets of measurements were performed in 500 m-deep wells at Xiaguan and Yongping (fig. 2). The Yongping well was drilled 15 km northeast of the Lancang River fault and the measurements were carried out during 1984.

The region is characterized by active normal and strike-slip faulting (Allen et al., 1984: Liu et al., 1986). The most

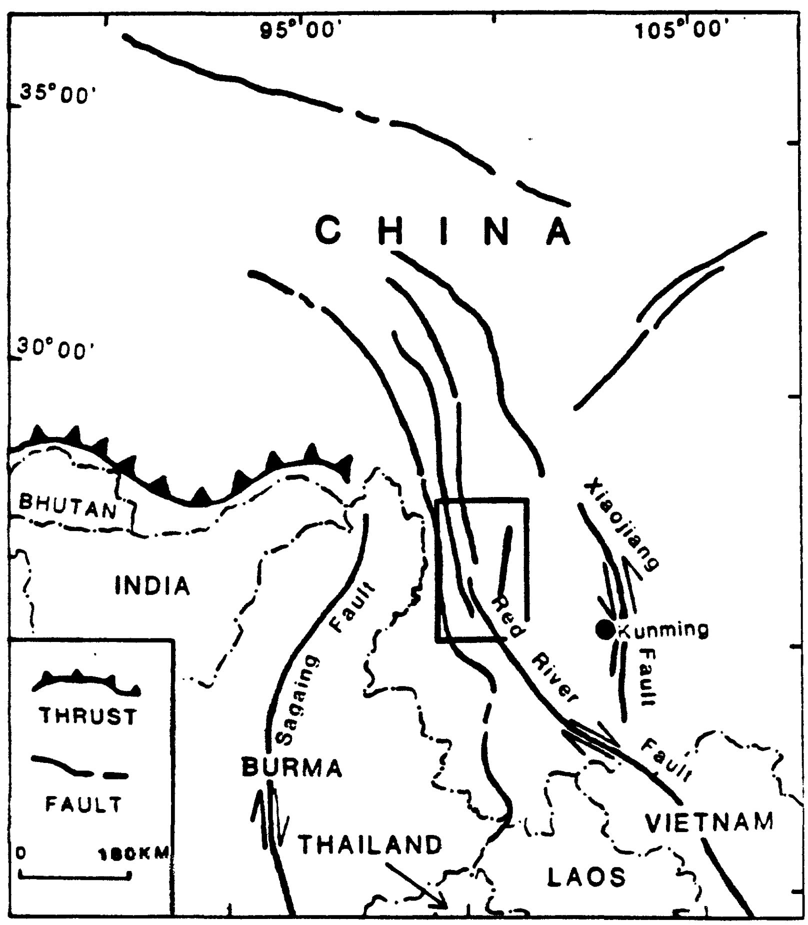

Figure 1. Location map showing the western Yunnan region where the stress measurements were made. The rectangle represents the area of fig. 2.

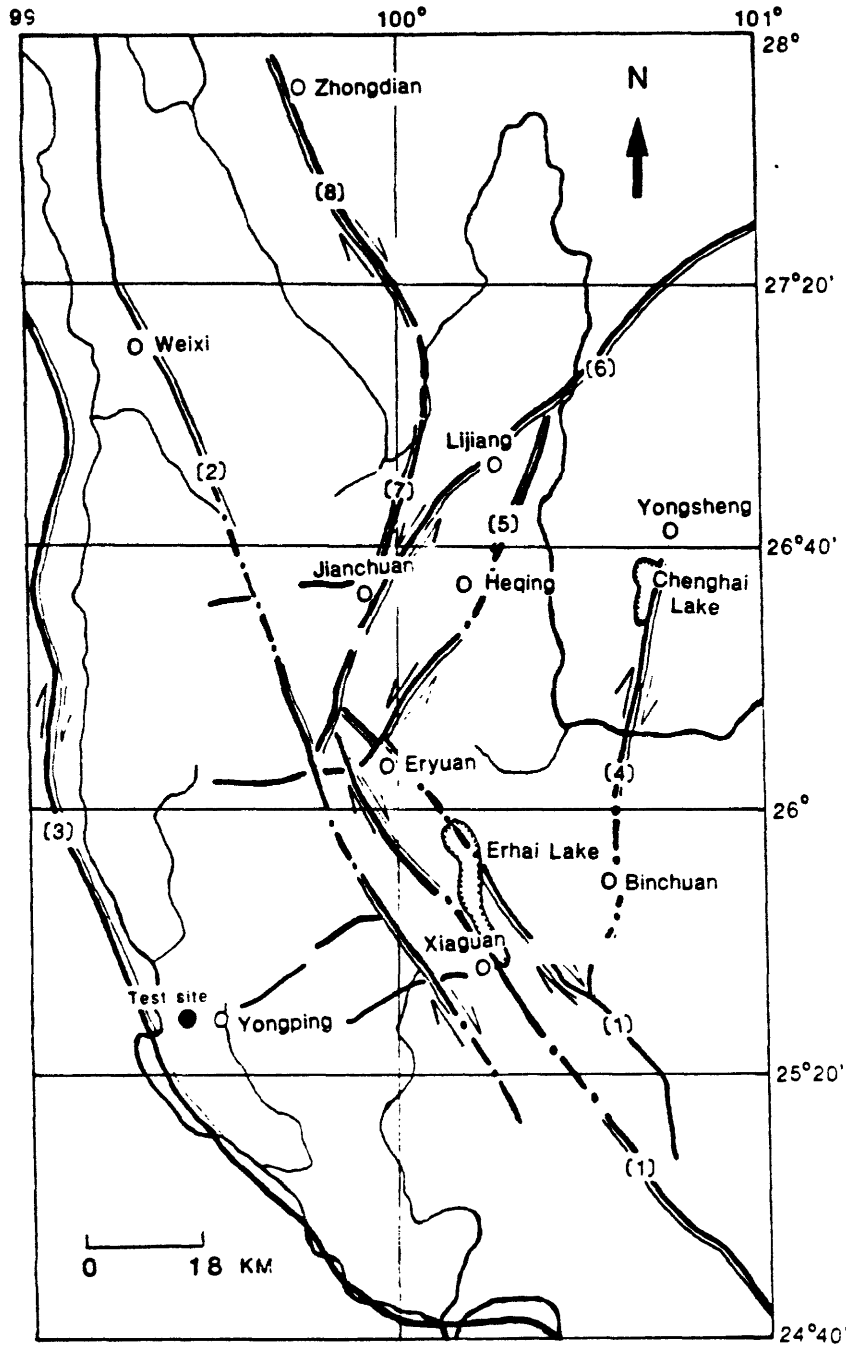

Figure 2. Generalized fault map showing the location of the hole. Faults keyed by number on the map are: (1) Red River fault, (2) Madeng fault, (3) Lancang River fault, (4) Chenghai-Binchuan fault, (5) Heqing-Eryuan fault, (6) Lijiang fault, (7) Jianchuan fault, and (8) Zhongdian fault. For more discussion of these faults, see Springer et al. (1987).

prominent tectonic feature is the Red River fault which has a length of at least 900 km and shows both normal and right-lateral strike-slip movement. The Lancang River fault, near Yongping is a similar type of fault, but has a much lower slip-rate (Institute of Crustal Dynamics, 1985). Another set of faults trends northeast and these have normal and left-lateral motion on them (Li et al., 1986; Liu et al., 1986; Wu and Deng, 1985; Yan et al., 1983).

The local geology and analysis of televiewer logs from the Yong Ping well is described in an open-file report (Springer et al., 1987). The analysis of the hydraulic fracturing stress measurements is presented in this paper. We first describe the methods used to interpret the data, then we present the results of each method and place upper and lower bounds on the principal stresses.

METHODS

Hubbert and Willis (1957) first described the relationship between hydraulic fracturing and in-situ stress. The method is based on the principle that, in mechanically isotropic rock, a hydraulically induced fracture will propogate in a plane normal to the least principal stress. Zoback and Zoback (1980) and McGarr and Gay (1978) present data supporting the assumption that, at depth, the vertical stress Sv and the maximum and minimum horizontal stresses (SHmax and Shmin) are nearly parallel to the three principal stresses.

The hydraulic fracturing technique consists of isolating a section of the borehole with inflatable rubber packers and pressurizing the interval between them. Assuming that the rock behaves elastically, the minimum tangential compressive stress occurs along the azimuth of SHmax and enough applied pressure results in tensile failure of the well bore in this direction. The induced fracture is usually vertical. An example of a pressure-time record is shown in fig. 3. The pressure at which the rock breaks, indicated by the first peak in the pressure-time record, is called the breakdown pressure, Pb. After the breakdown pressure is reached, the well is shut in and the pressure decays rapidly. When the fracture closes, the rate of this decay changes. The pressure at which this happens is called the instantaneous shut-in pressure (ISIP). Because this is the minimum pressure required to hold the fracture open, it is considered to be equal to the least horizontal principal stress.

Using the Kirsch equations (Jaeger and Cook, 1976) for stress concentrations around the borehole , Haimson and Fairhurst (1967) derived the relationship between Pb, SHmax, Shmin, the pore pressure Po and the tensile strength, T:

$$Pb = 3Shmin - SHmax - Po + T \qquad [1]$$

Since data on the tensile strength were not available, the fracture reopening pressure Pr was used to determine SHmax. This

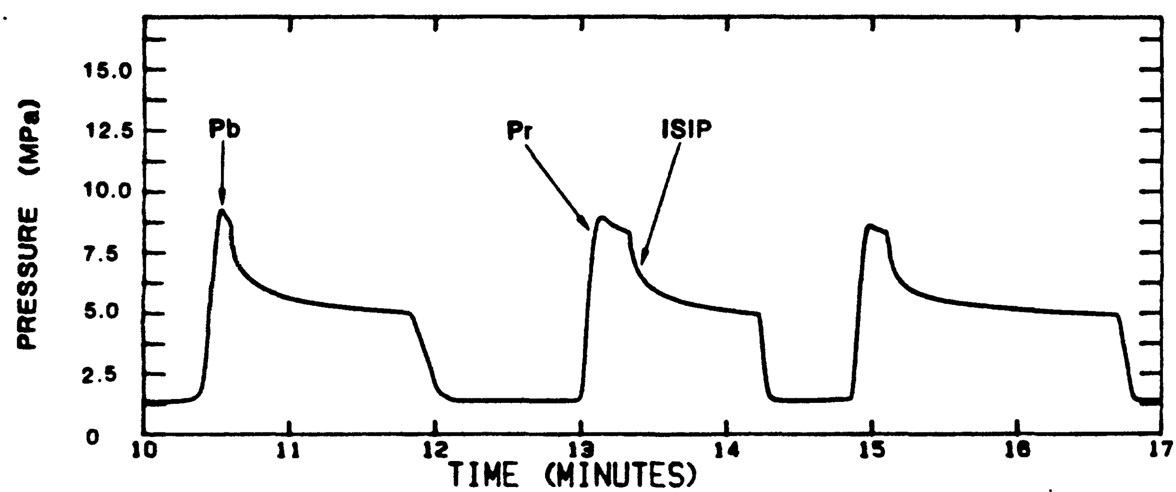

Figure 3. Example of a pressure-time record showing the ISIP, Pr, and Pb.

is equivalent to a breakdown pressure with zero tensile strength and is related to SHmax by the following relationship (Bredehoeft et al., 1976):

$$Pr = 3Shmin - SHmax - Po \qquad [2]$$

The fracture reopening pressure is estimated from a change in the pressure buildup curve during a pumping cycles (fig. 3). Constant flow rates yeild the best estimates of Pr and the best picks for Pr typically come from the third pumping cycle (Hickman and Zoback, 1983). Because we were unable to control the rates as well as we would have liked, the values of Pr were usually ambiguous and we picked them from whatever cycles we could. We present estimates of Pr values as upper and lower bounds.

Determination of Shmin

Because the ISIP on the decay curve is not always visible by inspection, five different methods were used to determine the value of Shmin. These methods can be divided into two categories, those involving the decay curve and those involving pumping pressures. The methods involving the decay curve are the inflection point method (IP), nonlinear regression (NLR), and the dP/dT vs P method. The methods involving pumping pressures are; flow rate vs pressure (FR) and low flow-rate pumping pressure (PLR). These methods are briefly described below:

Inflection Point Method. The inflection point method is the simplest method and it involves picking the inflection point on the decay curve after shut in. When the inflection point is not visible by inspection, a variation on this method, was used successfully by Gronseth and Kry (1983) in high modulus crystalline rock. To use this method, a straight line is drawn tangent to the decay curve from the point of shut in (fig. 4). The point at which this line departs from the decay curve is taken to be the ISIP.

Nonlinear Regression Method. The nonlinear regression method is based on the observation of Muskat (1937) that as fluid flows between a well and porous rock, the pressure decays in a negative exponential fashion. The first segment of the curve immediately following shut in usually does not fit the exponiential model because the fracture is still open. Assuming that the fracture loses its permeability after it closes, fluid flow into the well will be through the porous rock and will follow an exponential decay function of the form: $P = a + \exp(b-ct)$ where a, b, and c are constants, P is the borehole pressure, and t is time.

A nonlinear regression is run on the digitized pressure-time record from the time the well is shut in. If this regression does not provide a good fit to a negative exponential function, the first point is thrown out and the regression is run on the remaining points. This step is repeated until a negative exponential fit is acheived. The exponential curve is then extrapolated back to the point where shut in was initiated and that pressure

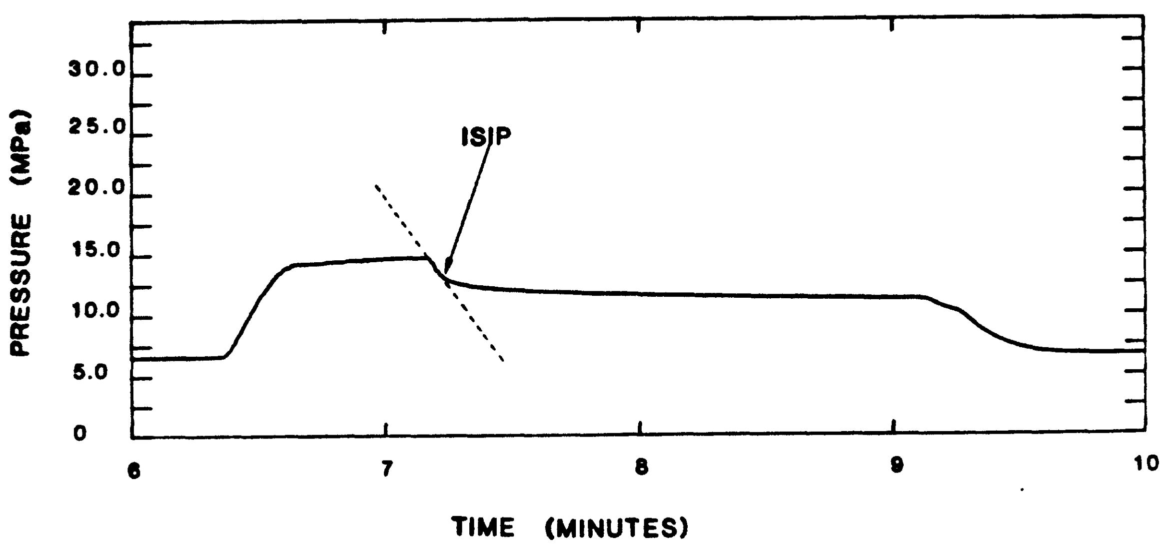

Figure 4. Example of the tangent method of chosing an inflection point on a pressure-time record.

is taken as the ISIP. An example of this method used on a laboratory sample (Haimson and Lee, 1987) is shown in fig. 5.

dP/dT vs P Method. Because the ISIP is chosen as the point at which the decay rate changes, it follows that there will be a significant change in the first derivative of the pressure-time curve. By plotting dP/dT vs pressue (fig. 6) a change in slope is found and that pressure is taken as the ISIP (Haimson et al., 1987).

Flow Rate vs Pressure Method. On cycles subsequent to the breakdown cycle, the pumping pressure at a constant flow rate usually stablizes. These pumping pressures are most stable when the fracture is barely open. By plotting the various flow rates against the stable pumping pressures, the ISIP can be determined. When the fracture is closed, or nearly so, plotted points fit a steep straight line curve. When the fracture is open, the line has a shallower slope. This shallower curve is extrapolated back to the abscissa and the point of intersection is taken to be the ISIP (fig. 7). This method works best when all the data are taken from a single cycle. This is because the fracture's behavior may change as it is extended away from the well bore.

Low Flow Rate Pumping. While pumping at a very low flow rate, the pressure usually increases until it reaches a stable pressure plateau. This pressure is the pressure at which the fracture is barely open, allowing fluid to leave the borehole at the same rate that it is being pumped in. The low flow rate pumping pressure is an upper bound on the ISIP.

RESULTS

Five intervals were tested at Yongping and a total of 39 cycles were analyzed. The intervals were chosen by inspection of the core and televiewer logs. After fracturing, a rubber impression was taken of the test interval in order to determine the orientation of the induced fractures. The lowest interval was 2.3 m long and the rest of the intervals were 2.5 m. General data on the borehole is presented in Table 1. A cycle by cycle tabulation of the results of each test is provided in the Appendix. Blank spaces on these tables mean that either the method was not attempted on that cycle or it did not work. By comparing the results of each method and inspecting the pressure records, upper and lower bounds were placed on the minimum and maximum horizontal stresses. These bounds, along with the vertical stress calculated from average densities, are provided in Table 2.

Test A - 175 m. A probable breakdown of 6.3 MPa occurred on the first cycle. The ISIP from inflection points decreased with successive cycles and a value of 3.9 MPa was chosen from the second cycle. This compares well with the values from the nonlinear regression (3.6 MPa), flow-rate vs pressure (3.7 MPa), and low flow-rate pumping pressure (3.8 MPa) methods. The dP/dT method yielded values from 2.4 to 3.5 MPa and a representative value of 2.9 MPa was taken as the lower bound for the ISIP.

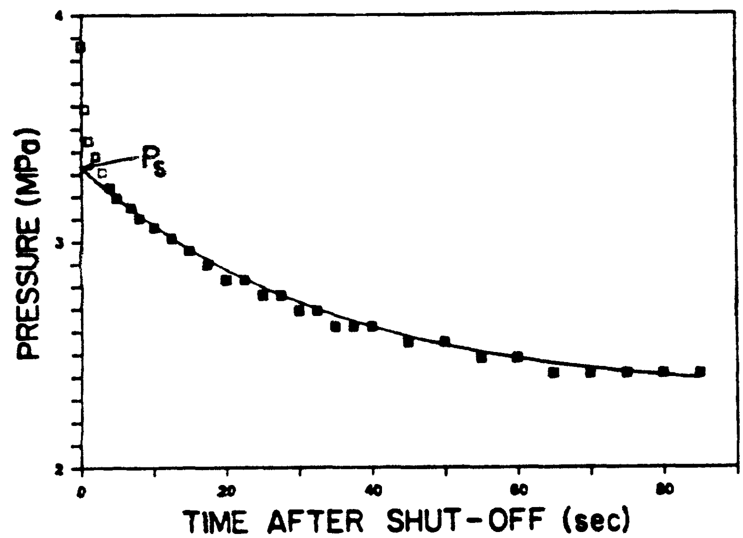

Figure 5. Example of the negative exponential nonlinear regression method for chosing the ISIP (after Haimson and Lee, 1987)

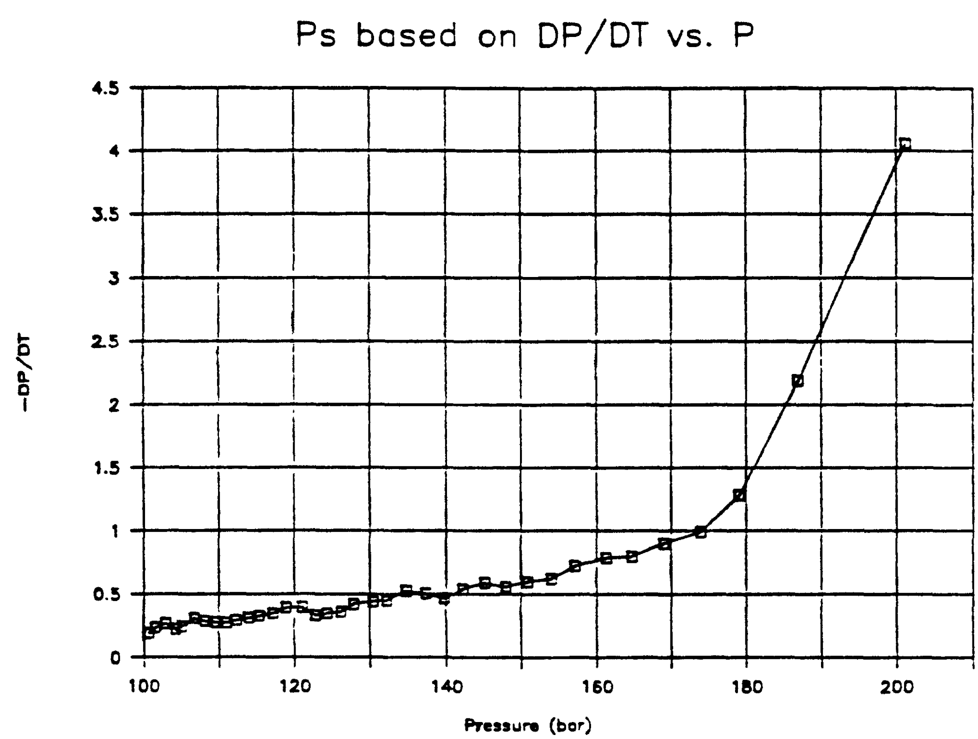

Figure 6. Example of the dP/dT method for chosing the ISIP (from Haimson et al., 1987)

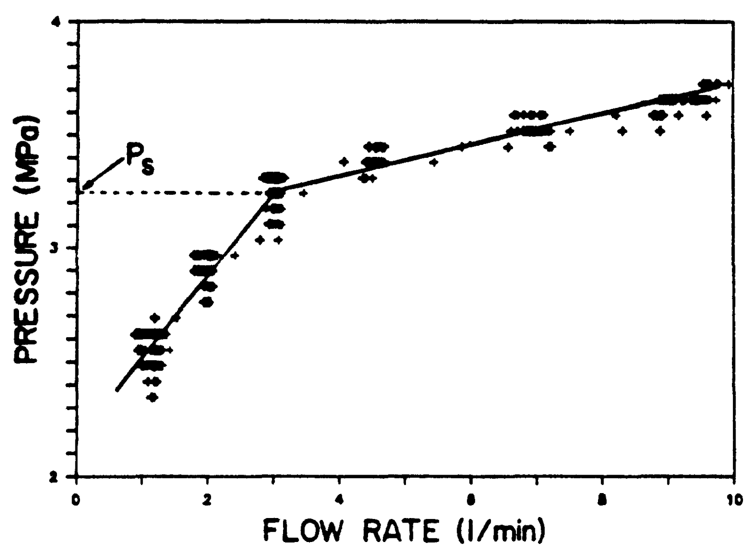

Figure 7. Example of the flow-rate vs pressure method for chosing the ISIP.

Fracture reopening pressures ranged from 3.1 to 3.7 MPa, yielding an uncertainty of ± 40 % for SHmax.

TABLE 1
General Data on the Yongping Borehole

Hole Name	Latitude and Longitude	Elevation (meters)	Water Level (meters)	Average Density
Yongping	25° 28'36"N 99° 26'30"E	2230	11	2.60

Test B - 202 m. Because of the extremely low flow-rates used, breakdown was not achieved on the initial cycle. On the second cycle, a breakdown pressure of 8.8 MPa was recorded. The impression packer showed a vertical fracture oriented N36E that was not preveously seen on the televiewer log (fig. 8). This suggests that a fracture was in fact created.

TABLE 2
Stress Determinations from Yongping

Test	Depth (m)	Shmin Min.	Shmin Max	SHmax Min.	SHmax Max.	Sv	Azimuth of SHmax
A	175	2.9	3.9	3.4	6.9	4.6	--
B	202	4.3	5.6	5.4	10.7	5.3	N36E
C	233	5.4	5.6	8.1	10.3	6.2	N26E
D	324	4.7	5.6	6.4	9.2	8.4	Unknown
E	445	7.9	8.4	13.2	15.1	11.6	--

Shut-in pressures from the inflection point method decreased with successive cycles and a representative value of 5.6 MPa was chosen from cycle number three as an upper bound. Values of 4.6 MPa and 4.3 MPa were chosen from the low flow-rate and flow-rate vs pressure methods. Values from the nonlinear regression method were higher, however they are questionable because the pressure was dumped to the surface too early for the curve to take on a good negative exponential form. Fracture reopening pressures varied from 4.2 to 5.6 MPa on cycles 3, 7, and 8. These yielded an uncertainty of ± 33 % for the value of SHmax.

Test C - 233 m. Again, the extremely low flow rates failed to

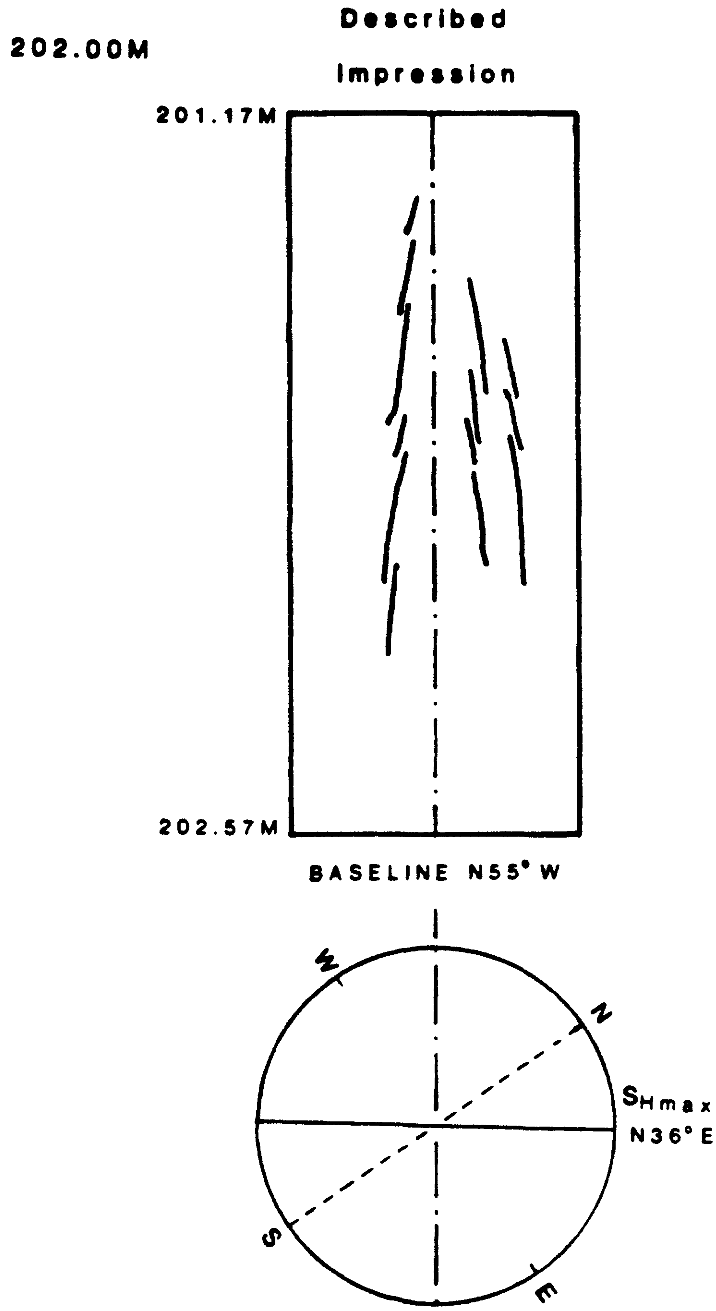

Figure 8. Tracing of the impression packer from Test B.

cause a breakdown pressure on the initial cycle, and a breakdown of 8.6 MPa was recorded for the second cycle. The impression revealed a new vertical fracture oriented N26E (fig. 9).

The ISIP from the inflection method was initially 5.4 MPa and dropped substantially on the remaining cycles. The nonlinear regression and dP/dT methods yeilded values of 5.6 and 5.4 MPa, respectively. The low flow-rate pumping pressure of 4.8 MPa was judged to be low and the flow-rate vs pressure method gave a high value of 6.2 MPa. Fracture reopening pressures ranged from 4.3 to 5.9 MPa, yielding an uncertainty of ±13 % for SHmax.

Test D - 324 m. A breakdown of 7.1 MPa was recorded on the first cycle. An impression was taken of a vertical fracture that was previously unseen on the televiewer log (fig. 10). Because the orientation mark was accidentally rotated, the orientation of this fracture is unknown.

From the inflection point method, shut-in pressures generally decreased with successive cycles and a value of 5.4 MPa was chosen from the second cycle. The dP/dT method provided a reasonable lower bound of 4.7 MPa. Values of 5.2, 5.4, and 5.6 MPa were taken from the flow-rate vs pressure, low flow-rate, and linear regression methods, respectively. The fracture reopening pressure was taken as 4.5 to 4.6 MPa, which yielded an uncertainty of ± 18% for the value of SHmax.

Test E - 445 m. No breakdown was achieved. There was no post-fracturing impression, so it is uncertain whether a new fracture was created. ISIP values of 8.4 MPa were derived from the inflection point, nonlinear regression, and low flow-rate pumping pressure methods. The flow-rate vs pressure method yielded a value of 8.5 MPa and the dP/dT method gave a lower bound of 7.9 MPa. Fracture reopening pressures range from 5.8 to 6.2 MPa and yield an uncertainty of ± 7% for SHmax.

At Yongping, the low flow-rate pumping pressures did not yield higher values than the other methods of obtaining ISIP's. This may be related to the extremely low flow rates, sometimes as low as 0.9 l/min, that were used in the tests. In some of the tests, insufficient time was allowed for the pressure decay to take on a negative exponential form, so the nonlinear regression method would not work. In the cases where it did work, the results were generally consistent. The dP/dT method provided a reasonable lower bound in nearly every case.

The value of Shmin was consistently lower than the lithostatic stress (fig. 11). The value of SHmax was generally greater than or equal to Sv. The likelyhood of for frictional sliding favorably oriented faults is related to the maximum shear stress, pore pressure Po, and coefficient of friction μ, by the relationship derived by Zoback and Healy (1984):

$$S1-P0/S3-Po = [(\mu^{2} + 1)^{1/2} + \mu]^{2} \qquad [3]$$

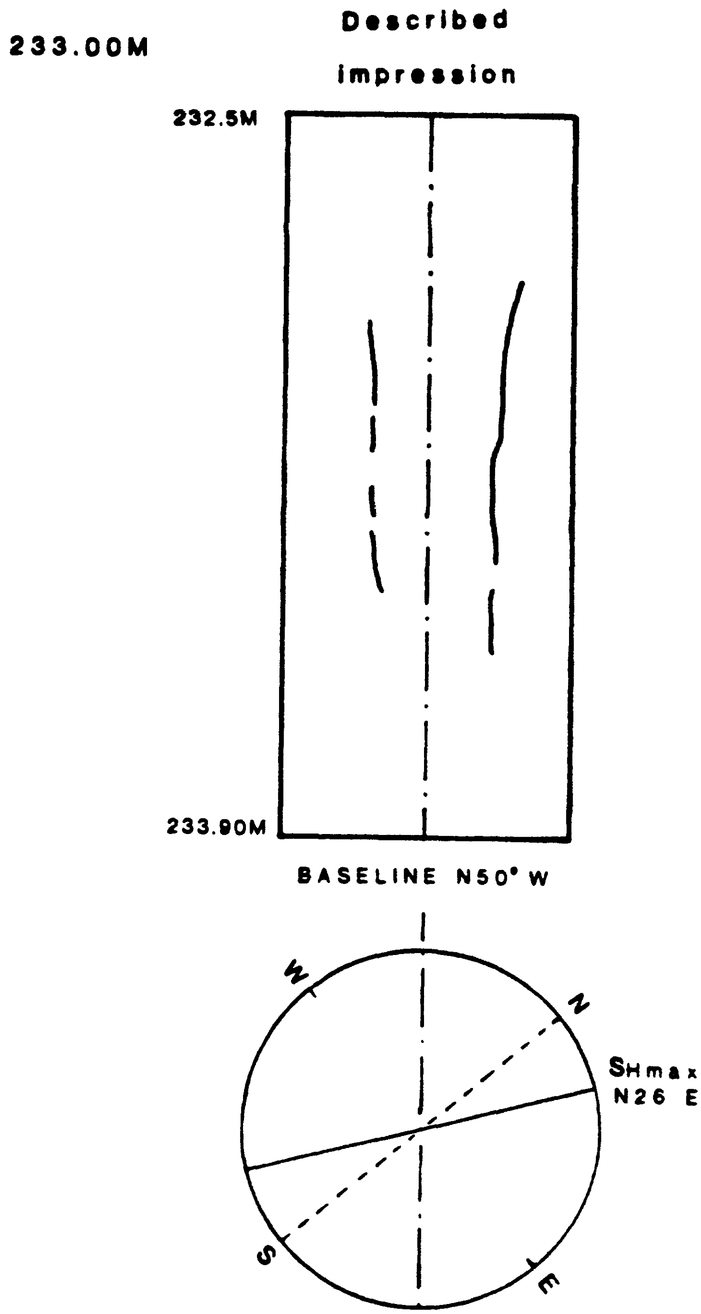

Figure 9. Tracing of the impression packer from Test C.

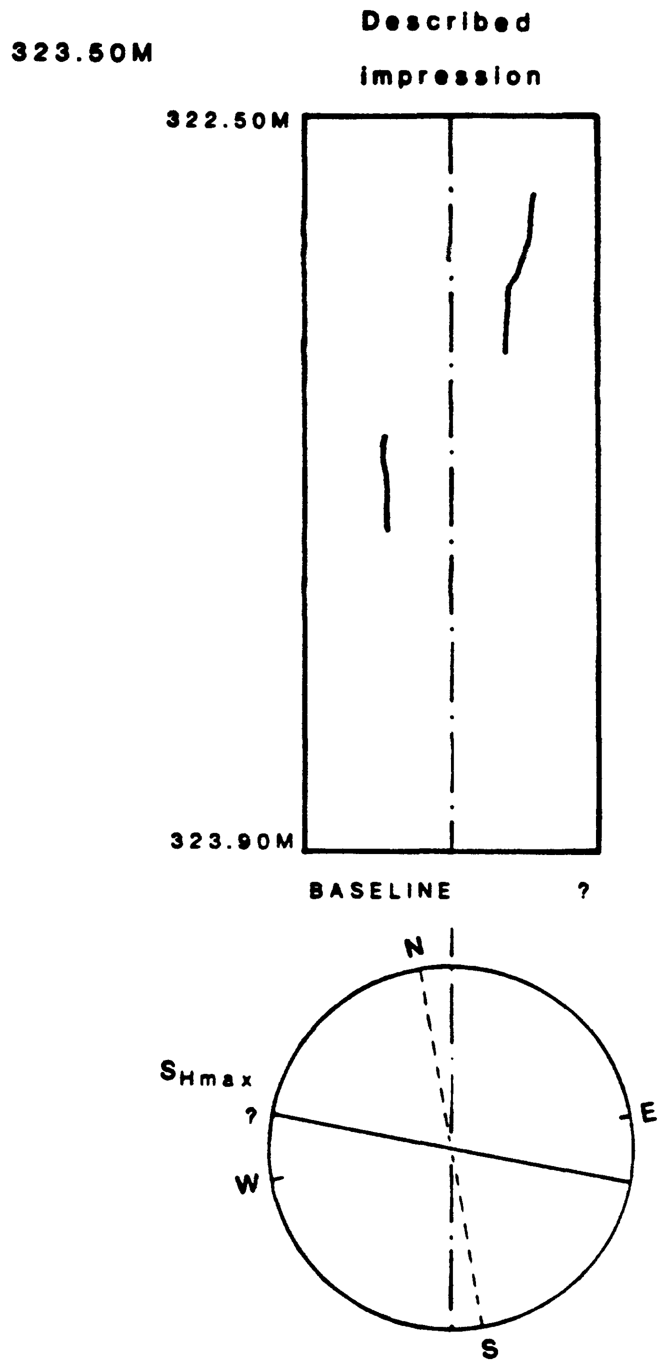

Figure 10. Tracing of the impression packer from Test D.

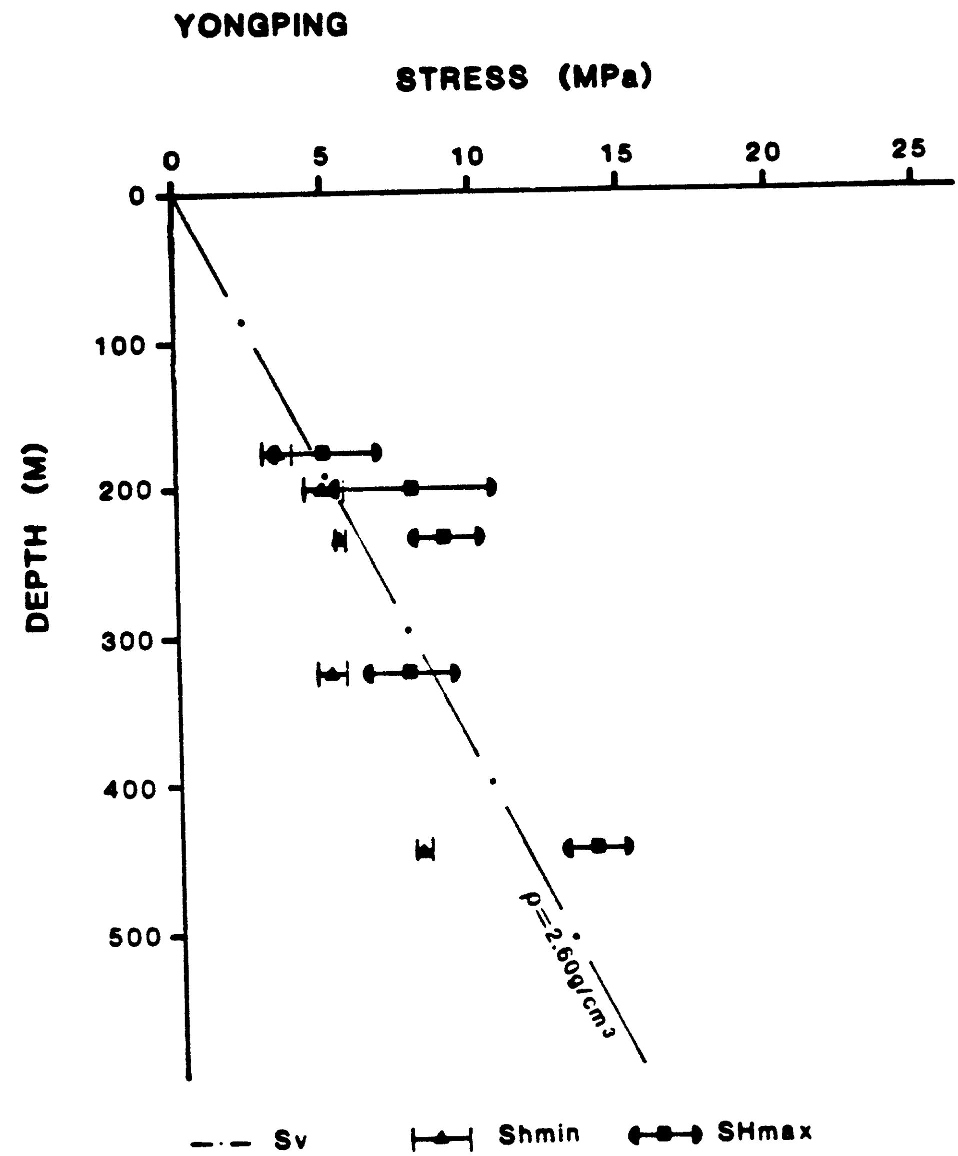

Figure 11. Plot of SHmax, Shmin, and Sv vs depth at Yongping.

where S1 and S3 are the maximum and minimum principal stresses, respectively. Assuming, based on the work of Byerlee (1978) for for normal stresses greater than 5 MPa, that the frictional coefficient is between 0.6 and 1.0, the measured stresses show that the rocks do not appear close to failure in the strike-slip or normal mode. The value of Shmin, however is increasing linearly at a rate of only 0.014 MPa/m, much lower than the lithostatic gradient. Assuming that these gradients remain constant, the shear stress would increase enough to bring rocks to failure on favorably oriented normal faults at a depth of about 1500 m. Although this is a crude and speculative estimate, it shows that the measurements at these depths are consistent with the active normal and strike-slip faulting found in the region (Allen et al., 1984; Kan et al., 1977).

CONCLUSIONS

The inflection point, low flow-rate pumping pressure, flow-rate vs pressure, dP/dT vs P and nonlinear regression methods wêre used in order to determine the ISIP. Although the inflection point method is the most subjective of all methods, the end results from it were very consistent. In most cycles, the pressure was not allowed to decay long enough to make the nonlinear regression method useful. On those tests where it worked, however, it was very consistent.

The low flow-rate pumping pressures were inconsistent. Sometimes they were too high and sometimes too low. This may have something to do with the very low flow rates that were used or it may be related to some property of the rock.

Plotting pressure vs flow-rate provided fairly consistent results. Because the pumping rates were not very well controlled we were unable to run a good stepped-rate injection test from an individual cycle. This degraded the results from this method, however, it still seems to be a good method that can be used when other methods fail.

The dP/dT method provided consistent results that were slightly lower than any of the other methods. We think that these results provide a good lower bound on Shmin in the Yongping well.

Clear breakdown pressures were not always seen on the pressure record. This was probably influenced by the very low flow rates used on the initial cycles.

Because the flow rates were so difficult to control, we had to estimate the fracture reopening pressures as large ranges of possible values. This was a problem in both holes and it resulted in uncertainties of up to 40% for the value of the maximum horizontal stress.

The orientations of the hydraulic fractures revealed a maximum horizontal stress orientation of N20-40E. This is in general agreement with the horizontal component of slip on major faults in the region (Springer et al., 1987).

REFERENCES

Allen, C.R., Gillespie, A.R., Han Yuan, Sieh, K.E., Zhang Buchun, and Zhu Chengnan, 1984, Red River and associated faults, Yunnan Province, China: Quaternary geology, slip rates, and seismic hazard: Geological Society of America Bulletin, v.95, pp.686-700.

Bredehoeft, J.D., R.G. Wolff, W.S. Keys, and E. Shuter, 1976, Hydraulic fracturing to determine the regional in-situ stress field, Piceance Basin, Colorado: Geological Society of America Bulletin, v.87, pp.250-258.

Gronseth, J.M. and P.R. Kry, 1983, Instantaneous shut-in pressure and its relationship to the minimum in-situ stress: in, Zoback, M.D. and B.C. Haimson, convenors, Hydraulic Fracturing Stress Measurements, National Academy Press, pp.55-60.

Haimson, B.C. and C. Fairhurst, 1967, Initiation and extension of hydraulic fractures in rock: Society of Petroleum Engineers Journal, v.7, pp.310-318.

Haimson, B.C. and C. Fairhurst, 1970, In-situ stress determination at great depth by means of hydraulic fracturing: Proceedings, 11th U.S. Symposium on Rock Mechanics, American Society of Civil Engineers, pp.135-156.

Haimson, B.C. and M.Y. Lee, 1987, The state of stress and natural fractures in a jointed preCambrian rhyolite in south-central Wisconsin: 28th U.S. Symposium on Rock Mechanics, A.A. Balkema, Rotterdam, Boston, pp.231-240.

Haimson, B.C., L.W. Tunbridge, M.Y. Lee, and C.M. Cooling, 1987, Measurement of rock stress using the hydraulic fracturing method in Cornwall, U.K., Part 2: Detailed interpretation of the records: International Journal of Rock Mechanics and Mining Sciences (in press).

Hickman, S.H. and M.D. Zoback, 1983, The interpretation of hydraulic fracturing pressure-time data for in-situ stress determination: in, Zoback, M.D. and B.C. Haimson, convenors, Hydraulic Fracturing Stress Measurements, National Academy Press, pp.44-54.

Hubbert, M.K. and D.G. Willis, 1957, Mechanics of hydraulic fracturing: Journal of Petroleum Technology, v.9, pp.153-168.

Institute of Crustal Dynamics, 1985, Second Sino-American hydraulic fracturing stress operation in the earthquake prediction site, west Yunnan Province: (in Chinese) 1985 Annual Report, 16p.

Jaeger, J.C. and N.G.W. Cook, 1976, Fundamentals of Rock Mechanics: (2nd edition), Chapman Hall, John Wiley & Sons, New York.

Kan Rongju, Zhang Sichang, Yan Fengtong, and Yu Linsheng, 1977, Present tectonic stress field and its relation to the characteristics of recent tectonic activity in southwest China: (in Chinese) Acta Geophysica Sinica, v.20, pp.96-109.

Li Xianggen, Ran Yongkang, Peng Gui, Zhang Jing, Guo Shunmin, Xiang Hongfa, Chen Tieniu, Zhang Guowei, Ji, Fengju, and Ye

Yongying, 1986, Active faults and their relationship with seismic activities in Dali of Yunnan Province and its adjacent regions: (in Chinese) Seismology and Geology, v. 8, no.4, pp.51-61.

Liu Guangxun, Li Fangquan, and Li Guirong, 1986, Active tectonics and the state of stress in seismic region of northwest Yunnan Province, China: Seismology and Geology, v.8, no.1, 14p.

McGarr A. and N.C. Gay, 1978, State of stress in the earth's crust: Annual Reviews of Earth and Planetary Science, v.6, pp.405-436.

Muskat, M., 1937, Use of data on build-up of bottom-hole pressures: Transactions, American Institute of Mining and Metallurgical Engineers, v.123, pp.44-48.

Springer, J.E., Zhai Qingshan, and Svitek, J.F., 1987, Summary of the geologic setting and televiewer logs from the Yongping test well, Yunnan Province, China: U.S. Geological Survey, Open-file Report, in press.

Wu Daning and Deng Qidong, 1985, Primary behavior of northwest Yunnan: Tectonic subsidence area and mechanics: (in Chinese) Modern Crustal Movement Research, v.1, pp.118-132.

Yan Shihua, Huang Kun, and Zhang Zusheng, 1983, Analysis of the horizontal deformation in Xiaguan-Weishan, Yunnan Province: (in Chinese) Journal of Seismological Research, v.6, pp.477-486.

Zoback, M.L. and M.D. Zoback, 1980, State of stress in the conterminous United States: Journal of Geophysical Research, v.85, pp.6113-6156.

APPENDIX

Cycle by Cycle Results of the Hydrofracturing Tests

TABLE 1A
ISIP Determinations from Yongping
(Downhole Pressures in MPa)

Cycle	Method IP	LF	dP/dT	NLR
Test A:	Depth = 175 m	Po = 1.6 MPa	FR result = 3.7 MPa	
1	4.2	--	3.5	--
2	3.9	--	2.9	3.2
3	--	--	--	--
4	3.7	3.8	2.4 to 2.8	3.6
5	3.3	--	--	--
6	3.1	3.8	--	--
Best Picks:	3.9	3.8	2.9	3.6
Test B:	Depth = 202 m	Po = 1.9 MPa	FR result = 4.3 MPa	
1	--	--	--	6.1?
2	7.0	--	--	7.0?
3	5.6	--	--	6.0?
4	--	4.6	--	--
5	--	--	--	--
6	--	--	--	--
7	3.8	--	--	--
8	3.8	--	--	--
9	--	--	--	--
Best Picks:	5.6	4.6	--	6.1?(ave)
Test C:	Depth = 233 m	Po = 2.2 MPa	FR result = 6.2 MPa	
1	--	--	--	--
2	5.4	--	5.4	5.6
3	--	--	4.6	4.9
4	--	--	3.5	4.0
5	--	--	--	--
6	4.9	--	--	--
7	4.5	4.7	--	--
8	4.5	--	--	--
9	4.3	4.9	--	--
Best Picks:	5.4	4.8(ave)	5.4	5.6
Test D:	Depth = 324 m	Po = 3.1 MPa	FR result = 5.2 MPa	
1	5.7	--	5.0	5.7
2	5.4	--	4.7	5.4
3	5.3	--	4.7	5.5
4	5.3	5.4	--	--
5	--	--	--	--
6	5.5	--	--	--
7	5.2	--	--	--
8	5.2	--	--	--
9	5.2	--	--	--
Best Picks:	5.4	5.4	4.7	5.6(ave)

TABLE 1A (continued)
ISIP Determinations from Yongping
(Downhole Pressures in MPa)

Cycle	Method IP	LF	dP/dT	NLR
Test E:	Depth = 445 m	Po = 4.3 MPa	FR result = 8.5 MPa	
1	9.8	--	9.1	9.2
2	8.4	--	7.8	8.2
3	8.4	8.9	7.9	8.4
4	8.4	8.2	--	--
5	--	8.4	--	--
6	--	8.0	--	--
Best Picks:	8.4	8.4	7.9	8.4

Methods: IP=inflection point, LF=low flow-rate pumping pressure, FR=flow-rate vs pumping pressure, dP/dT=dP/dT vs pressure, NLR=nonlinear regression.

TABLE 2A
Breakdown and Fracture Reopenning Pressures from Yongping
(Downhole Pressures in MPa)

Test	Cycle	Pb	Pr
A	1	6.3	--
175 m	2		3.1
	3		3.3
	4		3.7
	5		3.7
	6		3.1
Picks:		6.3	3.1 to 3.7
B	1	--	--
202 m	2	8.8	--
	3		4.2
	7		5.6
	8		5.1
Picks:		8.8	4.2 to 5.6
C	1	--	--
233 m	2	8.6	--
	6		5.9?
	7		4.3?
	8		4.3?
	9		4.1?
Picks:		8.6	4.3 to 5.9 ?
D	1	7.1	--
324 m	2		4.6
	3		4.5
	4		4.5
	6		4.5
	7		4.1
	8		4.3
	9		5.0
Picks:		7.1	4.5 to 4.6
E	1	--	--
445 m	2		6.0?
	3		6.2?
	4		6.4?
	5		5.8?
	6		6.2?
Picks:		no breakdown	5.8 to 6.2 ?