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EVALUATION OF EQUIPMENT AND METHODS TO MAP LOST CIRCULATION ZONES IN GEOTHERMAL WELLS*

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ABSTRACT

This report describes a study and evaluation of methods to locate, characterize, and quantify lost circulations zones. Twenty-five methods of mapping and quantifying lost circulation zones were evaluated, including electrical, acoustical, mechanical, radioactive, and optical systems. Each tool studied is described in the report. The structured, numerical evaluation plan, used as the basis for comparing the 25 tools, and the resulting ranking among the tools is presented.

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Although they are too numerous to name here, individuals from many service and operating companies provided essential information and advice on lost circulation mapping systems. That help and counsel contributed immeasurably to the evaluations and results. We sincerely appreciate their assistance.

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SUMMARY AND CONCLUSIONS

The purpose of this study is to assess the capability of equipment and methods to map and quantify lost circulation zones in geothermal wells. A comprehensive list and explanation of the tools available for this purpose is included.

Twenty-five methods of mapping and quantifying lost circulation zones are evaluated. These include electrical, acoustical, mechanical, radioactive and optical systems. Although some of the systems work at temperatures to 550°F, most do not, or are available for high-temperature operations only on a limited basis. Some tools require that the hole be precooled by mud circulation in order to run the survey. Some of the systems, such as the Hot Film Anemometer, are no longer available.

A structured numerical evaluation plan, described in Appendix I, is the basis of comparing methods. A detailed description and evaluation of each tool is presented in Appendix II. The information on the benefits and liabilities of each system allows assessments which are used in the evaluation procedures. Since each component entering the assessment is clearly defined and set down in the evaluation worksheet, the overall evaluation can be easily updated to reflect tool improvement or recent experience. Also, weighting criteria can be changed to reflect specific requirements.

No radically new design approaches for mapping lost circulation zones were found. The trend appears to be toward increasing the capabilities of existing technology for higher temperature, more hostile environments.

In general, no single tool is capable of completely mapping lost circulation zones in every instance, although some tools encompass a

wider range of applications and stand a greater chance of success. Rather, multiple tools are required to obtain sufficient information. Tools that measure more than one parameter tend to provide better results than single measurement tools. The choice of systems is dictated by the information required, the downhole environment and the performance and reliability of the tools considered. Knowledge or experience in a particular area or field is invaluable in deciding which systems are applicable to a given situation. In addition, the value and reliability of the information obtained is highly dependent on the skills of analysts and engineers conducting the surveys and interpreting the data.

Although no single method is best in all cases, the combined Sound ("noise") - Temperature Log has been used successfully in several diverse applications and is the single most promising tool.

Pressure limitations pose no problems and the future availability of high temperature geothermal tools looks bright because several companies are currently updating existing technologies, or are developing new ones, for use in high temperature environments. This development is primarily in response to the increasing number of deep, high temperature oil and gas wells and the growth in geothermal activity. Advances are primarily in the area of electronics, where extensive work is being conducted on the upgrading of temperature sensitive elements through design changes, flasking, the use of better insulation and development of high temperature circuitry. Notable among the companies working on high temperature technology are Dresser Atlas, The GO Company, NL McCullough, Schlumberger, and Sandia.

The following technology needs were recognized during the study. There has been no systematic testing of lost circulation mapping systems that would allow comparison of tool performance under controlled borehole conditions. Some tools useful in mapping lost circulation are

not available or cannot operate under severe geothermal conditions. Studies on high temperature versions of these tools could determine if the introduction or upgrading of these tools in commercial geothermal service would significantly increase the number of useful alternatives. Also work is needed on electrical resistivity devices to determine the geothermal conditions favorable for their use and to develop better interpretation techniques.

BACKGROUND

THE PROBLEM

Drilling fluid is normally circulated from the mud pits, down the drill pipe, through the bit, up the annulus, and back into the mud pits. The fluid at rest exerts a pressure on the borehole proportional to its density and the height of the column of fluid in the hole, and while circulating, an additional pressure is applied which depends on the flow properties of the drilling fluid. When whole mud escapes from the wellbore into the formation, reduced mud returns are observed at the flow line and lost circulation is said to have occurred.

Drilling problems resulting from lost circulation include poor hole cleaning, stuck pipe and loss of well control. Thus, drilling must usually be stopped until the lost circulation problem is solved. Treatments are somewhat arbitrary, and usually based on experience in an area. Since the consequence of lost circulation is increased hole cost, even possible loss of the hole, knowledge of the type, location and magnitude of the lost circulation zone can reduce the impact of the problem. The objective of the present study is to assess methods of obtaining such information.

UNDERSTANDING LOST CIRCULATION

For lost circulation to occur, 1) the openings in the rock must be so large that bridging does not occur by the particles in the drilling fluid and 2) the hydrostatic head of the column of fluid must be greater than the pressure of the fluid in the rock. Under these conditions, whole mud can be forced into highly permeable formations,

vugular formations, naturally fractured formations, or mechanically induced fractures in the rock.

Permeable formations are usually gravel beds and poorly cemented sand sections, normally encountered at shallow depths. Pore openings in the formations are relatively large and low viscosity drilling fluids can escape into the openings.

Large interconnected pore spaces exist in many limestone and dolomite formations. These openings are called vugs, and formations containing them are vugular formations. The openings occur as a natural consequence of the replacement of limestone by dolomite. When magnesium solutions percolate through limestone, calcium carbonate is converted to a calcium-magnesium carbonate which occupies less space than the original limestone. Voids formed by the shrinkage are then filled with formation fluids.

By far the most common cause of lost circulation while drilling in geothermal areas is the existence of natural fractures in the formations. Fractures and fissures are found in regions where ground movement has taken place and recementation has not yet occurred, or only partial recementation has occurred. In some cases, the fracture will not open until a critical pressure is exceeded; then the drilling fluid flowing into the opening propagates the fracture, allowing additional loss of mud.

Fractures can be induced by the hydraulic pressure exerted as the drilling fluid is circulated. This usually occurs while trying to break circulation after a trip, or while running pipe into the hole. The total pressure acting on the borehole surface is the sum of the pressure due to the hydrostatic head of the mud plus the pressure required to move the mud up the annulus. Hydraulic fracturing usually occurs in the weakest exposed formation; this is normally the formation immediately below the last string of casing.

STUDY APPROACH

Complete mapping of a lost circulation zone requires determining the type, height and well depth of the zone; and determining the rate of loss into the zone. In geothermal wells, high temperatures complicate measurement difficulties. The evaluation of lost circulation mapping tools required 1) collecting data on tools and techniques and 2) evaluating the data.

Tools

Tools and techniques for evaluating lost circulation problems were researched and are described in this report. The list of tools and their description was developed from technical literature on lost circulation, a review of brochures, catalogs and price schedules, and discussions with experienced field persons.

Manufacturers were contacted to determine which items are operational and which are in the developmental stages. Operators were also asked for their evaluation of how well the tools and techniques perform. Some of the tools evaluated are no longer available but are included in the report because of their potential for further development.

Twenty-five methods applying acoustical, electrical, mechanical, radioactive and optical techniques were found; they are listed in Table I, and described in detail in Appendix II.

Table 1.

TOOLS EVALUATED

Acoustic	**Mechanical**
Borehole Televiewer	Impression Packer
Sonic Logs	Straddle Packers
	Spinner Survey
Electrical	**Radioactive**
Hot Wire Survey	Neutron Logs
Hot Film Anemometer	Formation Density Logs
Dual Induction-Laterolog	Radioactive Tracer Logs
Induction Logs	Sonic Neutron Log
Sonic Potential Logs	
Lost Circulation Detector	**Optical**
Fluid Velocity Indicator	Downhole Camera
Conventional Resistivity Logs	Downhole Television
Micro-Resistivity Logs	
Focusing Electrode Logs	**Combination**
Fracture Identification Logs	Borehole Sound-Temperature Survey
Temperature Logs	Spinner-Temperature Survey

Tool Evaluation

The merits of each tool and technique were evaluated using the data collected. To assess each tool, a structured numerical procedure was devised whereby engineering judgments could be given numerical values. This approach resulted in each tool receiving a single score. The evaluation plan is described in detail in Appendix I.

The objective of the numerical procedure is to provide a method whereby one can evaluate a tool or technique against well defined criteria, then translate the judgment into a numerical value to give each tool evaluated a score.

There are several benefits derived from an invarient numerical evaluation procedure. One is that the evaluator's judgment can be quantified against a fixed scale so that each tool is rated in the same manner. Another benefit is that the reader can examine the rationale of the final scores by looking at each characteristic of a tool or technique that was given a grade and see exactly where the strong and weak points are in each. Since all tool selections are the result of trade-offs, the scoring system aids in a final ranking.

In data collection, each tool and technique was described in terms of design, method of use, response, and the theory upon which it operates. The tools were then assessed in order to determine the relative value of each tool or technique. Criteria for evaluating the tools were broken down into four categories:

- Performance criteria - the capability to achieve needed operational characteristics, plus reliability.
- Risk - the possibility that performance may not be met because of the design approach, absence of testing, or some specific technical consideration.
- Schedule - the availability of a system, or its stage of development.
- Cost - the estimated cost to use the system.

Each category was weighted as follows.

. Performance	50%
. Risk	25%
. Schedule	15%
. Cost	10%
	100%

Two of the basic criteria are further divided into elements and subelements with weightings assigned to each. For example, Performance, which has an overall weighting of 50%, has five constituent elements:

1. Ability to locate lost circulation zones
2. Ability to quantify zone
3. Capability for geothermal operation
4. Accuracy
5. Reliability

The complete procedure is described in Appendix I, and is illustrated by Table 2, a typical evaluation used to calculate the score of the Borehole Sound-Temperature Survey. Note that once the "Raw Score" is assigned, the remainder of the procedure is mechanical.

Table 2
Typical Evaluation Form

TOOL NAME - BOREHOLE SOUND - TEMPERATURE SURVEY							
Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	9	80%	72				
• Determine orientation	1	20%	2				
			74	22.5%	17		
Quantify zone size							
• Height	9	33%	30				
• Width	1	33%	3				
• Flow rate into zone	8	34%	27				
			60	22.5%	14		
Operate in geothermal well							
• Temp. rating	7	33%	23				
• Pressure rating	9	33%	30				
• Mud wt/type	9	34%	31				
			84	22.5%	19		
Accuracy							
• Tool accuracy	9	50%	45				
• Locate zone	9	25%	23				
• Quantify zone	7	25%	18				
			86	22.5%	19		
Reliability	8	100%	80	10.0%	8	X .50 =	39
					77		
RISK							
Stage of development							
• Temp. rating	8	45%	36				
• Pressure rating	9	45%	41				
• Mud wt/type	9	10%	9				
			86	33.0%	28		
Design approach							
• Locate zone	9	50%	45				
• Quantify zone	7	50%	35				
			80	33.0%	26		
Experience/Testing	9	100%	90	34.0%	31		
					85	X .20 =	17
COST	8	100%	80			X .10 =	8
AVAILABILITY	10	100%	100			X .20 =	20
						Final score	84

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

EVALUATION RESULTS

This section summarizes and presents the results of the evaluation. In addition to overall results, assessments based on performance, risk, availability and cost are presented. The detailed description of each tool and the evaluation worksheets are contained in Appendix II.

Results of the evaluation are shown in Tables 3 and 4. Table 3 is a master table summarizing the tool evaluation data. This table lists all of the tools in alphabetical order and gives the scores for the evaluation categories and elements for each tool. These data (except for rankings) are taken directly from the evaluation worksheets in Appendix II. A review of the table will help give an overall perspective of which factors are affecting the overall tool evaluation, and in what areas tools are superior or deficient.

Table 4 gives the rank ordering of tools based on an overall score, performance and risk. These data are excerpted from Table 3. The fact that a tool is not available lowers its overall rank, but such tools were not disqualified since some of the tools not available are worthy of further study.

In this study the geothermal capabilities have been judged on a relative basis. For example, low temperature tools have been ranked lower than high temperature tools. This does not imply that these tools cannot be used in geothermal wells. Many such tools can be used at shallow depths and also in deeper investigation applications in wells that have been adequately cooled.

Overall Results

A scatter plot of the overall scores is presented in Figure 1 from which several facts are apparent. First, there are no low scores. This

TABLE 3
TOOL EVALUATION SCORES

TOOL	TYPE*	PERFORMANCE (50%)							RISK (20%)					COST (10%)	AVAILABILITY (20%)	WEIGHTED FINAL SCORE	OVERALL RANK
		Locate Zones	Quantify Size	Geothermal Operations	Accuracy	Reliability	Weighted Sum	Performance Rank	Development Stage	Design Approach	Testing	Weighted Sum	Risk Rank				
Borehole Sound - Temperature Survey	C	74	60	84	86	80	77	1	86	80	90	85	2	80	100	84	1
Borehole Televiewer	A	42	59	72	63	60	58	13	86	45	70	67	9	60	100	68	8
Compensated Sonic Logs	A	20	23	77	46	70	44	23	76	25	50	50	19	70	100	59	18
Conventional Resistivity Logs	E	34	23	80	63	70	52	19	86	30	30	48	21	80	100	64	14
Downhole Camera	O	26	63	23	50	80	44	23	29	30	60	40	24	70	60	49	20
Downhole Television	O	82	63	30	66	50	59	12	38	60	40	47	23	10	20	44	24
Dual Induction-Laterolog	E	34	23	83	68	70	54	15	90	30	50	57	12	70	100	65	12
Fluid Velocity Indicator	E	58	40	67	78	70	62	11	55	70	30	51	15	0	0	41	25
Focused Electrode Logs	E	42	26	77	65	70	54	15	76	35	40	51	15	80	100	65	12
Formation Density Log	R	18	26	91	43	70	47	22	91	30	30	50	19	70	100	61	17
Fracture Indentification Log	E	42	26	77	71	70	55	14	90	45	50	62	11	70	100	67	9
Hot Film Anemometer	E	66	60	87	83	70	75	2	73	80	20	57	12	0	0	49	20
Hot Wire Survey	E	66	53	70	83	50	67	7	60	80	90	77	5	0	0	49	20
Impression Packers	M	26	63	91	66	90	64	9	91	40	90	74	7	90	100	76	7
Induction Logs	E	34	23	83	63	70	53	17	90	30	40	54	14	80	100	66	11
Lost Circulation Detector	E	74	56	67	78	70	70	4	65	75	50	63	10	0	0	48	23
Microresistivity Logs	E	36	26	70	58	70	50	21	76	35	40	51	15	80	100	63	15
Neutron-Log	R	10	16	91	45	70	43	25	91	15	10	38	25	70	100	57	19
Neutron-Sonic Porosity Log	C	34	26	77	58	70	51	20	76	35	40	51	15	60	100	62	16
Radioactive Tracer Log	R	58	53	77	73	70	65	8	70	80	80	76	6	90	100	77	5
Spinner Survey	M	58	60	77	78	60	68	6	91	80	80	83	3	90	100	80	3
Spinner-Temperature Survey	C	66	60	77	86	70	72	3	91	80	90	87	1	80	100	81	2
Spontaneous Potential Logs	E	34	30	80	55	80	53	17	91	25	30	48	21	100	100	67	9
Straddle Packer	M	58	53	74	78	90	69	5	64	70	80	71	8	90	100	78	21
Temperature Log	E	58	33	91	73	80	64	9	91	65	80	78	4	90	100	77	5

* A - Acoustic M - Mechanical R - Radioactive
E - Electrical O - Optical C - Combination

Table 4
RANKING COMPARISONS

	Performance Ranking	Risk Ranking	Overall Ranking
Borehole Sound - Temperature Survey	1	1	1
Spinner-Temperature Survey	3	1	2
Spinner Survey	6	3	3
Straddle Packer	5	8	4
Radioactive Tracer Log	8	6	5
Temperature Log	9	4	5
Impression Packers	9	7	7
Borehole Televiewer	13	9	8
Fracture Identification Log	14	11	9
Spontaneous Potential Logs	17	21	10
Induction Logs	17	14	11
Dual Induction-Laterolog	15	12	12
Focused Electrode Logs	15	15	12
Conventional Resistivity Logs	19	21	14
Microresistivity Logs	21	15	15
Neutron-Sonic Porosity Log	20	15	16
Formation Density Log	12	19	17
Compensated Sonic Logs	23	19	18
Neutron-Log	25	25	19
Downhole Camera	23	24	20
Hot Film Anemometer	2	12	20
Hot Wire Survey	7	5	20
Lost Circulation Detector	4	10	23
Downhole Television	12	23	24
Fluid Velocity Indicator	11	15	25

* Duplicate rankings indicate identical score.

bias occurs because no tools were evaluated which are not used presently, or have not been used in the past, in attempts at lost circulation detection and mapping. Next, there are no perfect or near-perfect scores. This is because each tool has limitations. Finally, the data fall into clusters. The seven tools in the top group are obviously better candidates, and should be considered first in selecting a system to attempt quantification of lost circulation zones. These seven are listed in Table 5.

FIGURE 1

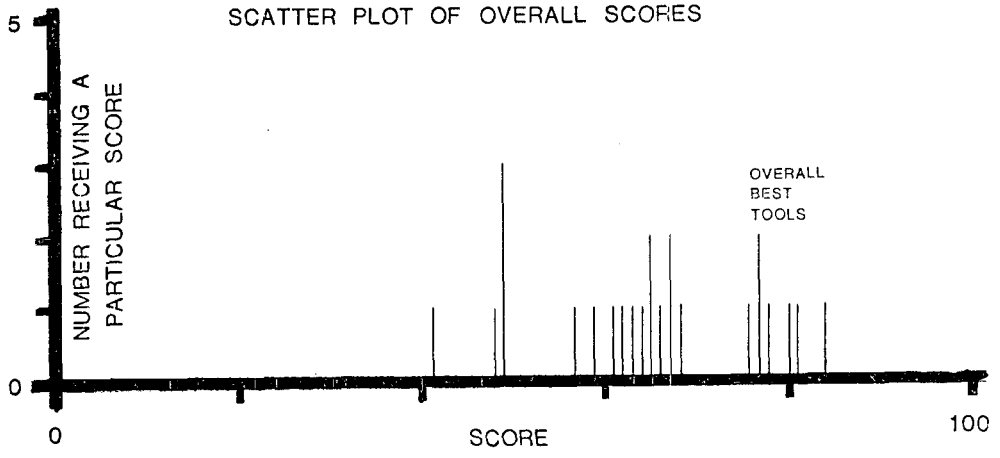


Table 5
OVERALL BEST TOOLS

Tool	Type	Performance Score	Performance Ranking	Overall Score	Overall Ranking
Borehole Sound-Temperature Survey	C	77	1	84	1
Spinner-Temperature Survey	C	72	3	81	2
Spinner Survey	M	68	6	80	3
Straddle Packer	M	69	5	78	4
Temperature Log	E	64	9	77	5
Radioactive Tracer Log	R	65	8	77	5
Impression Packers	M	64	9	76	7

The Sound-Temperature Survey received the top ranking because it offers excellent performance characteristics and reliability, and has the capability to provide the results in a wide range of harsh geothermal environments. It offers a greater capability to locate, and an equivalent capability to quantify lost circulation zones in geothermal wells when compared to the Spinner-Temperature Survey combination. A schematic of the Sound-Temperature Survey system is shown on page A-18.

Good results can be obtained in mapping lost circulation zones with the Spinner-Temperature Survey and the independent Spinner Survey (the number 2 and 3 ranked tools, respectively) especially when they are used in clean, single-phase fluids. Tools with similar capabilities are the Lost Circulation Detector, Radioactive Tracer Logs, Straddle Packers, and the Hot Wire Survey.

The Straddle Packer and the Radioactive Tracer Log are good choices for mapping lost circulation zones, although some improvements are required. In the case of the Straddle Packer, higher temperature seals are required if the system is going to be used in hotter downhole intervals. Also, the addition of a pressure transducer to some of the packer systems could prove helpful. The scintillation meters and Geiger counters of the gamma ray logging tools used in tracing the radioactive material must be further hardened for deep high-temperature applications.

The Temperature Log should only be used to locate the depth lost circulation zones. The system is well suited to this task, particularly in deep portions of the well where large temperature differentials may exist at the point of circulation loss. The tool is limited in its capabilities to quantify lost circulation zones, but the system is attractive because it is widely available, inexpensive, and capable of operating in harsh geothermal environments.

Impression Packers are best used after the lost circulation zones have been located since, like the Temperature Log, they are limited in

their capabilities to "map" lost circulation zones in the complete sense. Also, the method used in locating the lost circulation zone should provide the rate of loss into the zone. Subsequent use of Impression Packers then allows the zone to be completely quantified and the type of zone causing lost circulation to be determined.

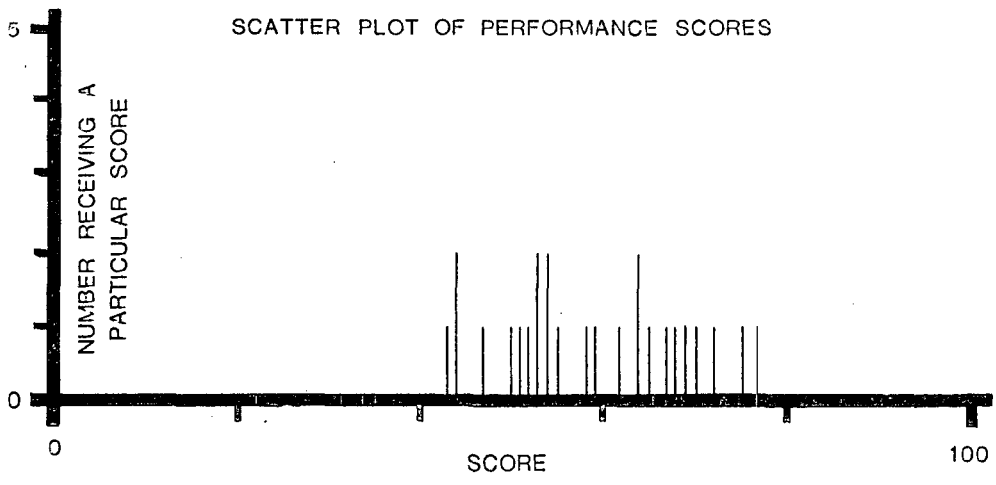
Performance Evaluation

Performance is the key criteria for tool selection, and represents 50% of the total evaluation score. It consists of the following elements, weighted as shown.

Capability to locate zones	22.5%
Capability to quantify size	22.5%
Capability to operate in Geothermal well	22.5%
Accuracy	22.5%
Reliability	10.0%
	100 %

Performance scores for the tools range from 43 to 77, and as shown by the scatter plot (Figure 2), are more or less uniformly distributed. However, the rank ordering of tools is different from that for the overall evaluation (see Table 4).

FIGURE 2



The main difference is the lack of availability of the Hot Film Anemometer, the Lost Circulation Detector, and the Hot Wire Survey which lowered their overall score and ranking. Availability of reliable, higher temperature tools, particularly in the case of the Hot Wire Survey, would increase capabilities to map lost circulation zones. Like the Sound-Temperature Survey, the Hot Film Anemometer is not influenced by mud type or weight, and has high-temperature and high-pressure capabilities. However, it is less accurate than the Sound-Temperature Survey. Unfortunately, there appears to be no plans for reintroducing these three tools into service.

For special applications, the use of Impression Packers, Downhole Camera, Downhole Television and Borehole Televiewer can be effective, particularly if location of the lost circulation zones is known. The Downhole Camera's ability to film the flow of fluid into the lost circulation zone and provide information on the orientation of the zone makes it one of the most direct survey available. An added benefit is that the type of lost circulation zone is discovered such as fractured or vugular. But, because the tool is restricted to clear fluids and low temperatures and pressures (200°F, 6000 psi), its applicability is sharply curtailed. This is shown in its geothermal ranking of eighth.

The Downhole Television is available as a substitute for the Downhole Camera which, although accurate for mapping lost circulation zones, is limited in range of effective operation, geothermal capabilities, and availability. Both the Downhole Television and the Downhole Camera have a risk of failure at high temperatures, are restricted in the types of mud in which they can be used, and do not have a capability to determine flow rates. The Borehole Televiewer provides no flow information, but can help with 'visualization' of the borehole in most geothermal drilling fluids. Significant progress is being made toward developing a high temperature Televiewer by Sandia. The good performance scored by the Impression Packers can be misleading

since some vendors may not have geothermal capability, and should be used with caution in the higher temperature range.

The use of a particular survey in geothermal wells is strongly dictated by the temperatures encountered, the pressure, the type and weight of drilling fluid. Therefore, the system that combines good performance with the ability to function under a wide range of conditions is a better choice than one that offers somewhat better results but is limited to a narrow range of effective operation.

The best performing tool for locating circulation zones in geothermal wells is the Sound-Temperature Survey. While the survey cannot provide information on the orientation of the zone like the Downhole Television it can locate the depth of the zone, the most important aspect of location, with comparable accuracy. Furthermore, its high temperature and pressure capabilities, coupled with its insensitivity to the type or weight of mud, allow it to operate in a much wider range of conditions. This enables the system to provide successful results in almost all environments. A focused device may allow the lost circulation zone to be localized. No work is currently being done in this respect.

Comparing the Lost Circulation Detector and Spinner-Temperature Survey, the tradeoff of performance versus geothermal applicability is again seen. In this case the difference in performance is slight, the Lost Circulation Detector having somewhat greater resolution in locating the depth of the zone. On the other hand the temperature capabilities are quite different. Currently there exists Spinner-Temperature Logging tools rated to 500°F and 25,000 psi. The original Lost Circulation Detector was capable of operating up to 250°F. Both tools are affected by mud type and weight. The Lost Circulation Detector requires conductive mud while the spinner portion of the Spinner-Temperature log is subject to clogging when used in muds containing sealing agents. A

high-temperature lost circulation detector would be superior to the Spinner-Temperature Log.

Other tools have also shown good performance in locating lost circulation zones. The reasons for their assigned rankings are similar to those already discussed, namely,

- the applicability of the method,
- the accuracy with which it can locate the zone, and
- its geothermal capabilities.

These tools can be classified into two main categories:

- Tools That Aid - These tools are used to locate fractures, vugs and high permeability zones that may be indicative of lost circulation. Such tools are unable to provide a characteristic response to lost circulation.

- Limited Application - This category represents those tools which can provide a characteristic response to lost circulation zones in certain, limited instances.

The demarcation between the ability of these tools to locate lost circulation zones and the tools previously mentioned is quite sharp. These tools should only be used when:

- conditions are favorable for their use*, and
- experience in the area has proved the worth of the method.

Notable among the limited application tools are the Borehole Televiewer, Downhole Camera, Fracture Identification Log and Focusing Electrode Logs.

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* See Appendix II for more information on individual tools.

As noted, the Borehole Televiewer and the Downhole Television provide similar information. Both tools record features of the borehole wall like intersecting fractures and vugs - the televiewer employing a near-field acoustic signal, the camera obtaining photographs. These two tools are much better suited to locating fracture and vugular zones than the resistivity logs.

The Fracture Identification Log (FIL) and the Focusing Electrode Log are the best of the resistivity devices. The FIL logging sequence consists of a Dual Induction-Laterolog (DIL) and a microresistivity log. The DIL can provide a characteristic response to high conductivity lost circulation zones while the microresistivity device is useful in locating fractures that may be the cause of lost circulation. The Focusing Electrode Log also responds to changes in resistivity, but has better vertical resolution.

The following tools are not recommended for locating lost circulation zones:

Impression Packers - The limited length of investigation and its inability to provide a characteristic response to loss zones make its use of limited practicality.

Neutron Logs - The tools shallow depth of investigation (2 to 6 inches) coupled with its inability to always provide a discernable response rule out the use of this tool.

Formation Density Log - The portion of the bulk density measurement subject to change is quite small. Furthermore, the tool is a shallow investigation device which averages values over a fairly large volume. The cost versus benefit is too high to make this survey an acceptable method.

Risk, Cost and Availability Evaluation

The Criteria of Risk (20%), Cost (10%), and Availability (20%) constitute the other half of the evaluation weighting. The Risk Ranking is given in Table 4. Risk and Availability (either 0 or 100%) can significantly impact overall ranking. For example, Downhole Television drops from a high performance potential to near the bottom of the list in overall potential because its use entails the risk of failure at high temperatures or in opaque muds. More important, however, is the fact that this survey is highly limited in availability. A high temperature tool, if available, would place this tool above the Spinner Survey.

Three of the better methods for mapping lost circulation zones are unavailable. No plans were found for reintroducing the Hot Film Anemometer, the Hot Wire Survey or the Lost Circulation Detector into commercial use. As a result, these tools had to be judged on technical properties only (and scores therefore adjusted). Of these tools the Hot Wire Survey and the Lost Circulation Detector were found highly successful in use, testing of the latter being limited however. High temperature tools and increased reliability, particularly that of the Hot Wire Survey would add greater capabilities to map lost circulation zones. The Hot Film Anemometer had high temperature capabilities but lacked sufficient testing or experience.

Evaluation Conclusions

Conclusions resulting from the assessment of the capability of equipment and methods to map and quantify lost circulation zones in geothermal wells are:

1. Several methods are available to map lost circulation zones in geothermal wells at temperatures to 275°C (527°F). No single tool is capable of completely mapping lost circulation zones. Rather, multiple tools, usually two, are required to obtain sufficient information.

2. No single method is the best in all cases. However, the new combined Sound-Temperature Log has been used successfully in several diverse applications and is the single most promising tool.

3. Tools that measure more than one parameter generally reinforce one another and tend to provide better results than single measurement tools.

4. The choice of a tool must be dictated by the type of information required and the downhole environment's influence on the performance and reliability of the tools being considered.

5. No radically new design approaches for mapping lost circulation zones were found. The development trend appears to be focused on increasing the capabilities of existing technologies.

6. Presently available systems can improve lost circulation understanding, treatment, and control.

7. Future availability of high-temperature geothermal logging tools having 260° to 288°C (500° to 550°F) and limited 316°C (600°F) capacity appears promising with several companies currently updating existing technology, or developing new technologies, for use in high-temperature environments.

8. Several tools beneficial in mapping lost circulation zones, e.g., Lost Circulation Detector, are not available. Feasibility studies on high-temperature versions of these tools as well as cost/benefit analysis could determine if the introduction of these tools into commercial use would significantly increase the number of useful alternatives.

9. Further research on electrical resistivity devices is needed to determine conditions favorable for their use, develop better interpretation techniques, and establish the possibility of new applications.

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BROCHURES, CATALOGS AND PRICE SCHEDULES

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Dresser Atlas
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July, 1980

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A Halliburton Company
South Texas Division
January 1, 1980

NL McCullough
Inland Waters
July 1, 1980

NL McCullough
Southeast
July 1, 1980

Lynes, No. 110-13-T
Area -
May 1, 1980

Lynes, No. 110-13-T
Area 1
May 1, 1980

Lynes, No. 110-12-T
Area 3
October 1, 1979

TAM International
Domestic
February 1, 1980

Dresser Atlas
South Louisiana
October 16, 1979

Dresser Atlas
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APPENDIX I

EXPLANATION OF EVALUATION PROCEDURE

The following Appendix describes in detail the numerical procedure used in evaluating lost circulation mapping systems. Each of the basic criteria, elements and subelements is discussed and the weighting factors set forth. An example of using the procedure is provided.

The Appendix is organized as follows:

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APPENDIX I

EXPLANATION OF EVALUATION PROCEDURE

The approach to evaluation, the evaluation criteria, the rationale for weighting the criteria and the scoring methodology are described in this appendix.

THE APPROACH

The objective of the evaluation plan was to provide a procedure whereby one could evaluate a tool or technique against well defined criteria, then translate the judgment into a numerical value to give each tool evaluated a numerical score.

There are several benefits derived from a numerical evaluation scheme. One is that the evaluator's judgment can be quantified against a fixed scale so that each tool is rated in the same manner, thus showing its merit in comparison with each other.

Another benefit is that the reader can examine the rationale of the final scores by looking at each characteristic of a tool or technique that was given a grade and see exactly where the strong and weak points are in each. Since all tool selections are the result of trade-offs, the scoring system aids in a final ranking.

In data collection, each tool and technique was described in terms of design, method of use, response, and the theory upon which it operates. The tools were then assessed individually and collectively in order to determine the relative value of each tool or technique.

EVALUATION CRITERIA

The first step was to define a set of criteria by which each tool could be measured. The approach was to look at each tool within four categories of criteria, further divided into elements and subelements.

1. Criteria Categories

To define the top level, criteria categories are:

Performance - the capability to achieve needed operational characteristics, plus reliability.

Risk - the possibility that performance may not be met because of the design approach, absence of testing, or some specific technical consideration.

Availability - the availability of a design depending upon the stage of development.

Cost - the estimated cost of the system including development and manufacturing costs.

Each of the above criteria categories is broken into subcriteria, or elements.

2. Criteria Elements

Each criteria category was further divided into elements and subelements.

A. Performance

Locate Zones - In order to locate a lost circulation zone, the tool must provide a characteristic response at the point of loss. It must provide information on the depth and orientation of the zone. The depth of the zone is the most important aspect of locating the zone and has greater importance than the orientation.

Quantify Zone Size - To quantify zone size, the tool or technique must provide information on the height, width, and flow rate into the zone. This information allows the volume of the zone to be computed, its geometry to be described, and provides a direct measure of the rate of loss.

Operate in Geothermal Well - This aspect of performance is the assessment of the tool's ability to operate at elevated temperature. In preliminary findings, the effects of pressure and the type and weight of drilling mud were found to have a profound influence on many tools' ability to properly function. Consequently, these parameters have been incorporated into this category.

Accuracy - When this facet of performance was examined, two types of accuracy where found to be present. First, there is the accuracy of the measurements. Secondly, there is the accuracy with which the tool can define the location and size of the zone. This latter accuracy is a composite relationship between the type of measurements obtained, technique used and other pertinent factors, such as sonde size.

Reliability - Reliability is the ability of the tool to perform without downtime due to system failure.

B. Risk Criteria

Stage of Development - The stage of development reflects the current state-of-the-art of the tools and is representative of the risk involved in using the tool in terms of its degree of completion, hereafter referred to as timetable, temperature, and pressure capabilities.

Design Approach - This element assesses the risk of using a particular tool to locate and quantify the zone with respect to the measurements obtained, the theory upon which operation, is based and overall design of the tool.

Experience/Testing - Assesses the risk involved in using the tool in terms of its success under field conditions and in testing.

C. Cost Criteria

Cost assessment is the comparison of the total cost to operate a tool with the cost to operate other tools. Costs for each tool represented the direct costs (not rig time, hauling, etc.) of running that tool under the following conditions:

Total Depth	8,000 feet
Survey Length	500 feet
Temperature	450°F
Time (Round Trip)	6 hours

The adoption of a standard set of conditions, realistic in nature, allows each tool to be judged in the same manner.

D. Availability Criteria

Availability is concerned with the ease with which a tool can be acquired. For experimental tools availability is judged on the proposed market entry date and total scheduled production.

With the evaluation criteria identified, defined and structured into manageable elements, the means was available for examining each tool against the same set of standards.

The next necessity was to determine proper weights for each criteria, an essential step described in the next section.

WEIGHTING AND RATIONALE FOR EVALUATION CRITERIA

The values given to each of the evaluation criteria and rationale for the weights assigned is discussed below.

1. Category Weighting

Although the assigned category weights shown are subjective in nature and, therefore, somewhat arbitrary, they represent a concensus of discussions with several field engineers on the relative importance of these characteristics in making decisions on tools to run.

• Performance	50%
• Risk	20%
• Availability	20%
• Cost	10%
	100%

In assessing the various tools and techniques applicable to the program, major emphasis must be placed on performance characteristics. These characteristics represent the main program objectives and constitute the largest portion of the evaluation plan. Risk, availability, and cost, while important, attain true worth only if they are judged in the light of the desired characteristics. To this end, performance has been given a 50% weighting.

Risk and availability have been given equal weightings of 20%. Risk, the probability of success, has direct bearing on the capa-

bility of a tool or technique to perform in a given set of well conditions. Availability, particularly the availability of high-temperature tools, provides a measure of the number of tools with these desired characteristics. These categories are more important than cost (10% weighting), which has no relation to the actual functioning of the tool, or the choice of a tool with respect to obtaining it for use.

2. Elements Weighting

Performance and risk are composed of several elements. These elements are in turn broken into supporting subelements. This section discusses the weighting rationale for these elements and subelements. Availability and cost contain single elements, equivalent to a 100% element weighting, and require no further discussion.

Performance consist of five important elements:

a.	Locate Lost Circulation Zones	22.5%
b.	Quantify Zone Size	22.5%
c.	Operate in Geothermal Well	22.5%
d.	Accuracy	22.5%
e.	Reliability	10 %
		100 %

The first four elements (a - d) are weighted equally at 22.5% and constitute 90% of performance. Each of these elements is equally important for the following reasons. Elements a, b, and c are the performance characteristics required to completely map lost circulation zones in geothermal wells. Each one is indispensible to the fulfillment of the program. Element d, Accuracy, is necessary to assess the resolution capability of the tool or technique.

The remaining 10% of performance is assigned to reliability. While reliability is not a true performance characteristic, its impact is apparent. This weighting allows its impact to be fairly represented without detracting from the "pure" performance characteristics.

3. Subelement Weighting - Performance

A. Locate Lost Circulation Zones

Find Depth	80%
Determine Orientation	20%
	100%

To locate the zone of lost circulation, the tool must provide information on the depth and orientation of the zone. The depth of the zone is the most important factor in terms of describing the zone's position and is always applicable. The orientation of the zone is of use when the hole is deviated, when correlation information is needed or when orientation impacts interpretation. For the above reasons, the depth information is weighted 80% and the orientation 20%.

B. Quantify Zone Size

Height	33%
Width	33%
Flow Rate into Zone	34%
	100%

In order to quantify zone size, it is necessary to know the volume of the zone and the rate at which much loss is occurring. Such knowledge is available if the height, width and flow rate into the zone can be determined. These parameters are needed to describe the shape of the zone, to compute the volume of the zone, and to provide a direct measure of the rate of loss. These parameters are equally important, as reflected by the weighting.

C. Operate in Geothermal Well

Temperature Rating	33%
Pressure Rating	33%
Drilling Mud Type	34%
	100%

Three subelements have been found pertinent in judging a tool's ability to operate in geothermal wells. The most obvious criteria are the effects of pressure and elevated temperatures associated with geothermal wells. Less obvious, though equally important, are the effects of mud type and density on a tool's ability to operate. Many electrical devices are restricted in the type of mud they can be used in, due to the resistivity requirements of the tool. The density of mud was found to have high impact on some mechanical and acoustic devices. Since each subelement, independently or concerted, can rule out the use of a particular tool and exhibit similar effects on the tool's ability to operate, they have been equally weighted.

D. Accuracy

Tool Accuracy	50%
Accuracy with which the tool (open & cased holes)	50%
- locates the depth of the zone (25%)	
- quantifies the zone (25%)	
	100%

Accuracy is a representation of the accuracy of the measurements obtained and the accuracy with which the tool can locate and quantify zone size. These subelements have been equally weighted in an arbitrary manner. Although the weighting is arbitrary, each tool is still rated in the same manner by providing a common "yardstick."

4. Subelement Weighting - Risk

Risk is composed of three elements.

• Stage of Development	33%
• Design Approach	33%
• Experience/Testing	34%
	100%

These elements represent the various aspects of risk. Each one is needed to adequately describe risk and all appear to exert equal influence on the final assessment.

A. Stage of Development

Temperature Rating	45%
Pressure Rating	45%
Timetable	10%
	100%

The stage of development deals with the state-of-the-art of the tools and techniques detailed in our study. Temperature and pressure ratings compose 90% of the total, for reasons similar to those described earlier. Timetable has been assigned the remaining 10%. Its importance in comparison to the temperature and pressure limitations is very small and it is adequately represented under availability.

B. Design Approach

Impact of design approach on tool's capability to:

- locate lost circulation zones	50%
- quantify zone	50%
	100%

Each subelement assesses the risk of the design approach with respect to performance characteristics. Both are essential and must be equivalent.

C. Experience/Testing
(Contains no subelements)

Table 1 summarizes all the criteria and the values assigned them. The breakdown structure (Figure 1) shows the same information in graphic form.

Table 1. Evaluation Criteria

		Subelement Weight	Element Weight	Category Weight
1.0	PERFORMANCE			50% (of 100%)
1.1	LOCATE LOST CIRCULATION ZONES		22.5%	
1.1.1	Find Depth	80%		
1.1.2	Determine Orientation	20%		
1.2	QUANTIFY ZONE SIZE		22.5%	
1.2.1	Height	33%		
1.2.2	Width	33%		
1.2.3	Flow Rate into Zone	34%		
1.3	OPERATE IN GEOTHERMAL WELL		22.5%	
1.3.1	Temperature Rating	33%		
1.3.2	Pressure Rating	33%		
1.3.3	Drilling Mud Type	34%		
1.4	ACCURACY		22.5%	
1.4.1	Tool Accuracy	50%		
1.4.2	Accuracy with which the tool (open & cased holes)	50%		
	- Locates the depth of the zone			
	- Quantifies the zone			
1.5	RELIABILITY		10%	
2.0	RISK			20% (of 100%)
2.1	STAGE OF DEVELOPMENT		33%	
2.1.1	Temperature Rating	45%		
2.1.2	Pressure Rating	45%		
2.1.3	Timetable	10%		
2.2	DESIGN APPROACH		33%	
	Impact of design approach on tool's capability to:			
	- Locate lost circulation zones	50%		
	- Quantify zone	50%		
2.3	EXPERIENCE/TESTING		34%	
3.0	COST			10% (of 100%)
3.1	RELATED TO OTHER TOOLS		100%	
4.0	AVAILABILITY			20% (of 100%)
4.1	Ease of Obtainment		100%	

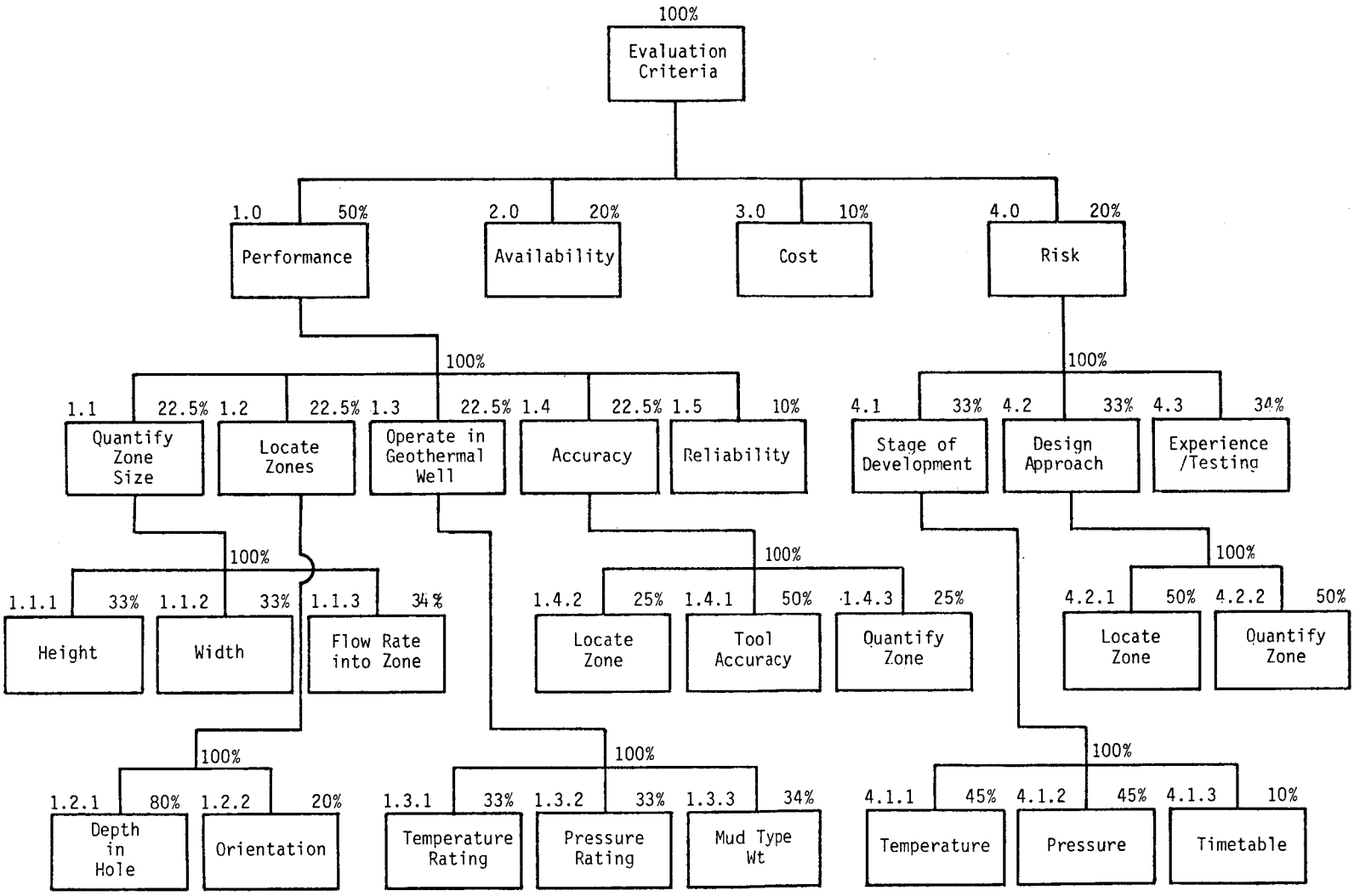

Figure 1

Evaluation Criteria Breakdown Structure and Weights

Example of Scoring Methodology

The final step was to assess each tool using the different levels of criteria or standard; assign a value to each judgment and ultimately arrive arithmetically at a single, final score for each tool.

Each kind of criteria has been assigned a weight, depending upon its importance, as follows:

A sample scoring worksheet is shown in Figure 2. To use this worksheet, the evaluator must assign to each subelement or element a basic or "Raw" score from 0 to 10, 0 being valueless and 10 being highest. Using the Raw Score, the various weights are applied and summed to arrive at the Final Score. Thus, once the Raw Score is assigned, calculation of the final score becomes a straight-forward arithmetic process.

Figure 2
Sample Scoring Sheet

TOOL NAME - BOREHOLE SOUND - TEMPERATURE SURVEY							
Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	9	80%	72				
• Determine orientation	1	20%	2				
			74	22.5%	17		
Quantify zone size							
• Height	9	33%	30				
• Width	1	33%	3				
• Flow rate into zone	8	34%	27				
			60	22.5%	14		
Operate in geothermal well							
• Temp. rating	7	33%	23				
• Pressure rating	9	33%	30				
• Mud wt/type	9	34%	31				
			84	22.5%	19		
Accuracy							
• Tool accuracy	9	50%	45				
• Locate zone	9	25%	23				
• Quantify zone	7	25%	18				
			86	22.5%	19		
Reliability	8	100%	80	10.0%	8	X .50 =	39
					77		
RISK							
Stage of development							
• Temp. rating	8	45%	36				
• Pressure rating	9	45%	41				
• Mud wt/type	9	10%	9				
			86	33.0%	28		
Design approach							
• Locate zone	9	50%	45				
• Quantify zone	7	50%	35				
			80	33.0%	26		
Experience/Testing	9	100%	90	34.0%	31		
					85	X .20 =	17
COST	8	100%	80			X .10 =	8
AVAILABILITY	10	100%	100			X .20 =	20
						Final score	84

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

APPENDIX II

DESCRIPTION AND SCORING WORKSHEET FOR EACH LOST CIRCULATION TOOL

The following Appendix contains a section on each lost circulation mapping tool evaluated. Each section includes a description of the tool, comments on each category of the evaluation help explain the numerical assessment assigned. Individual evaluation scoring forms are included. Finally, a list of references for each tool is provided.

The tools described and evaluated are as follows:

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Name of Tool: Borehole Sound - Temperature Survey

Type: Acoustic (Passive in Operation)

Manufacturer: Baker Production Services, Birdwell, DIA-LOG, Dresser-Atlas, The GO Company, NL McCullough, Pengo, Worth Systems

Cost: Approximately $3,850 per run plus rig costs.

State of Development:

The majority of the tools are developed for temperatures up to 350°-400°F, 15,000 psi. Higher temperature capabilities are currently feasible with hybrid circuitry.

Several companies expressed their ability to develop 500°F tools capable of continuous operation using off-shelf hybrid circuitry. Production of these tools is not planned, however, until sufficient demand makes it an economical venture.

Birdwell offers only dry hole service.

NL McCullough has 10 1-11/16" sound-temperature probes that operate at 600°F for 6 hrs and at 400°F continuously.

General Description:

The tool is a combination sound and temperature logging device capable of providing sequential surveys on a single trip in the hole. Applications include:

- locating lost circulation zones
- locating underground blowouts
- use in producing wells having communication problems behind cemented casing
- finding channeling in cement before perforating or after squeezing, and
- determining of relative flow rates.

The tool (see Figure 1) consists of a casing collar log (CCL), electronic and amplification assembly, noise and temperature sondes.

General Description (continued)

The temperature probe is a highly sensitive, continuous reading thermister which measures the absolute and differential temperature of the borehole fluid.

The noise probe is a piezo-electric crystal which detects sound energy generated by fluid movement in the hole or behind casing. The detector is not directional. The entire frequency spectrum is seldom recorded. Rather, a spectral "finger-printing" is used. Output from the probe is broken into bands at selected frequencies (normally 200, 600, 1,000, 2,000, 4,000, and 6,000 hz) and the amplitudes of these bands are recorded in millvolts or decibels vs. depth.

Logging Procedure for Lost Circulation

If a noise log is to be run to locate lost circulation zones, fluid flow into the zone must be occurring. In some cases, zones accepting whole mud when circulating fail to do so when the well is "shut-in" and allowed to stand. In these instances, it is necessary to force flow while running the survey.

The preferred technique for locating lost circulation zones is described below.

As the tool is lowered from the surface to the total depth of testing, a temperature log is run. The benefit of logging temperature while "running-in" is that the probe encounters fluid undisturbed by the mass of the tool or wire line. The resulting log is compared with a previous static and/or flowing gradient and any anomalies associated with lost circulation are noted.

The tool is then raised to the levels warranting more investigation, stopped to allow extraneous noise to reduce to the "deadwell" signal, and a sound survey made. The dead well signal is the background noise level of the well. It determines the minimum level of sound energy to which the probe can respond. Each station normally requires 10 to 20 seconds per reading after the noise level has stabilized.

Information is presented in an overall condensed view and a detailed expanded view. The condensed view allows the trouble zone to be easily recognized while the detailed view provides greater description. Sound and temperature surveys taken together are superior to either an independent temperature or sound log. Each fills the gaps of the other and enhances interpretation. In normal operation, the tool is run on wire line and can be used through the drill string, and in open and cased holes.

A new tool, the Radial Differential Temperature Log, can sometimes be used to provide directional (azimuthal) information. However, the RDT Log is primarily intended for cased hole applications.

Ability to Locate Lost Circulation Zones

A good tool for defining the depth of the zone(s) losing circulation. For multiple zones it is advisable to run the temperature-sound logging sequence under shut-in and various flowing conditions. This enables the operator to change the level of the dead-well signal and provides the sensitivity needed to identify each zone. Poor tool for showing the orientation of the zone.

Capability to Quantify Size of Zone and Rate of Loss

The tool provides accurate determination of the depth of the zone and the relative rate of flow into the zone. Flow rate calculations are based on McKinley's formulas. The width of the zone is unresolved by the survey. Tool can detect changes in sound energy to about 10 inches, the length of the sonde.

Capability to Operate in Geothermal Well

The tool is currently limited to environments where the temperatures do not exceed 350-400°F. Has been run in higher temperature wells that were adequately cooled to the operating temperature of the tool. Higher temperature capabilities are feasible with current state-of-the-art electronics. Dresser expects to field test a 450°F tool soon.

This tool is able to operate in all drilling fluids without adverse effects on performance.

Accuracy

The built-in accuracy of the tool is extremely good. Temperature changes as small as 0.01°F and small noise sources as far as 1,000 feet away are detectable. Under most conditions the tool can locate the boundaries of the lost circulation zone within a foot or so. The accuracy of the flow rate determination is dependent upon how well known the geometry of the hole is and whether the pressure differential is known or assumed. In holes that are well described, the flow rate can be calculated within ± 10%. Conversely, the flow rate accuracy may only be accurate to within ± 50% when used in poorly described intervals.

Reliability

The sound-temperature probe is passive in operation and highly reliable in downhole environments.

Availability

The tool is widely available. Future availability looks even brighter with several companies gearing up for production and others considering adding the tool to their services.

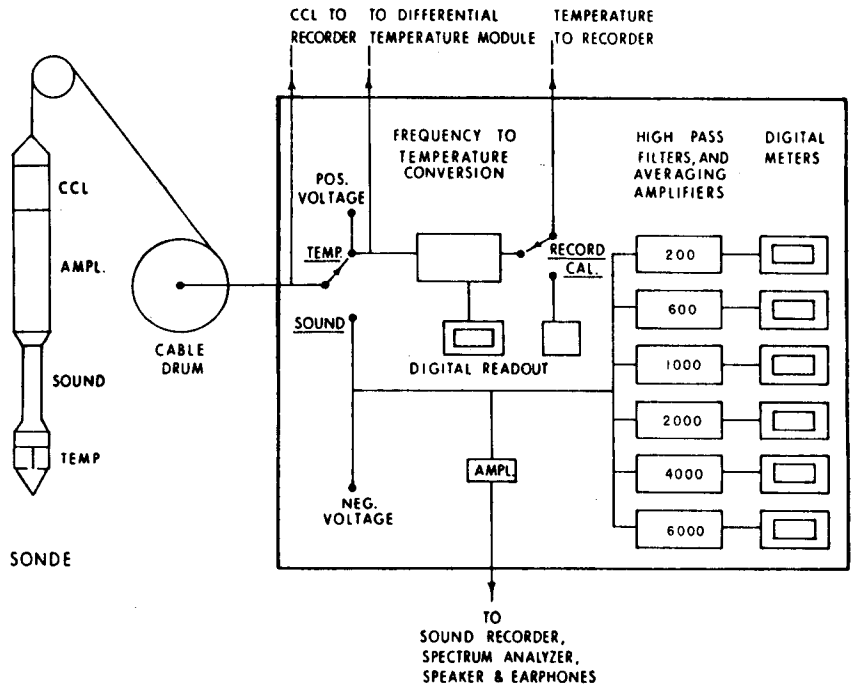


Figure 1. Schematic of Borehole Sound-Temperature Survey

Figure 2 shows sound log made in LASLs EE-I Well on November 14, 1978. Log was run in an attempt to locate hydraulic fracture created in the well. The log indicates that the top of the fracture occurred at depth of 8,200 to 8,500 feet. Essentially the same techniques are used to locate lost circulation zones.

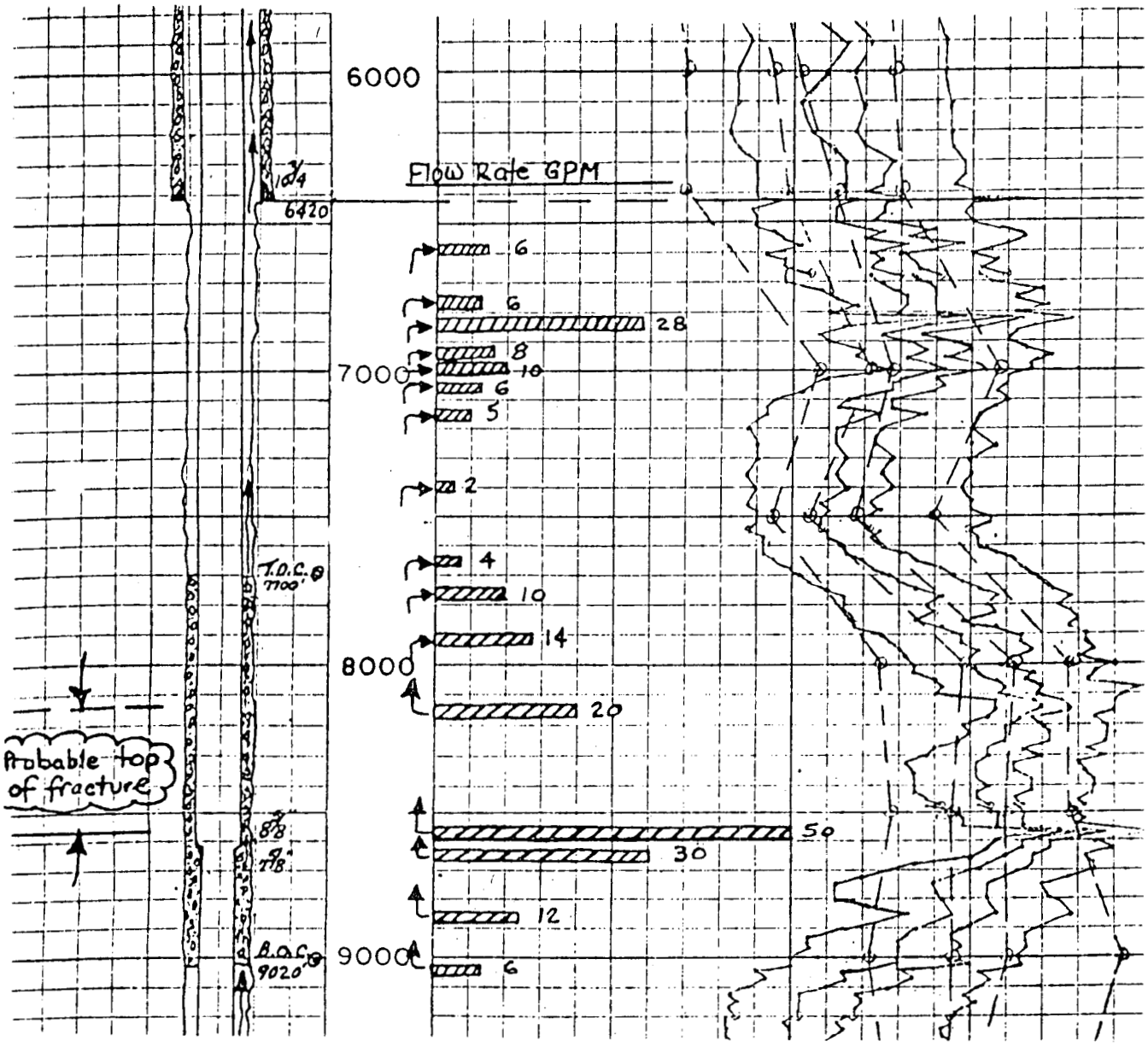


Figure 2. Sound Log of LASL EE-I Well

TOOL NAME - BOREHOLE SOUND - TEMPERATURE SURVEY

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	9	80%	7.2				
• Determine orientation	1	20%	.2				
			7.4	22.5%	1.7		
Quantify zone size							
• Height	9	33%	3.0				
• Width	1	33%	.3				
• Flow rate into zone	8	34%	2.7				
			6.0	22.5%	1.4		
Operate in geothermal well							
• Temp. rating	7	33%	2.3				
• Pressure rating	9	33%	3.0				
• Mud wt/type	9	34%	3.1				
			8.4	22.5%	1.9		
Accuracy							
• Tool accuracy	9	50%	4.5				
• Locate zone	9	25%	2.3				
• Quantify zone	7	25%	1.8				
			8.6	22.5%	1.9		
Reliability	8	100%	8.0	10.0%	.8		
					7.7	X .50 =	3.9
RISK							
Stage of development							
• Temp. rating	8	45%	3.6				
• Pressure rating	9	45%	4.1				
• Mud wt/type	9	10%	.9				
			8.6	33.0%	2.8		
Design approach							
• Locate zone	9	50%	4.5				
• Quantify zone	7	50%	3.5				
			8.0	33.0%	2.6		
Experience/Testing	9	100%	9.0	34.0%	3.1		
					8.5	X .20 =	1.7
COST	8	100%				X .10 =	.8
AVAILABILITY	10	100%				X .20 =	2.0
						Final score	8.4

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

References

BOREHOLE SOUND - TEMPERATURE SURVEY

1. "An Introduction to Sonic Logging," Dresser-Atlas Technical Memorandum, February 1979.

2. Britt, E. L.; "Theory and Applications of the Borehole Audio Tracer Survey," SPWLA Seventeenth Annual Logging Symposium, Denver, Colorado, June 9-12, 1976.

3. Pennebaker, E. S., Jr., and Woody, R. T.; "Scanner, Orienter Help Solve Casing Leaks," Oil & Gas Journal, pp. 75-80. November 28, 1977,

4. Pennebaker, E. S., Jr., and Woody, R. T.; "The Temperature-Sound Log and Borehole Channel Scans for Problem Wells," SPE Technical Paper No. 6782, 50th Annual Fall Meeting of Soc. of Pet. Engineers, Oct. 9-12, 1977.

5. Robinson, W. S.; "Field Results from the Noise-Logging Technique," J. Pet Tech, pp. 1370-1376, November 1976.

6. Robinson, W. S.; "Recent Application of the Noise Log," SPWLA Seventeenth Annual Logging Symposium, Denver, Colorado, June 9-12, 1976.

Name of Tool: Borehole Televiewer

Type: Acoustic

Manufacturer: Birdwell, Simplec

Cost: $30,000 to purchase

State of Development: The tool is rated for continuous operation at 300°F, 20,000 psi. This rating is the maximum operating temperature for the unit manufactured by Birdwell. The Simplec version can operate to 480°F, 20,000 psi.

General Description:

The Borehole Televiewer provides a means for locating and quantifying fracture zones as well as other types of borehole inspection. A rotating piezo-electric transducer probes the borehole wall with bursts of acoustic energy (2,000 pulses/sec). A portion of this energy is reflected back to the transducer where the received impulses are coded and transmitted up hole. The portion of energy reflected is a function of the physical properties of the surface. Accordingly, vugs, chips, and fractures will be characterized by low intensity signals and appear as dark areas on the "acoustic picture." The resulting log represents the borehole wall as if it were split vertically at magnetic north and laid flat.

Tool orientation is determined by a flux-gate magnetometer. The Borehole Televiewer gives a 360° scan of the borehole wall surface depicting casing, fractures and bedding planes. The tool is run on multi-conductor cable, usually in conjunction with a caliper log, and can operate in any gas-free homogeneous liquid. The tool is sensitive to mud weights and is recommended for use in clear (no solids) drilling fluids.

Ability to Locate Lost Circulation Zone

The tool has essentially no ability to directly locate lost circulation zones. The tool can only give clues to the levels where mud loss is occurring by providing a visualization of the borehole wall. When used in conjunction with some other device that is capable of locating the level of the zone, it can determine the type of lost circulation zone, viz., if this zone is a fracture, void zone or permeable bed.

Capability to Quantify Size of Zone and Rate of Loss

Tool gives an accurate interpretation of conditions existing downhole. It provides information on the length and orientation of fractures and voids. Tool tends to exaggerate fracture and/or void width, however. The degree of exaggeration is negligible in round holes and becomes more pronounced in out-of-round or highly rugose holes.

Tool has no application in determining the flow rate of escaping mud.

Capability to Operate in Geothermal Well

Tool is currently restricted to environments where the temperature is at or below 480°F (249°C). Tool accuracy is impaired at the upper temperature limit. Major work on updating the temperature capabilities of the tool (525°F) by running it in Dewar flask and installing higher temperature electronics is currently being conducted by Sandia Laboratories. Field testing of the improved version is scheduled for the summer of 1981 and if successful the tool will be introduced commercially. Tool can operate in any gas-free homogeneous liquid. Mud weights should not exceed 10-12 lb/gal if a good record is to be obtained.

Accuracy

The tool has good resolution in holes that have a low level of rugosity and have a high degree of sphericity. In holes with significant rugosity, or fluids containing appreciable concentrations of sealing agents, the acoustic picture can be washed out. This situation occurs when the incident pulse is not normal to the wall surface or is attenuated by solids in the mud stream and becomes excessively dispersed. This situation can be somewhat corrected for by computer enhancement of the images. Tool can record fractures or voids as narrow as 1/16 of an inch. Vertical position of voids and fractures is accurate to within 3° tended angle.

Reliability

The tool is less reliable than most other well logging survey tools for the following reasons:

- the mechanical and electrical complexity of the tool, and
- insufficient industry research and effort in updating design.

Availability

The tool is available for sale from Simplec and limited service from Birdwell by special arrangements. Information indicates Birdwell may discontinue the service altogether.

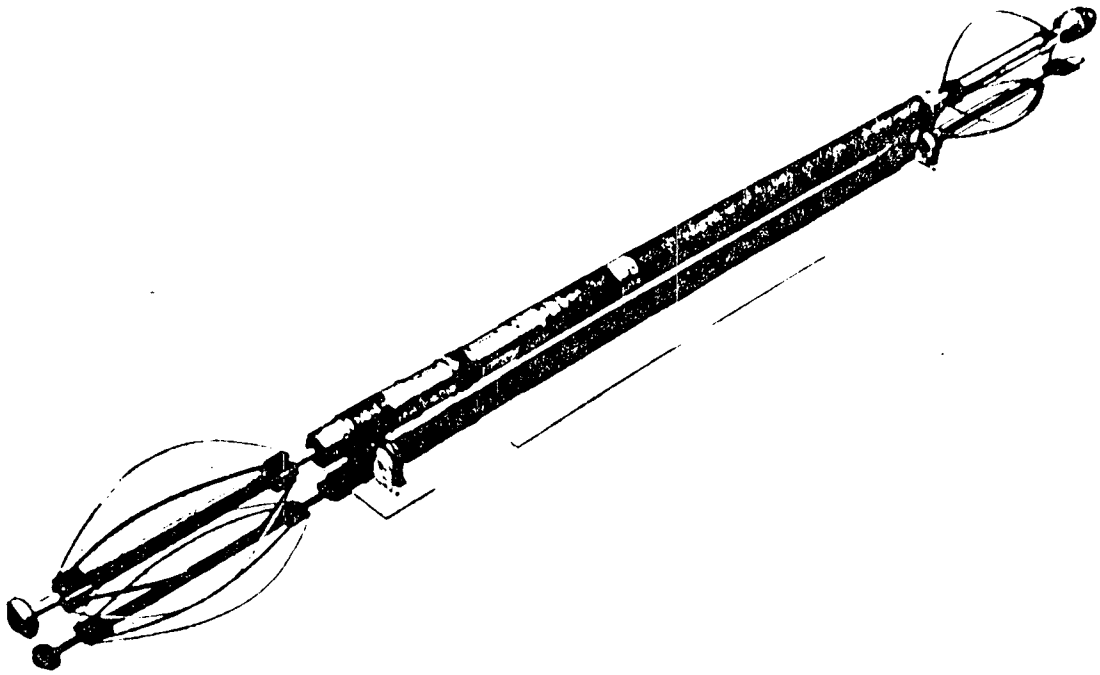


Figure 3. Borehole Televiewer Logging Tool

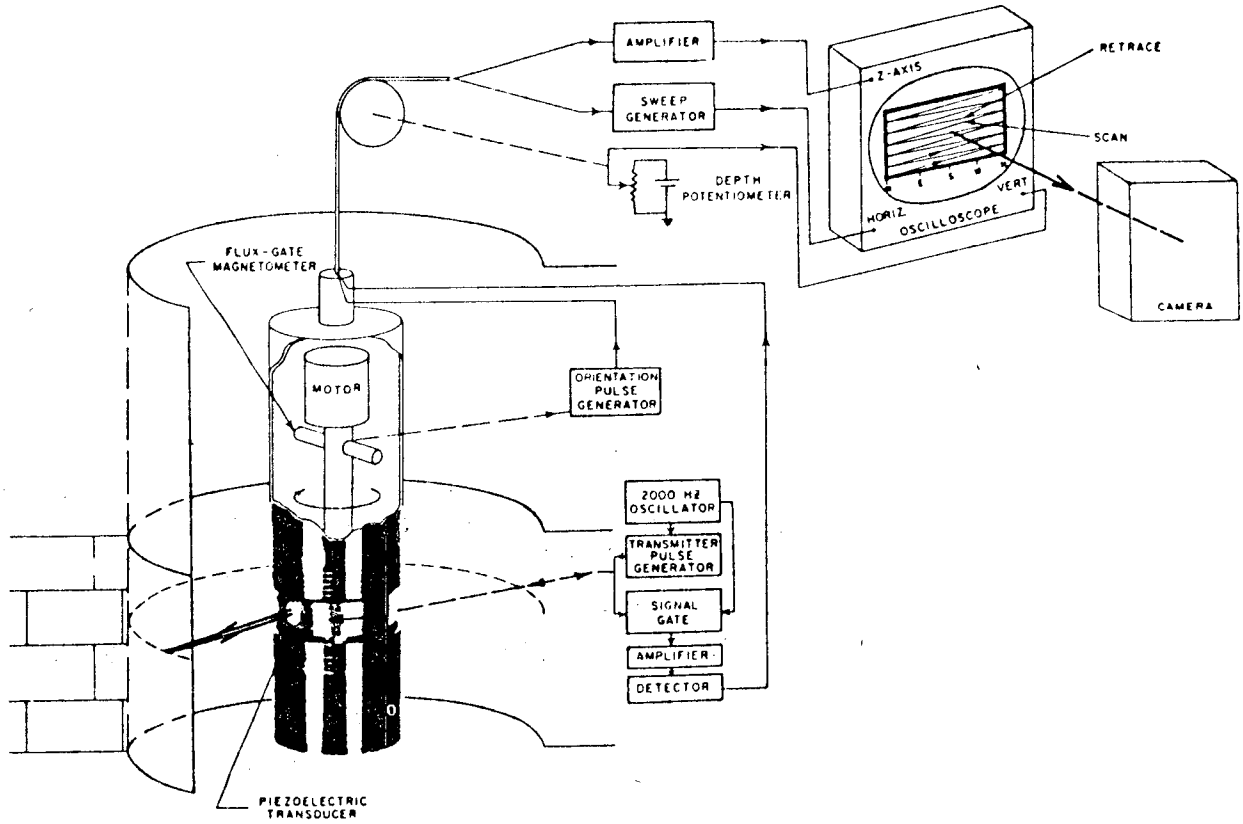


Figure 4. Block Diagram of Borehole Televiewer Logging System

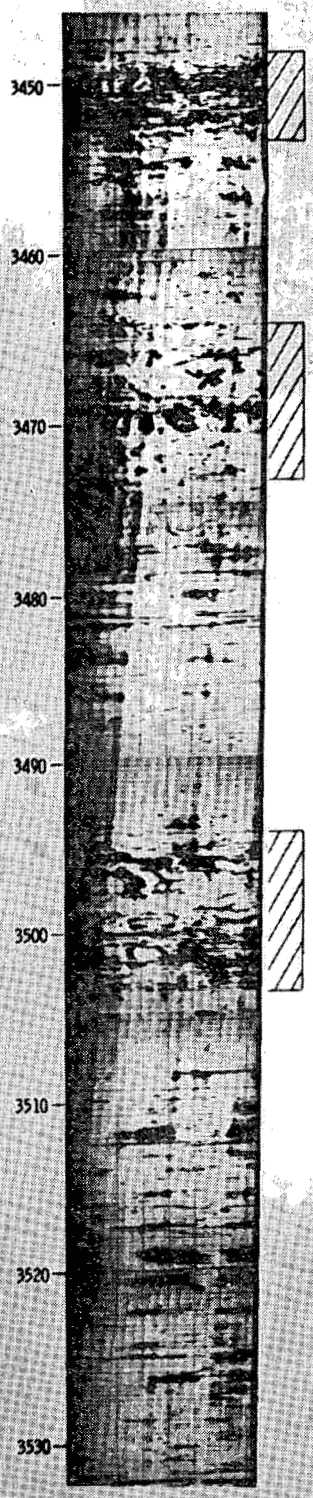


Figure 5

Borehole Televiewer log of dolomite showing vuggy porosity and natural fractures.

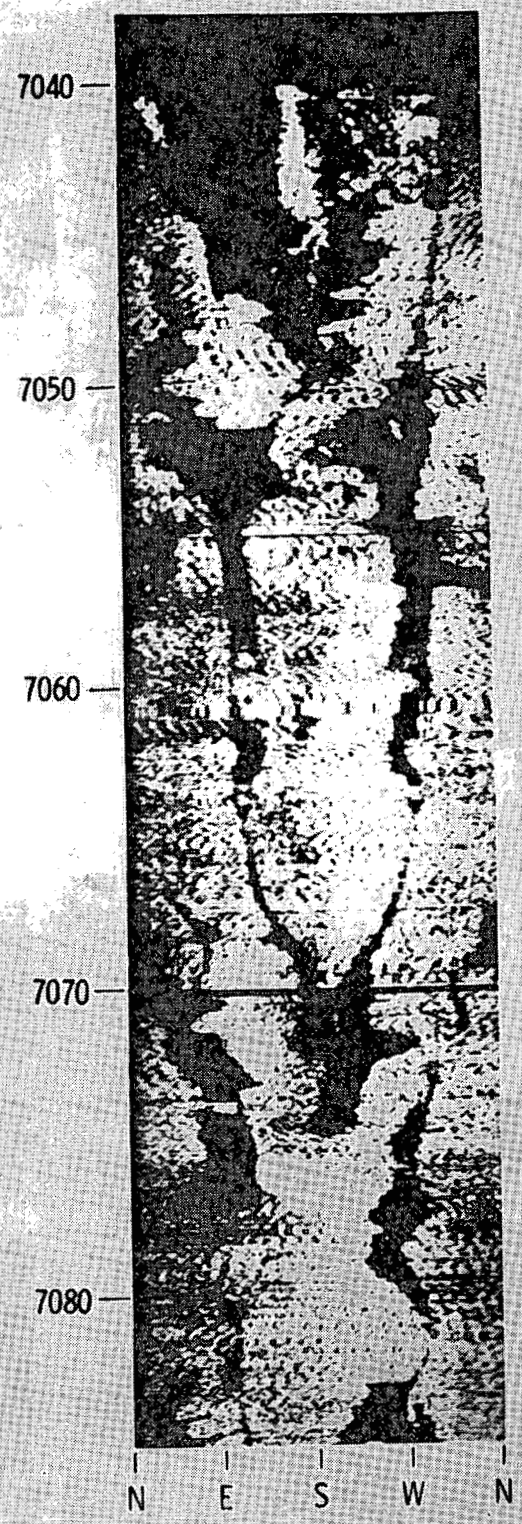
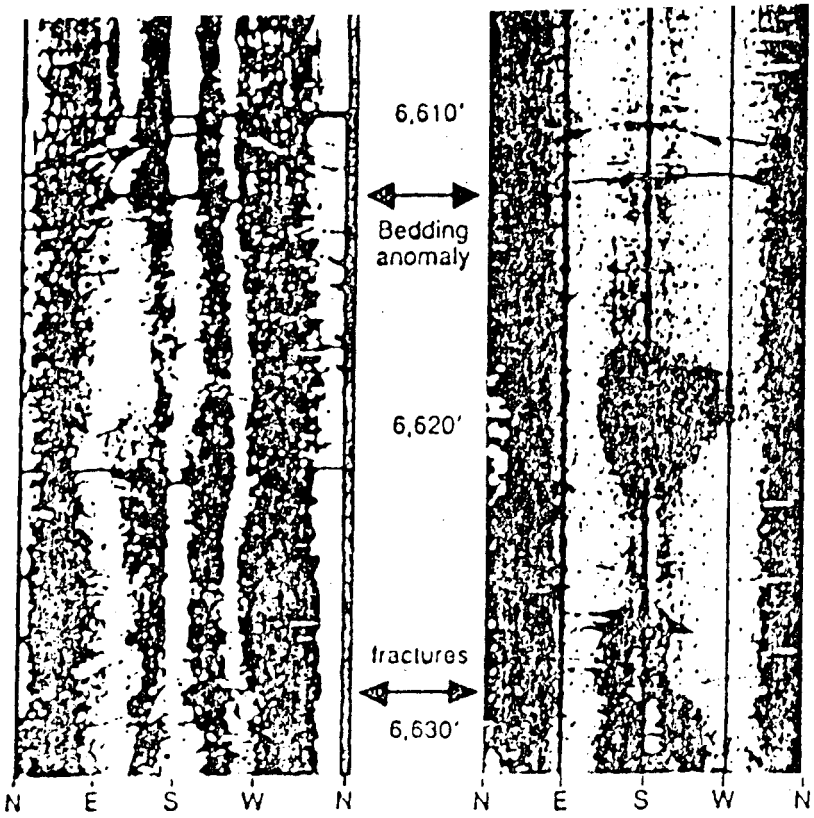


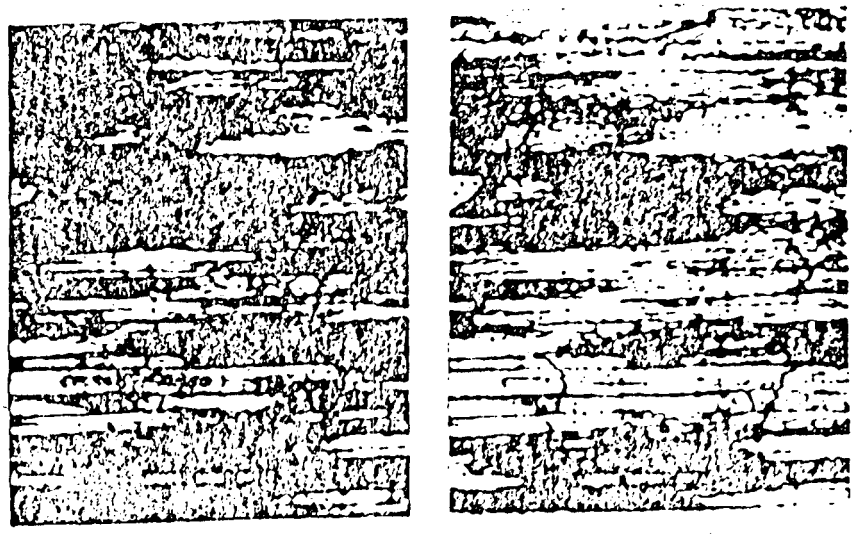
Figure 6

Borehole Televiewer log of hydraulically induced fractures. Fracture appears at 7,045 and continues until it disappears into hole enlargement at 7,072 ft. Additional fracture is at 7,068 ft.



Left Right

Figure 7



Left Right

Figure 8

Figures 7 and 8
Example of resolution "wash-out" caused by elliptical holes (left).
Same pictures (right) after computer enhancement.

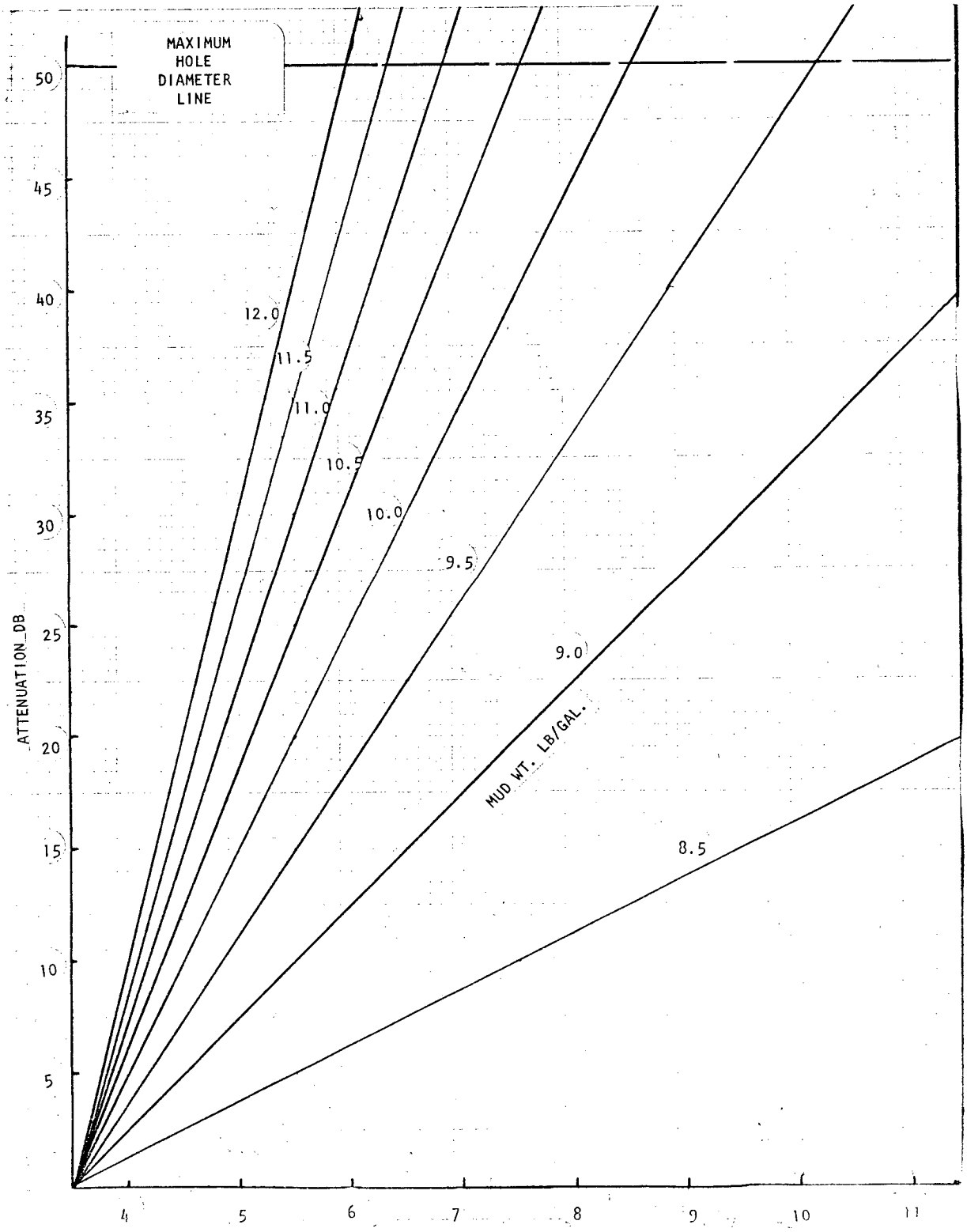


Figure 9. Effect of Mud Weight on Attenuation of Borehole Televiewer Signal.

TOOL NAME - BOREHOLE TELEVIEWER

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	3	80%	2.4				
• Determine orientation	9	20%	1.8				
			4.2	22.5%	.9		
Quantify zone size							
• Height	9	33%	3.0				
• Width	8	33%	2.6				
• Flow rate into zone	1	34%	.3				
			5.9	22.5%	1.3		
Operate in geothermal well							
• Temp. rating	8	33%	2.6				
• Pressure rating	8	33%	2.6				
• Mud wt/type	6	34%	2.0				
			7.2	22.5%	1.6		
Accuracy							
• Tool accuracy	8	50%	4.0				
• Locate zone	2	25%	.5				
• Quantify zone	7	25%	1.8				
			6.3	22.5%	1.4		
Reliability	6	100%	6.0	10.0%	.6		
					5.8	X .50 =	2.9
RISK							
Stage of development							
• Temp. rating	8	45%	3.6				
• Pressure rating	9	45%	4.1				
• Mud wt/type	9	10%	.9				
			8.6	33.0%	2.8		
Design approach							
• Locate zone	2	50%	1.0				
• Quantify zone	7	50%	3.5				
			4.5	33.0%	1.5		
Experience/Testing	7	100%	7.0	34.0%	2.4		
					6.7	X .20 =	1.3
COST	6	100%				X .10 =	.6
AVAILABILITY	10	100%				X .20 =	2.0
						Final score	6.8

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

References

BOREHOLE TELEVIEWER

1. Caldwell, John W., and Strabala, J. M.; "Applications of Modern Well Logging Methods to Salt Solution Cavities," Third Symposium on Salt, pp. 341-352, 1966.

2. "Innerspace - Televiewer Provides Sonic Photo Record Of Borehole," Petroleum Engineer, pp. 38-39, July 1969.

3. Jageler, A. H.; "New Well Logging Tools Improve Formation Evaluation," World Oil, pp. 89-103, March 1980.

4. Zemanek, J. et al.; "The Borehole Televiewer - A New Logging Concept for Fracture Location and Other Types of Borehole Inspection," J. Pet Tech., pp. 762-774, June 1969.

Name of Tool:	Compensated Sonic Logs
Type:	Acoustic - Active in Operation
Manufacturer:	Birdwell, Dresser-Atlas, Schlumberger, Welex, The GO Company
Cost:	Approximately $5,800 per run; various presentations are extra
State of Development:	The majority of sonic logs are developed for temperatures to 325°F.

General Description:

Sonic Logs are used to obtain two important measurements: transit time and the amplitudes of compressional (P) and shear (S) waves. Several methods of recording and presenting the data exist. Notable among these are:

- Transit Time Systems, recording data with centralized or sidewall tool
- Amplitude Systems, recording P and S amplitudes
- Variable Density Systems, recording entire wave train

A. Transit Time Systems

These tools measure the time required for a sound wave to travel from the transmitters through the formation and back to the receivers. Transit time measurements are primarily dependent upon formation matrix, density, porosity, and associated fluids.

The transmitters alternately deliver pulses of acoustic energy (20,000 - 30,000 Hz) to the formation at a rate of 10 to 20 times a second. The receivers detect the first arrivals of the pulse. (They are the faster moving compressional waves.) Several time interval measurements are averaged to provide transit times. This transit time is used to determine the porosity and lithology of the formation. Some systems also record the first shear arrivals. Other applications include the detection of fractures and gas zones.

In formations containing fractures, unconsolidated sands or gas, a phenomenon known as cycle skipping can occur. Cycle skipping is characterized by unusually large transit times, this occurs when one of the first arrivals has been attenuated to the extent that it fails to trigger one of the receivers.

General Description (continued):

In hard formations cycle skipping is a good fracture indicator. Conversely, in soft formations, it is more variable and therefore, less conclusive.

B. Acoustic Amplitude Systems

Acoustic Amplitude Logs are used primarily as an indicator of the existence of fractures, vugs or other nonuniform porosity. When a fracture or vug lies between the transmitter/receiver spacing, part of the acoustic energy striking the fracture or vug is reflected back to the source, thereby causing a reduction of the amplitude of the compressional wave. While fractures cause amplitude reduction of compressional waves, shear waves are nearly or completely stopped. Unfortunately, the state-of-the-art is such that it is very difficult to effectively separate the various wave train components. Log spacing tools offer the greatest ability to separate the component waves.

C. Variable Density Systems

The variable density systems display the amplitude of the entire wave train on a gray scale similar to that used for seismograph data. Experienced analysts can use this display as an interpretative aid to determine formation character (such as the presence of fractures or vugs).

Ability to Locate Lost Circulation Zones

Sonic Logs provide no specific characteristic response to lost circulation zones and therefore cannot be used to directly locate such zones. They can, however, be used as an aid in locating the zone by providing two important pieces of information:

- the existence of fractures, and
- the relative mechanical strengths of the various zones.

The use of sonic logs in locating fractured zones is well documented. Various, sometimes conflicting, results have been reported although several general conclusions have been reached.

- Axially mounted transmitter/receiver arrangements have been useful in locating horizontal and high angle fractures. Vertical fractures tend to be ignored because they provide negligible interruption to the travel path of the wave.

- Alternately, preliminary field tests of the use of circumferentially traveling waves for locating vertical fractures appears to be a viable method.

Such fractures may be the cause of lost circulation, particularly in geothermal wells.

Ability to Locate Lost Circulation Zones (continued):

The relative strength of the various zones can be ascertained by travel time systems. Weaker zones that may be conducive to taking mud are characterized by high P and S wave travel times.

Capability to Quantify Size of Zone and Rate of Loss

Information sometimes is furnished on the height of the fractured zone. The width of the zone is undetermined. No information is afforded on the rate of loss. Process acoustic flow meters (liquid only) have been developed for temperatures as high as 700°F. These tools derive fluid velocity from travel time or Doppler frequency shift equations. Such systems appear to have good potential for downhole geothermal logging.

Capability to Operate in Geothermal Well

Most tools are able to operate at temperatures up to 325°F. Higher temperature capabilities seem feasible. Tools are able to operate in all liquid filled holes.

Accuracy

The accuracy of the measurements is generally good, particularly those obtained with the compensated system.

Performance is seriously affected by gas-cut mud or when solid content exceeds liquid content in the drilling fluid.

Reliability

The tool is reliable when properly used.

Availability

Widely available.

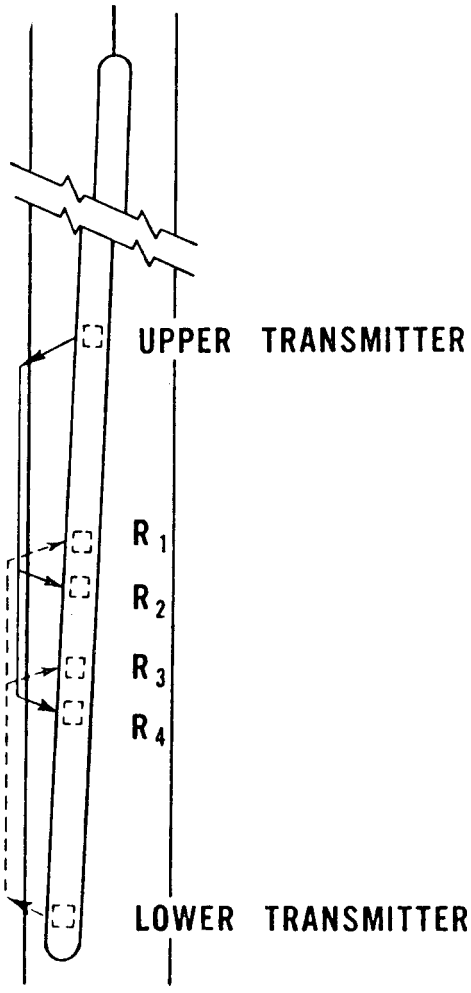


Figure 10. Sonic Log

TOOL NAME - COMPENSATED SONIC LOGS

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	2	80%	1.6				
• Determine orientation	2	20%	.4				
			2.0	22.5%	.5		
Quantify zone size							
• Height	5	33%	1.7				
• Width	1	33%	.3				
• Flow rate into zone	1	34%	.3				
			2.3	22.5%	.5		
Operate in geothermal well							
• Temp. rating	6	33%	2.0				
• Pressure rating	9	33%	3.0				
• Mud wt/type	8	34%	2.7				
			7.7	22.5%	1.7		
Accuracy							
• Tool accuracy	7	50%	3.5				
• Locate zone	3	25%	.8				
• Quantify zone	1	25%	.3				
			4.6	22.5%	1.0		
Reliability	7	100%	7.0	10.0%	.7		
					4.4	X .50 =	2.2
RISK							
Stage of development							
• Temp. rating	6	45%	2.7				
• Pressure rating	9	45%	4.1				
• Mud wt/type	8	10%	.8				
			7.6	33.0%	2.5		
Design approach							
• Locate zone	3	50%	1.5				
• Quantify zone	2	50%	1.0				
			2.5	33.0%	.8		
Experience/Testing	5	100%	5.0	34.0%	1.7		
					5.0	X .20 =	1.0
COST	7	100%				X .10 =	.7
AVAILABILITY	10	100%				X .20 =	2.0
						Final score	5.9

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

References

COMPENSATED SONIC LOGS

1. Koerperich, E. A.; "Evaluation of the Circumferential Micro Sonic Log - A Fracture Detection Device," SPWLA 16th Annual Logging Symposium, pp. 1-8, June 4-7, 1975.

2. Koerperich, E. A.; "Investigation of Acoustic Boundary Waves and Interference Patterns as Techniques for Detecting Fractures," SPE T.P. No. 6820, 52nd Annual Fall Meeting of Soc. of Pet. Engr., Oct. 9-12, 1977.

3. Kowalski, J.; "Formation Strength Parameters from Well Logs," Internal Report (no date), Dresser Atlas Div., Dresser Ind. Inc.

4. Suau, J., and Gartner, J.; "Fracture Detection from Well Logs," The Log Analyst, pp. 3-13, March-April 1980.

5. Walker, T.; "The Interpretation of the Fracture Finder Micro-Seisogram Log," SPWLA 16th Annual Logging Symposium, 7 pp, June 4-7, 1975.

Name of Tool:	Conventional Resistivity Logs
Type:	Electrical
Manufacturer:	Baker Production Services, Birdwell, The GO company, Welex, Dresser-Atlas, Schlumberger
Cost:	Approximately $5,700 per run
State of Development:	Operates at temperatures as high as 500°F, 20,000 psi. The majority of tools in service are rated for 300 - 400°F.

General Description:

Conventional Resistivity Logs provide information on the apparent resistivity of the formations. They are wireline tools that can be run only in open hole.

The method involves passing a constant intensity current through certain electrodes and measuring the voltage through other electrodes. There are two basic arrangements:

- the normal device with two effective downhole electrodes, and
- the lateral device with three measuring electrodes.

While the main use of resistivity logs has been the determination of hydrocarbon saturation, it can sometimes be used to detect lost circulation zones. These devices are affected by lost circulation zones, under the following conditions:

- continuous water-filled fractures or highly permeable beds tend to short circuit the current lines resulting in abnormally low resistivity readings.
- the conductivity pathway of a fractured zone occurring in very low porosity rock is largely uni-directional. This tends to significantly increase the apparent resistivity and is particularly important for deep-reading tools.

Ability to Locate Lost Circulation Zones

Can be a good tool for locating large lost circulation zones, particularly fracture-caused lost zones, if sufficient contrast exists between the zone taking mud and the zones bounding it.

Capability to Quantify Size of Zone and Rate of Loss

The tool can be used to determine the height of the lost circulation zone if this zone is large enough to fall within the tool's vertical resolution. The flow rate and width of the zone are not provided by the survey.

Capability to Operate in Geothermal Well

Operates up to 300 - 400°F, 20,000 psi depending on manufacturer. 500°F tools are available. Can be run in any conductive drilling fluid.

Accuracy

The accuracy of the measurements is good provided that descriptive borehole effects are properly accounted for. The accuracy of the height determination is variable depending on the influence of the surrounding formations. Generally, lost circulation zones occurring in beds several feet thick are clearly identified. Smaller beds, less than five feet thick, may be missed or their heights inaccurately defined.

Reliability

Reliable as most other wireline logging tools.

Availability

Readily available.

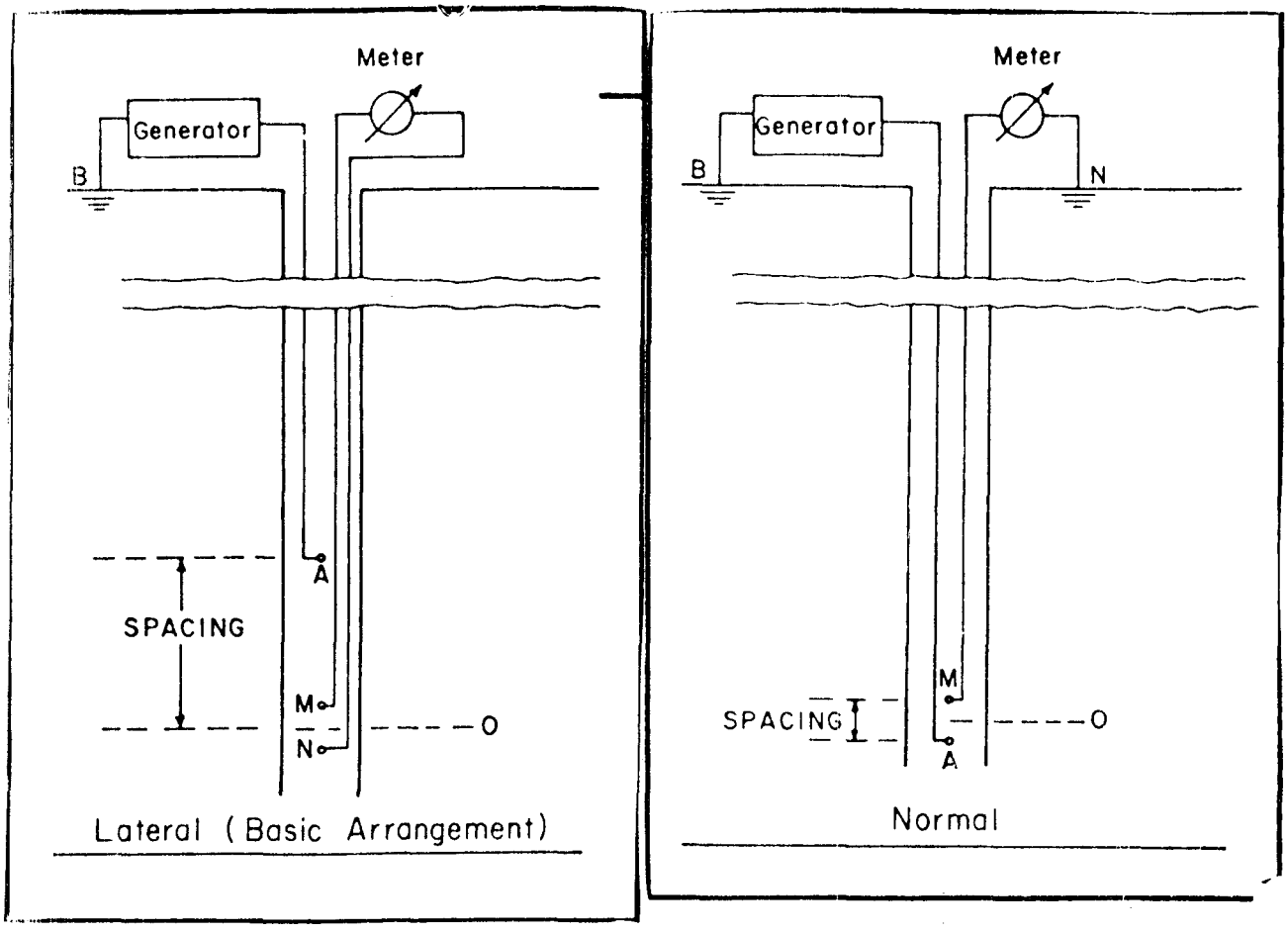


Figure 11. Conventional Resistivity Logs

TOOL NAME - CONVENTIONAL RESISTIVITY LOGS

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	4	80%	3.2				
• Determine orientation	1	20%	.2				
			3.4	22.5%	.8		
Quantify zone size							
• Height	5	33%	1.7				
• Width	1	33%	.3				
• Flow rate into zone	1	34%	.3				
			2.3	22.5%	.5		
Operate in geothermal well							
• Temp. rating	8	33%	2.6				
• Pressure rating	9	33%	3.0				
• Mud wt/type	7	34%	2.4				
			8.0	22.5%	1.8		
Accuracy							
• Tool accuracy	9	50%	4.5				
• Locate zone	5	25%	1.3				
• Quantify zone	2	25%	.5				
			6.3	22.5%	1.4		
Reliability	7	100%	7.0	10.0%	.7		
					5.2	X .50 =	2.6
RISK							
Stage of development							
• Temp. rating	8	45%	3.6				
• Pressure rating	9	45%	4.1				
• Mud wt/type	9	10%	.9				
			8.6	33.0%	2.8		
Design approach							
• Locate zone	4	50%	2.0				
• Quantify zone	2	50%	1.0				
			3.0	33.0%	1.0		
Experience/Testing	3	100%	3.0	34.0%	1.0		
					4.8	X .20 =	1.0
COST	8	100%				X .10 =	.8
AVAILABILITY	10	100%				X .20 =	2.0

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

Final score 6.4

References

CONVENTIONAL RESISTIVITY LOGS

1. Log Review I, Dresser-Atlas, 1974.

2. Log Interpretation - Vol. I, Principles, New York, New York, Schlumberger, 1972.

3. Suau, J., and Gartner, J.; "Fracture Detection from Well Logs," Log Analyst, pp. 3-13, March - April 1960.

4. Tixier, M. P.; "Fundamentals of Logging," University of Kansas, Petro. Eng. Conf., pp. 43-66, 1956.

Name of Tool: Downhole Camera

Type: Optical

Manufacturer: Deep Venture Diving Service, Laval, Underground Well Surveys, Water Well Developers, Henning Brothers

Cost: Approximately $900 per run plus orienting costs

State of Development: Operates up to 200°F, 4,000 psi

General Description:

The Downhole Camera obtains stereoscopic photographs of the borehole wall. The camera uses either 16 or 35 millimeter film and is capable of obtaining 250 to 600 pictures per run. In operation, the camera is lowered on two-conductor cable to the desired depth. Light is supplied by a doughnut shaped strobe which surrounds the lens and is surface triggered. After each exposure the film is automatically advanced to the next ready position. The strip of wall photographed is approximately 18 inches in small holes (under 6 inches diameter) and 30 inches in larger holes. Tool orientation is provided by a compass or other suitable equipment.

The camera can operate in dry gas, fresh water and up to 60% saturated brine solution. When pictures are desired in wells drilled with opaque muds or dilling fluids having colloidal suspensions, the system is modified in order to inject clear fluid (usually calcium chloride solution) into the area of interest thereby displacing the mud. Tool can be run in open and cased holes.

Ability to Locate Lost Circulation Zones

The tool has no direct capability to detect zones of loss. It can, however, provide valuable clues to where the loss may be occurring by showing fractures, voids and other rock characteristics. When the zone has been located by some other device, it provides an accurate picture of the type of zone and its orientation.

Capability to Quantify Size of Zone and Rate of Loss

Tool accurately represents the height, width and orientation of the lost circulation zone. Tool has no application in determining the rate of loss.

Capability to Operate in Geothermal Well

Essentially none due to the temperature (200°F) and pressure restrictions of the tool. Future tools with substantial geothermal applications are feasible though unlikely to be developed in the short-term.

Accuracy

The tool has high resolution which may be decreased in highly reflective formations.

Reliability

There is limited experience with this tool. In interviewing people knowledgeable in the operation of the tool, it was found to be reasonably reliable in operation.

Availability

Good.

TOOL NAME - DOWNHOLE CAMERA

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	1	80%	.8				
• Determine orientation	9	20%	1.8				
			2.6	22.5%	.6		
Quantify zone size							
• Height	9	33%	3.0				
• Width	9	33%	3.0				
• Flow rate into zone	1	34%	.3				
			6.3	22.5%	1.4		
Operate in geothermal well							
• Temp. rating	1	33%	.3				
• Pressure rating	3	33%	1.0				
• Mud wt/type	3	34%	1.0				
			2.3	22.5%	0.5		
Accuracy							
• Tool accuracy	7	50%	3.5				
• Locate zone	2	25%	.5				
• Quantify zone	4	25%	1.0				
			5.0	22.5%	1.1		
Reliability	8	100%	8.0	10.0%	.8		
					4.4	X .50 =	2.2
RISK							
Stage of development							
• Temp. rating	3	45%	1.4				
• Pressure rating	3	45%	1.4				
• Mud wt/type	1	10%	.1				
			2.9	33.0%	1.0		
Design approach							
• Locate zone	2	50%	1.0				
• Quantify zone	4	50%	2.0				
			3.0	33.0%	1.0		
Experience/Testing	6	100%	6.0	34.0%	2.0		
					4.0	X .20 =	0.8
COST	7	100%				X .10 =	0.7
AVAILABILITY	6	100%				X .20 =	1.2

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

Final score 4.9

References

DOWNHOLE CAMERA

1. Dempsey, J. C., and Hickey, J. R.; "Use of Borehole Camera for Visual Inspection of Hydraulically - Induced Fractures," Producers Monthly, April, 1958.

2. Fons, L. C.; "Downhole Camera Helps Solve Production Problems," World Oil, pp. 150-152, October 1960.

3. Jensen, O. F., Jr., and Ray, W.; "Photographic Evaluation of Waterwells," Presented at 53rd Annual Conference of the Southwest Section American Waterworks Association, pp. 15-19, October 20, 1964.

Name of Tool: Downhole Television

Type: Optical

Manufacturer: Amoco, Oceanographic Engineering Corp.

Cost: Special arrangements required

State of Development: Operates up to 200°F, 9,000 psi

General Description:

The Downhole Television Camera perpendicularly scans and films the inside of the wellbore by looking through a 45° mirror. The mirror can be rotated by surface command to provide a 360° scan of the wellbore. Other features include variable light source and a magnetic compass for orientation determination. The tool has had extensive use in fracture evaluation in Amoco's West Texas fields.

To locate lost circulation zones the television camera is lowered into the borehole by wire line. Colored markers or other visible particulates (e.g., cotton seed hulls) are added to the drilling fluid. The camera then tracks the flow of these markers into the lost circulation zone.

Ability to Locate Lost Circulation Zones

The tool can accurately locate the depth and orientation of the lost circulation zone when used in clear fluids. In opaque fluids, the drilling system is modified to replace the opaque mud with clear fluid. Results using this technique depend on how well the opaque fluid is displaced.

Capability to Quantify Size of Zone and Rate of Loss

Survey determines the height and width of the zone. It provides qualitative assessment of the rate of loss into the zone.

Capability to Operate in Geothermal Well

The tool operates up to 200°F, and is useful in evaluating lost circulation zones occurring at shallow depths. Deeper zones are beyond the temperature and pressure ratings of the tool. Best results are obtained in clear fluids. Higher temperature capabilities are feasible though unplanned for the near future.

Accuracy

The resolution of the tool is good in clear fluids. Cloudy fluids may mask some detail.

Reliability

The tool was found to be reliable in operation in limited service.

Availability

Limited availability. Special arrangements are required.

TOOL NAME - DOWNHOLE TELEVISION

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	8	80%	6.4				
• Determine orientation	9	20%	1.8				
			8.2	22.5%	1.8		
Quantify zone size							
• Height	9	33%	3.0				
• Width	9	33%	3.0				
• Flow rate into zone	1	34%	.3				
			6.3	22.5%	1.4		
Operate in geothermal well							
• Temp. rating	1	33%	.3				
• Pressure rating	5	33%	1.7				
• Mud wt/type	3	34%	1.0				
			3.0	22.5%	0.7		
Accuracy							
• Tool accuracy	7	50%	3.5				
• Locate zone	9	25%	2.3				
• Quantify zone	3	25%	.8				
			6.6	22.5%	1.5		
Reliability	5	100%	5.0	10.0%	5		
					5.9	X .50 =	3.0
RISK							
Stage of development							
• Temp. rating	3	45%	1.4				
• Pressure rating	5	45%	2.3				
• Mud wt/type	1	10%	.1				
			3.8	33.0%	1.3		
Design approach							
• Locate zone	6	50%	3.0				
• Quantify zone	6	50%	3.0				
			6.0	33.0%	2.0		
Experience/Testing	4	100%	4.0	34.0%	1.4		
					4.7	X .20 =	0.9
COST	1	100%				X .10 =	.1
AVAILABILITY	2	100%				X .20 =	.4
						Final score	4.4

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

References

DOWNHOLE TELEVISION

1. Briggs, R. O.; "Development of Downhole Television Camera," The Log Analyst, March 1965.

Name of Tool:	Dual Induction - Laterolog
Type:	Electrical
Manufacturer:	The GO Company, Halliburton, Schlumberger, Dresser-Atlas
Cost:	Approximately $5,500 per run
State of Development:	Capable of operating at temperatures to 350°F. 500°F tools are available.

General Description:

The Dual Induction-Laterolog is a fresh mud resistivity device capable of simultaneously measuring resistivity of the formation at shallow, medium and deep radial investigation depths. The tool is composed of a shallow reading laterolog and medium and deep reading induction logs.

The basic idea behind the Dual Induction-Laterolog is that each component responds differently to a given depth of mud invasion. This fact enables the survey to provide quantitative information on the true formation resistivity, R_t. Alternately, the tool yields qualitative information on the extent of invasion and can be used for fracture detection.

A fracture or permeable bed filled with whole mud will be seen as a lower resistivity reading on the shallow laterolog curve when compared with the medium and/or deep resistivity curves. This difference is somewhat dependent upon the design of the tool and hole geometry.

Ability to Locate Lost Circulation Zones

It is one of the better electrical resistivity devices for locating lost circulation zones in medium and thick beds if the resistivity contrast between mud and formation fluid is high. Success in locating fracture zones causing lost circulation is dependent on factors such as fracture geometry, mud resistivity, and interpretive skills of the log analyst. Lithologic logs such as the SP or gamma ray log are required for correlation.

Capability to Quantify Size of Zone and Rate of Loss

Provides approximate height of a lost circulation zone, but cannot resolve the width or rate of loss of the zone.

Capability to Operate in Geothermal Well

500°F tools are available for service.

Accuracy

Measurements are fairly accurate due to the focusing of the induction logs. Vertical resolution is good, able to resolve beds as thin as 3-5 feet thick.

Reliability

Reliable as other wireline tools.

Availability

Easily obtained.

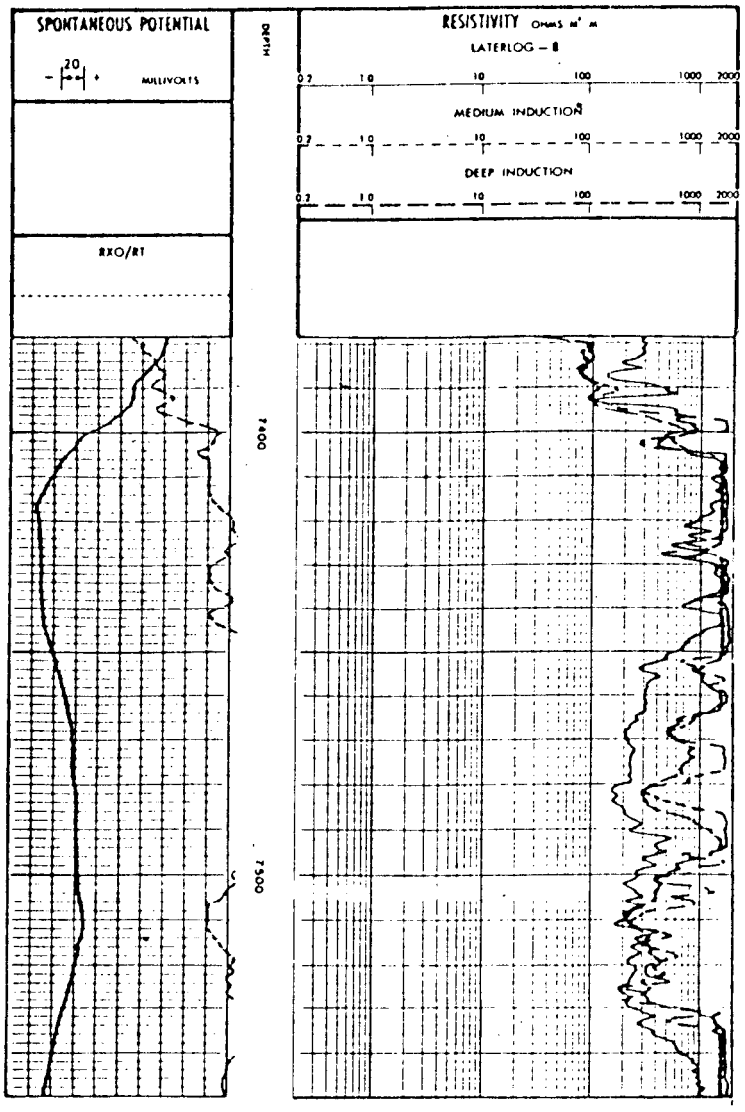


Figure 12. Dual Induction Laterolog of Fractures. Extensive Fracturing is Present at a Depth of 7,450 to 7,500 feet

TOOL NAME - DUAL INDUCTION-LATEROLOG

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	4	80%	3.2				
• Determine orientation	1	20%	.2				
			3.4	22.5%	.8		
Quantify zone size							
• Height	5	33%	1.7				
• Width	1	33%	.3				
• Flow rate into zone	1	34%	.3				
			2.3	22.5%	.5		
Operate in geothermal well							
• Temp. rating	8	33%	2.6				
• Pressure rating	9	33%	3.0				
• Mud wt/type	8	34%	2.7				
			8.3	22.5%	1.9		
Accuracy							
• Tool accuracy	9	50%	4.5				
• Locate zone	6	25%	1.5				
• Quantify zone	3	25%	.8				
			6.8	22.5%	1.5		
Reliability	7	100%	7.0	10.0%	.7		
					5.4	X .50 =	2.7
RISK							
Stage of development							
• Temp. rating	9	45%	4.1				
• Pressure rating	9	45%	4.1				
• Mud wt/type	8	10%	.8				
			9.0	33.0%	3.0		
Design approach							
• Locate zone	4	50%	2.0				
• Quantify zone	2	50%	1.0				
			3.0	33.0%	1.0		
Experience/Testing	5	100%	5.0	34.0%	1.7		
					5.7	X .20 =	1.1
COST	7	100%				X .10 =	.7
AVAILABILITY	10	100%				X .20 =	2.0

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

Final score 6.5

References

DUAL INDUCTION - LATEROLOG

1. Log Review I, Dresser-Atlas, 1974.

2., Log Interpretation - Vol. I Principles, New York, New York, Schlumberger, 1972.

3. Shanks, R. T., et al.; "A Review of Fracture Detection with Well Logs," SPE Tech. Paper No. 6159, 51st Annual Fall Tech. Conf. of the Soc. of Pet. Engr., Oct. 3-6, 1976.

4. Suau, J. and Gartner, J.; "Fracture Detection from Well Logs," The Log Analyst, pp. 3-13., March-April 1, 1980.

Name of Tool: Fluid Velocity Indicator

Type: Electrical

Manufacturer: Gulf Research and Development

Cost: Not available

State of Development: When in use, the tool was a low-temperature device.

General Description:

The tool consists of a short cylinder which is open at the top and swaged at the bottom to partially restrict the flow of mud through the cylinder. Located on the side of the tube between two fixed electrodes is a movable electrode mounted on a neoprene diaphragm. An alternating current is impressed on the fixed electrodes and a potential exists at the movable electrode. This potential is dependent on the position of the movable electrode with respect to the two fixed electrodes.

When fluid flows through the tool, a differential pressure force is exerted on the diaphragm. This force displaces the movable electrode, resulting in a measurable change in potential. This change provides a means for the detection of static fluid areas, characterized by 'normal' calibration potential, and flow situations where fluid loss is occurring.

The recommended field procedure is to determine the change in the rate of flow at fixed stations with the mud pumps on and then with the pumps off. The instrument is run on wireline from a standard logging truck. There are two approaches to lost circulation detection. One method is known as the "bracketing method." In this approach, the device is lowered halfway to the bottom. If flow is indicated here, the loss zone is in the lower half of the well. If no flow is indicated, the zone is in the upper half of the well. The tool is then moved to the middle half of the well and flow measurements are recorded. This procedure is repeated until the zone is located. The other method is to raise the tool from TD through an interval of 10 ft or more at a rate of 680 ft/hr and record flow variations.

Ability to Locate Lost Circulation Zones

The FVI is a good tool for accurately locating the depth and extent, upper and lower boundaries, of the lost circulation zone provided the following conditions are satisfied:

- mud is conductive enough to provide sufficient electrical continuity needed for system operation, and

- the rate of loss is such that the differential velocity between the drill fluid going down the borehole and the fluid flowing into the lost circulation zone is at least 5 ft/min.

The tool is unsatisfactory for providing information on the orientation of the zone that is losing circulation.

Capability to Quantify Size of Zone and Rate of Loss

The tool accurately determines the depth in the hole and height of the lost circulation zone. Width of the zone is left unresolved by the tool. The tool provides qualitative assessment of the rate of loss.

Capability to Operate in Geothermal Well

The tool was designed in the 1950s by Gulf Research and Development and was a low temperature device. It is able to operate in any liquid that is conductive enough to provide required electrical conductivity. It is believed that with sufficient interest and current technology the tool can be updated for use in geothermal wells.

Accuracy

The tool can accurately determine the extent of a circulation zone to within a foot. The tool is sensitive to changes in flow as low as 5 ft/min. Multiple zones of lost circulation may require recalibration of the tool. Calibration can be necessitated if the zones are closely spaced or the flow rates into the zones are significantly different from the main flow stream. This recalibration can be performed to within the accuracy of the on-site linear velocity indicator.

Reliability

The tool is not easily clogged by fibrous, flaky materials normally added when the onset of lost circulation is detected by surface equipment, a possible advantage over spinner surveys. It has good overall reliability.

Availability

Not available.

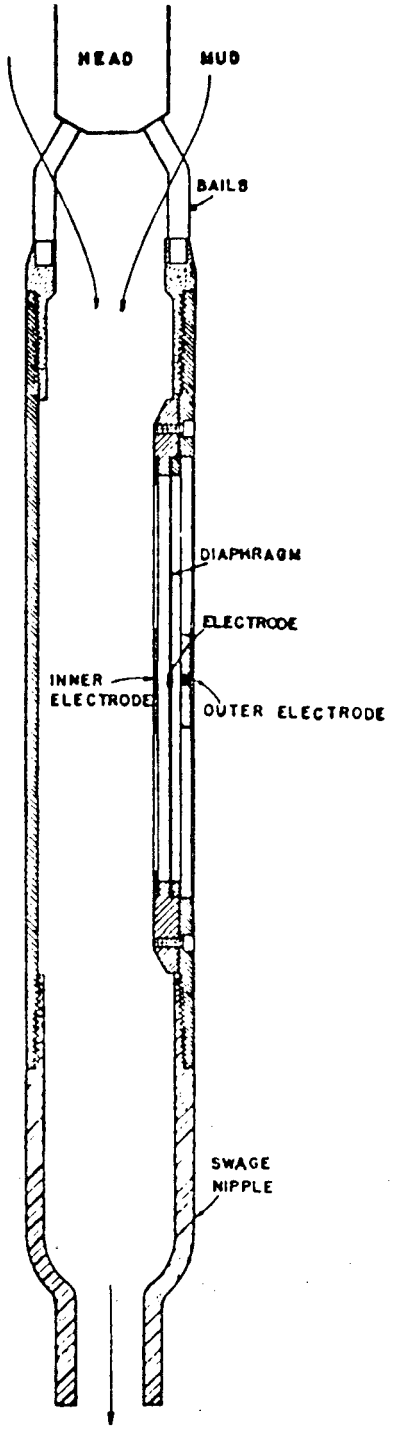


Figure 13. Schematic of Fluid Velocity Indicator

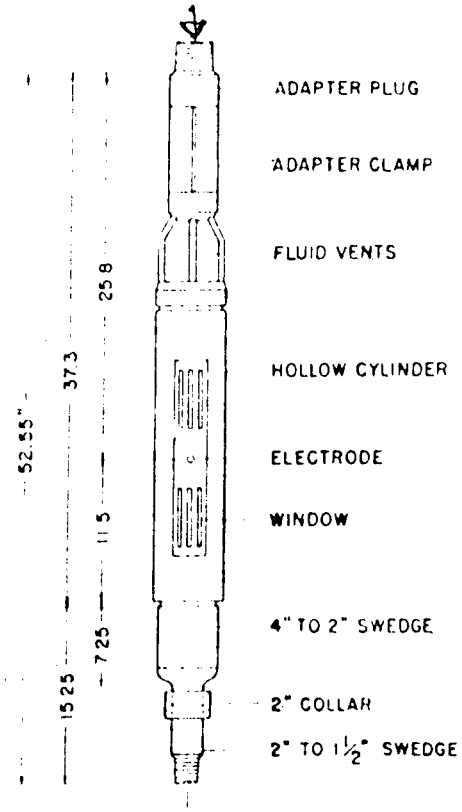


Figure 13a. Fluid Velocity Indicator

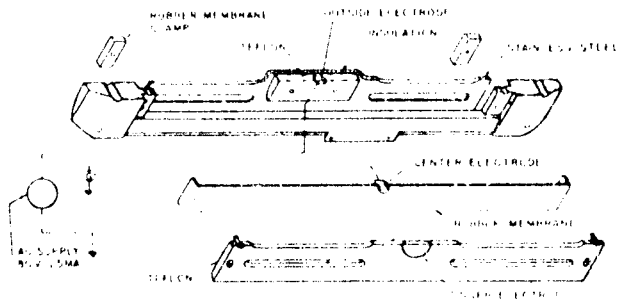


Figure 14. Diaphragm Electrode Assembly

TOOL NAME - FLUID VELOCITY INDICATOR

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	7	80%	5.6				
• Determine orientation	1	20%	.2				
			5.8	22.5%	1.3		
Quantify zone size							
• Height	7	33%	2.3				
• Width	1	33%	.3				
• Flow rate into zone	4	34%	1.4				
			4.0	22.5%	.9		
Operate in geothermal well							
• Temp. rating	4	33%	1.3				
• Pressure rating	9	33%	3.0				
• Mud wt/type	7	34%	2.4				
			6.7	22.5%	1.5		
Accuracy							
• Tool accuracy	9	50%	4.5				
• Locate zone	8	25%	2.0				
• Quantify zone	5	25%	1.3				
			7.8	22.5%	1.8		
Reliability	7	100%	7.0	10.0%	.7		
					6.2	X .50 =	3.1
RISK							
Stage of development							
• Temp. rating	4	45%	1.8				
• Pressure rating	8	45%	3.6				
• Mud wt/type	1	10%	.1				
			5.5	33.0%	1.8		
Design approach							
• Locate zone	9	50%	4.5				
• Quantify zone	5	50%	2.5				
			7.0	33.0%	2.3		
Experience/Testing	3	100%	3.0	34.0%	1.0		
					5.1	X .20 =	1.0
COST	N/A	100%				X .10 =	-
AVAILABILITY	N/A	100%				X .20 =	-

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

Final score: 4.1

References

FLUID VELOCITY INDICATOR

1. Bardeen, T. and Teplitz, A. J.; "Lost Circulation Information with a New Tool for Detecting Zones of Loss," Petroleum Transactions, pp. 36-40, 1955.

2. Gallagher, C. F.; "Methods and Devices for Locating the Zone of Lost Circulation," API Paper No. 801-32C presented at the Spring Meeting of the Pacific Coast District, Div. of Prod., API, Los Angeles, CA, May 10-11, 1956.

Name of Tool: Focused Electrode Logs

Type: Electrical

Manufacturer: Birdwell, Dresser-Atlas, Schlumberger, Welex

Cost: Approximately $5,300 per run

State of Development: Models available that operate up to 350°F

General Description:

The Focused Electrode Log uses focusing currents to control the path taken by the measuring current. This feature offers superior response to actual in situ conditions by minimizing the effects of the borehole and adjacent formations on readings. The electrode pairs are arranged in such a manner that the measure current penetrates the formation horizontally or vertically. The tool quantatively measures the true resistivity, R_t, and the resistivity of the flushed zone, R_{xc}.

Like other resistivity devices, the tool can be used in certain instances to locate lost circulation zones; specifically, those zones which have resistivity characteristics that allow them to be separated from zones having integrity.

Advantages of the focused electrode logs are:

- the effects of the borehole and adjacent formations are minimized
- superior to conventional resistivity tools in salt muds and/or highly resistive formations, and
- greater resolution of these beds.

Ability to Locate Lost Circulation Zones

Under the proper conditions, the tool can be a good lost circulation detector. It is noted, however, that it has limited applications.

Capability to Quantify Size of Zone and Rate of Loss

Can locate the height of the zone. No other information is generated by the survey.

Capability to Operate in Geothermal Well

Operates up to 350°F, 20,000 psi which implies limited useage in geothermal wells. Can be run in both fresh and salty muds. Higher temperature capabilities are feasible.

Accuracy

Not a quantitative tool for width and flow rate, but accurate for height determination.

Reliability

Good.

Availability

Readily available from several sources.

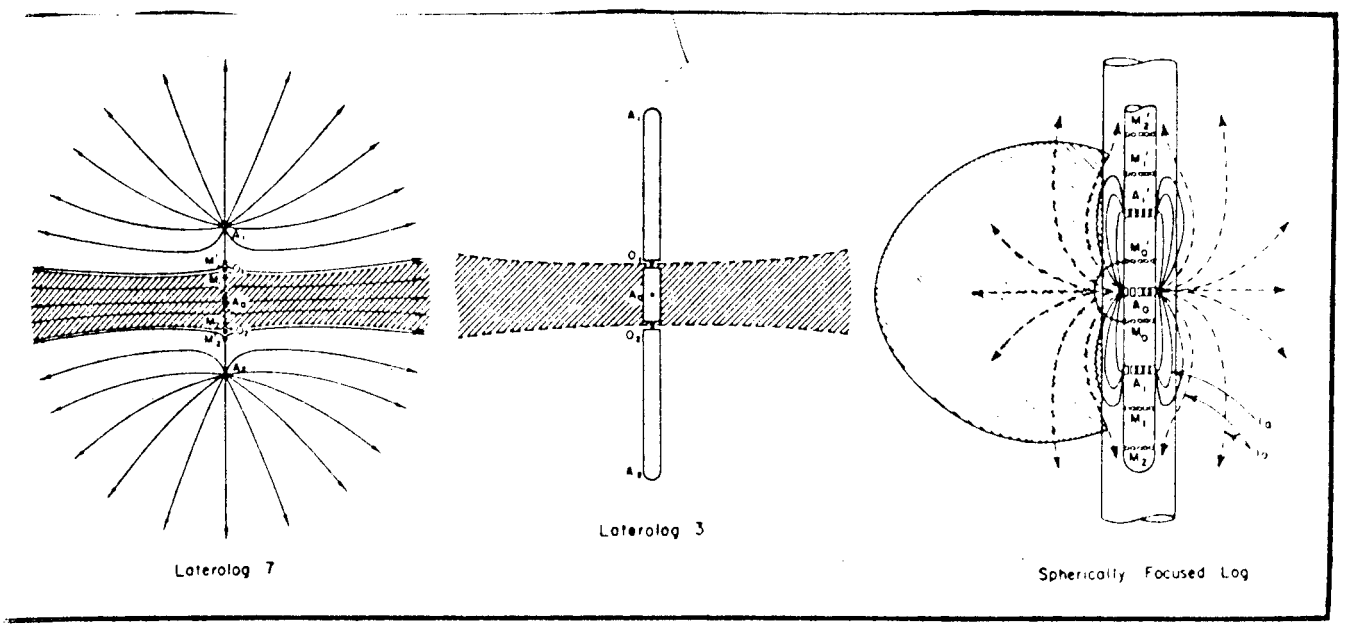


Figure 15. Schematics of Focusing-Electrode Devices
Focused Electrode Logs Chart

TOOL NAME - FOCUSED ELECTRODE LOGS

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	5	80%	4.0				
• Determine orientation	1	20%	.2				
			4.2	22.5%	.9		
Quantify zone size							
• Height	6	33%	2.0				
• Width	1	33%	.3				
• Flow rate into zone	1	34%	.3				
			2.6	22.5%	.6		
Operate in geothermal well							
• Temp. rating	6	33%	2.0				
• Pressure rating	9	33%	3.0				
• Mud wt/type	8	34%	2.7				
			7.7	22.5%	1.7		
Accuracy							
• Tool accuracy	9	50%	4.5				
• Locate zone	6	25%	1.5				
• Quantify zone	2	25%	.5				
			6.5	22.5%	1.5		
Reliability	7	100%	7.0	10.0%	.7		
					5.4	X .50 =	2.7
RISK							
Stage of development							
• Temp. rating	6	45%	2.7				
• Pressure rating	9	45%	4.1				
• Mud wt/type	8	10%	.8				
			7.6	33.0%	2.5		
Design approach							
• Locate zone	4	50%	2.0				
• Quantify zone	3	50%	1.5				
			3.5	33.0%	1.2		
Experience/Testing	4	100%	4.0	34.0%	1.4		
					5.1	X .20 =	1.0
COST	8	100%				X .10 =	.8
AVAILABILITY	10	100%				X .20 =	2.0
						Final score	6.5

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

References

FOCUSED ELECTRODE LOGS

1. Log Review I," Dresser-Atlas, 1974.

2. Log Interpretation - Vol. I, Principles, New York, New York, ... Schlumberger, 1972.

3. Suau, J. and Gartner, J.; "Fracture Detection from Well Logs," The Log Analyst, pp. 3-13, March - April 1960.

4. Tixier, M.P.; "Fundamentals of Logging," University of Kansas Petro. Eng. Conf., pp. 43-66, 1956.

Name of Tool:	Formation Density Log
Type:	Radioactive
Manufacturer:	Dresser-Atlas, The GO Company, Schlumberger, Halliburton, Birdwell
Cost:	Approximately $6,000 per run. Hostile environment extra.
State of Development:	The majority of tools operate at temperatures up to 350°F, 20,000 psi. Dresser-Atlas version can be run in 500°F environments. Schlumberger has 500°F, 25,000 psi tools available in limited supply.

General Description:

The Formation Density Log is a sidewall device carrying a natural gamma ray source which uses the attenuation of reflected gammas to determine the density of the adjacent formation. Medium energy gamma rays collide with electrons, lose some energy, and then continue on their paths with diminished energy. The scattering of the gamma rays, known as Compton scattering, is measured by long and short spacing detectors. The number of scattered rays counted by the detectors is a direct measure of the bulk formation density. This information is used in lithology evaluation and porosity determinations. The porosity determination requires that the grain density and fluid density (pore fluids) are known or have been assumed.

The tool has not been used in lost circulation applications. From interviews with log analysts on the feasibility of using the formation density logging tool for mapping lost circulation zones it appears the tool has limited applicability for such use because:

- formation bulk density is an average measure of the grain density of the rock and the density of the pore fluids. Thus the measurement is subject to changes in density differences between the drilling mud and the pore fluids. Such a change may be indiscernible. Furthermore, the pore fluid density is not determined by the tool.

General Description (continued)

- The tool is a shallow investigating device, about 6 inches, and cannot distinguish between zones of lost circulation (i.e., formations accepting whole mud) and normally invaded zones (mud filtrate) due to the similar densities of mud filtrate and whole mud.

- Averages density values over a fairly large volume.

- Would require base formation density log for correlation.

Ability to Locate Lost Circulation Zones

It cannot be used to directly locate lost circulation zones because it provides no characteristic response at the point of loss. Can be helpful as an aid by identifying vugular or high porosity zones that may be associated with lost circulation.

Capability to Quantify Size of Zone and Rate of Loss

The height of the vugular or porous zone can be ascertained by the tool. The width of the zone and the rate of loss remain unknown.

Capability to Operate in Geothermal Well

Operates at temperatures up to 500°F and can be run in any borehole fluid. Higher temperature tools are feasible. The main temperature-sensitive element is the detector system electronics.

Accuracy

The accuracy of the measurements is generally good, and the tool gives good depth resolution.

The tool's accuracy to find and quantify lost circulation zones is poor.

Reliability

Fairly reliable.

Availability

Tool is readily accessible.

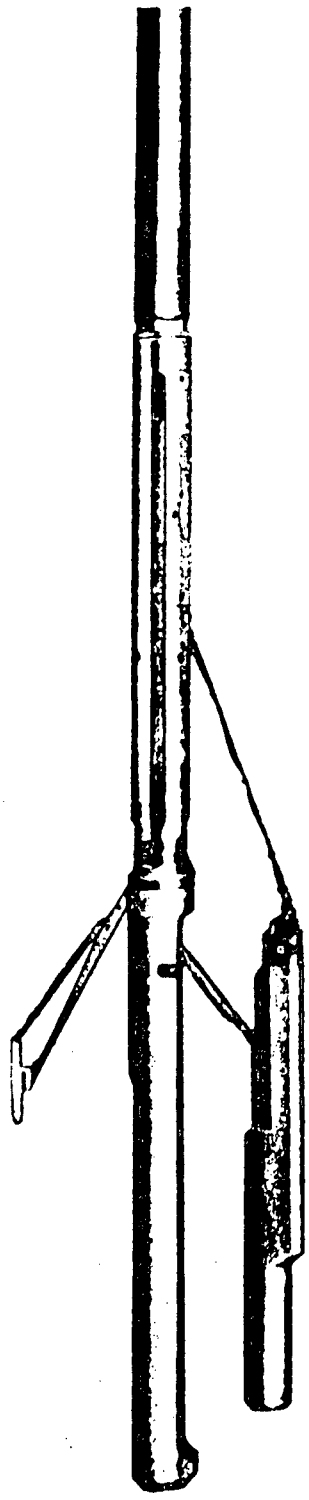


Figure 16. Formation Density Log Tool

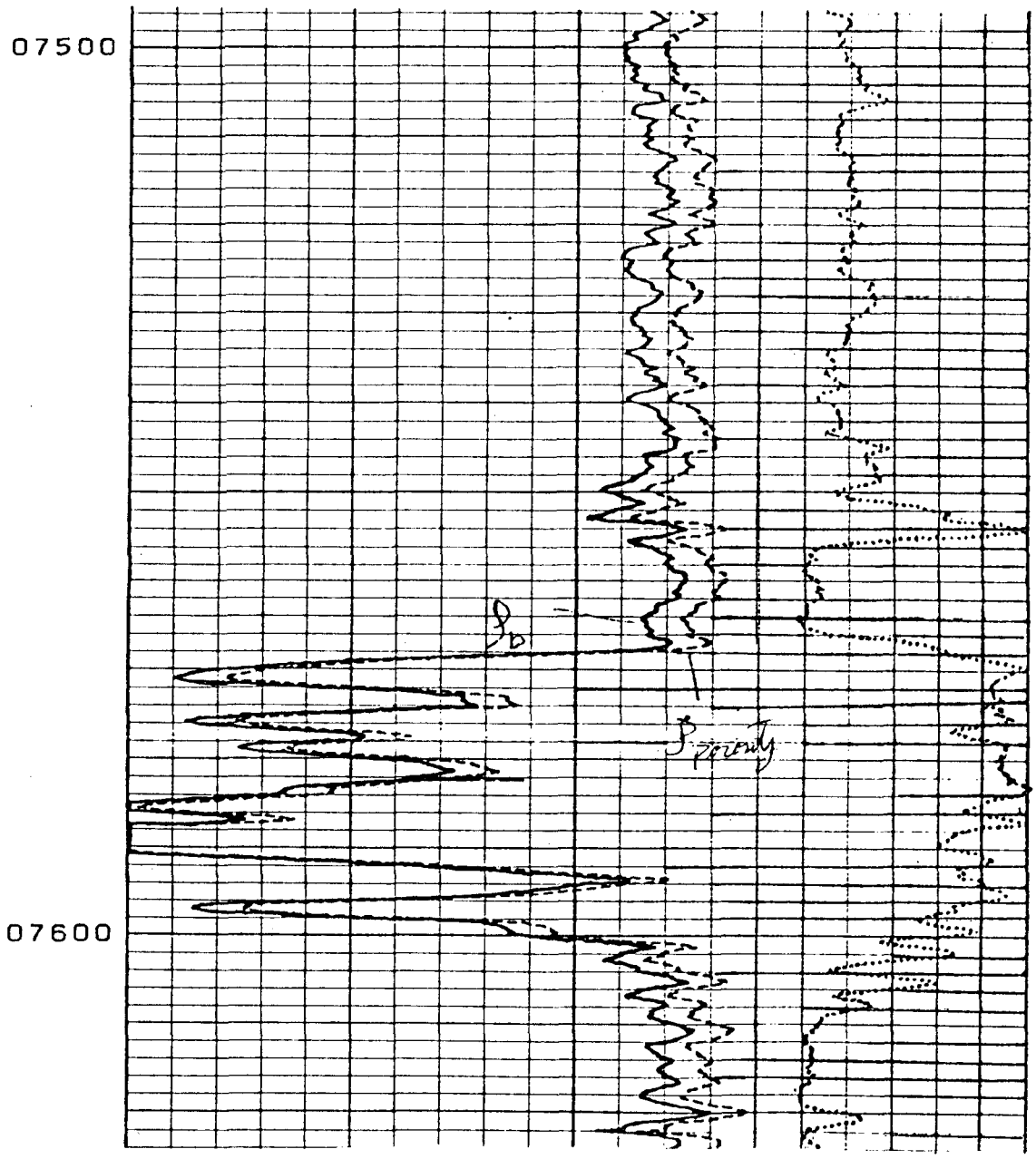


Figure 17. Example of the Formation Density Logs response to fractures. In this real example the tool detected a fractured zone in Austin chalk that starts at 7,568 ft and continues until 7,600 ft.

TOOL NAME - FORMATION DENSITY LOG

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	2	80%	1.6				
• Determine orientation	1	20%	.2				
			1.8	22.5%	.4		
Quantify zone size							
• Height	6	33%	2.0				
• Width	1	33%	.3				
• Flow rate into zone	1	34%	.3				
			2.6	22.5%	.6		
Operate in geothermal well							
• Temp. rating	9	33%	3.0				
• Pressure rating	9	33%	3.0				
• Mud wt/type	9	34%	3.1				
			9.1	22.5%	2.0		
Accuracy							
• Tool accuracy	6	50%	3.0				
• Locate zone	3	25%	.8				
• Quantify zone	2	25%	.5				
			4.3	22.5%	1.0		
Reliability	7	100%	7.0	10.0%	.7		
					4.7	X .50 =	2.4
RISK							
Stage of development							
• Temp. rating	9	45%	4.1				
• Pressure rating	9	45%	4.1				
• Mud wt/type	9	10%	.9				
			9.1	33.0%	3.0		
Design approach							
• Locate zone	3	50%	1.5				
• Quantify zone	3	50%	1.5				
			3.0	33.0%	1.0		
Experience/Testing	3	100%	3.0	34.0%	1.0		
					5.0	X .20 =	1.0
COST	7	100%				X .10 =	.7
AVAILABILITY	10	100%				X .20 =	2.0
						Final score	6.1

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

References

FORMATION DENSITY LOG

1. Hamilton, R. G. and Myung, J. I.; Summary of Geophysical Well Logging, Seismograph Service Corp., Tulsa, OK.

2. "Humble Well Logging School," 1969.

3. Tittman, J.; "Radiation Logging: Applications," University of Kansas, Petrol. Eng., Conf. 1956.

4. Tittman, J.; "Radiation Logging: Physical Principles."

Name of Tool: Fracture Identification Log

Type: Electrical

Manufacturer: Schlumberger

Cost: Approximately $6,500 per run

State of Development: Operates up to 350°F, 20,000 psi

General Description:

The Fracture Identification logging sequence requires two trips in the hole to obtain data. The first trip consists of running a Dual Induction-Laterolog to correlate sections and to give initial indication of fractures. A four-arm 90° phased micro-resistivity log is then run upon completion of the Dual Induction - Laterolog. This device simultaneously examines the four sides of the borehole wall to better identify vertical and horizontal frctures.

Ability to Locate Lost Circulation Zones

This combination is one of the best resistivity devices for locating those lost circulation zones characterized by conductive anomalies. A good tool for locating fractures that may be associated with lost circulation, it provides information on orientation of the encountered fractures.

Capability to Quantify Size of Zone and Rate of Loss

When applicable, the tool can provide a good estimate on the height of the zone.

Capability to Operate in Geothermal Well

Capable of operating in environments where the temperature does not exceed 350°F. Dual Induction Laterolog operates up to 500°F, 25,000 psi. Reader is referred to Dual Induction Laterolog and Microresistivity Logs in this appendix.

For information on the ability of individual components to operate in various well fluids, see sections that describe the Dual Induction - Laterolog and the Microresistivity Logs.

Accuracy

The accuracy of the resistivity measurements is good. The height determination is the best of the electrical resistivity devices.

Reliability

Good.

Availability

Readily available from Schlumberger.

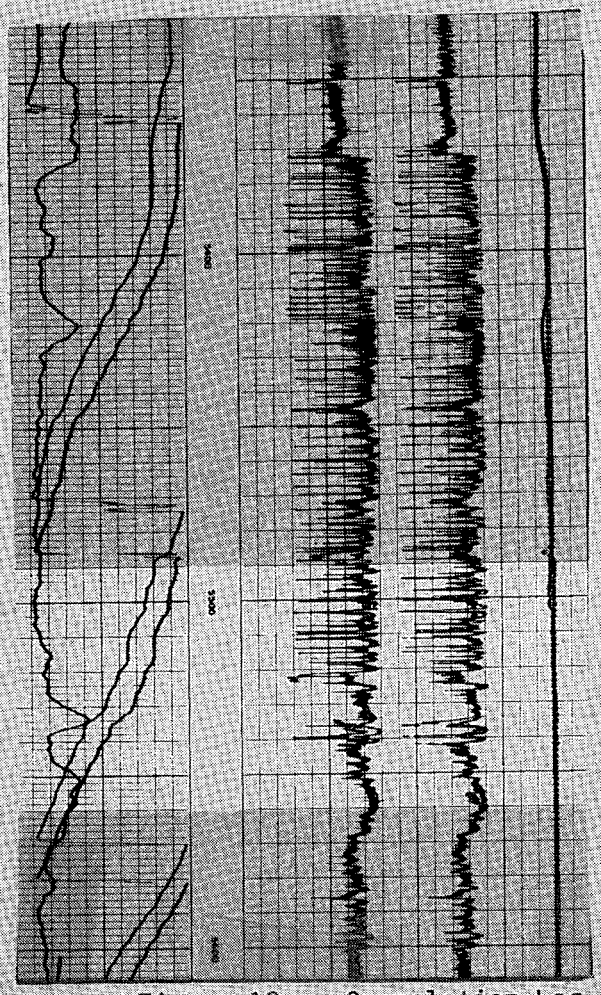


Figure 18. Correlation Log

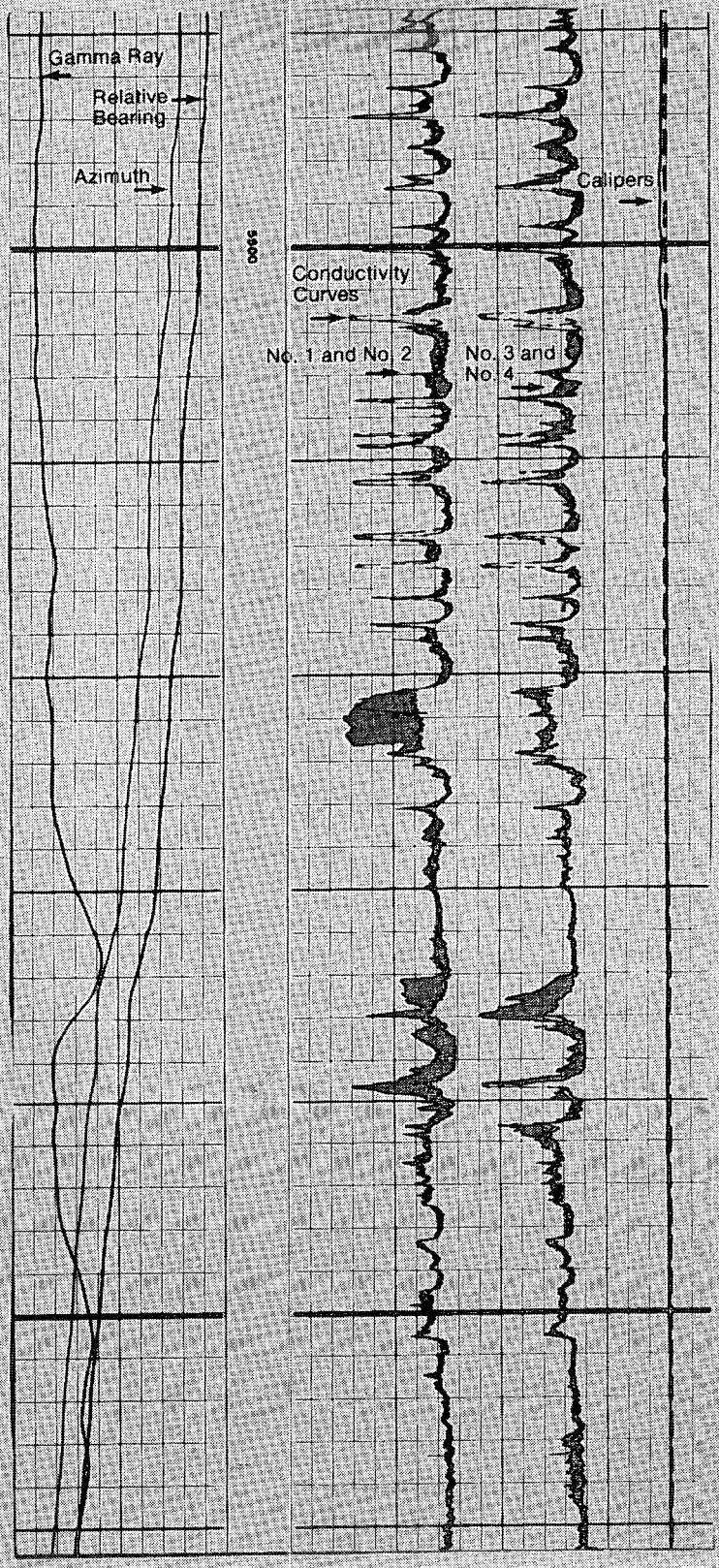


Figure 19. FIL Log Showing Fractures

TOOL NAME - FRACTURE INDENTIFICATION LOG

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	5	80%	4.0				
• Determine orientation	1	20%	.2				
			4.2	22.5%	.9		
Quantify zone size							
• Height	6	33%	2.0				
• Width	1	33%	.3				
• Flow rate into zone	1	34%	.3				
			2.6	22.5%	.6		
Operate in geothermal well							
• Temp. rating	7	33%	2.3				
• Pressure rating	9	33%	3.0				
• Mud wt/type	7	34%	2.4				
			7.7	22.5%	1.7		
Accuracy							
• Tool accuracy	9	50%	4.5				
• Locate zone	7	25%	1.8				
• Quantify zone	3	25%	.8				
			7.1	22.5%	1.6		
Reliability	7	100%	7.0	10.0%	.7		
					5.5	X .50 =	2.8
RISK							
Stage of development							
• Temp. rating	9	45%	4.1				
• Pressure rating	9	45%	4.1				
• Mud wt/type	8	10%	.8				
			9.0	33.0%	3.0		
Design approach							
• Locate zone	7	50%	3.5				
• Quantify zone	2	50%	1.0				
			4.5	33.0%	1.5		
Experience/Testing	5	100%	5.0	34.0%	1.7		
					6.2	X .20 =	1.2
COST	7	100%				X .10 =	.7
AVAILABILITY	10	100%				X .20 =	2.0

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

Final score 6.7

Name of Tool: Hot Film Anemometer

Type: Electrical

Manufacturer: CGS Datametrics Corporation

Cost: Unknown

State of Development: Sensor assemblies have been designed to operate in excess of 500°F.

General Description:

Developed in 1955, the Hot Film Anemometer is a flow rate device used for the detection and quantification of gas or liquid entry and exit zones.

The tool is composed of a heated assembly and an ambient temperature assembly located between adjustable packers. These sensor assemblies are maintained at a fixed resistance ratio. When the tool encounters lost circulation zones, the escaping fluid is caused to flow past the sensors. This fluid carries heat away from the hot junction thereby causing an unbalanced bridge. Heat source temperature and bridge balance are restored by increasing the current to the sensors. The current needed to restore the fixed resistance ratio is proportional to the fluid velocity. Thus, by knowing the fluid velocity and the spacing of the packers, the lost circulation zone can be identified and its flow capacity deduced.

Ability to Locate Lost Circulation Zones

A geothermal tool would appear to have good potential for success in locating the depth of lost circulation and in quantifying the net loss (or gain).

Capability to Quantify Size of Zone and Rate of Loss

The tool can determine the height and rate of loss into the zone. The width of the zone is undetermined by this method.

Capability to Operate in Geothermal Well

The tool could likely be made to operate at temperatures in excess of 500°F, in high pressures, and run in any drilling fluid.

Accuracy

The tool is sensitive to even very small changes in fluid velocity. This sensitivity provides for accurate determinations of the height and flow rate into the zone.

Reliability

Reliable in process plant operation. Downhole Bureau of Mines tool was also found to be reliable.

Availability

Downhole tool unavailable.

TOOL NAME - HOT FILM ANEMOMETER

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	8	80%	6.4				
• Determine orientation	1	20%	.2				
			6.6	22.5%	1.5		
Quantify zone size							
• Height	8	33%	2.6				
• Width	1	33%	.3				
• Flow rate into zone	9	34%	3.1				
			6.0	22.5%	1.4		
Operate in geothermal well							
• Temp. rating	8	33%	2.6				
• Pressure rating	9	33%	3.0				
• Mud wt/type	9	34%	3.1				
			8.7	22.5%	2.0		
Accuracy							
• Tool accuracy	9	50%	4.5				
• Locate zone	8	25%	2.0				
• Quantify zone	7	25%	1.8				
			8.3	22.5%	1.9		
Reliability	7	100%	7.0	10.0%	.7		
					7.5	X .50 =	3.8
RISK							
Stage of development							
• Temp. rating	8	45%	3.6				
• Pressure rating	8	45%	3.6				
• Mud wt/type	1	10%	.1				
			7.3	33.0%	2.4		
Design approach							
• Locate zone	9	50%	4.5				
• Quantify zone	7	50%	3.5				
			8.0	33.0%	2.6		
Experience/Testing	2	100%	2.0	34.0%	.7		
					5.7	X .20 =	1.1
COST	NA	100%				X .10 =	–
AVAILABILITY	NA	100%				X .20 =	–

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

Final score: 4.9

References

HOT-FILM ANEMOMETER

1. Thomas, H.E.; "The Hot Film Flow Log - A Formation Evaluation Tool Designed for Shallow In Situ Oil Shale Experiments," SPE-3501, 40th Annual Fall Mtg. AIME-SPE, New Orleans, LA, October 3-6, 1971.

2. Thomas, H. E. and Sterner, T. E.; "Hot-Film Flow Logging as Applied To In Situ Oil Shale and Moving Experiments," SPWLA 13th Annual Logging Symposium, pp. 1-14, May 7-10, 1972.

Name of Tool: Hot Wire Survey

Type: Electrical

Manufacturer: Dowell (1950s)

Cost: Tool is not available

State of Development: The Dowell version was a low temperature device being able to withstand temperatures up to 250°F.

General Description:

The hot wire survey tool is a calibrated resistance wire which functions as a highly sensitive flowmeter. Its operation is based on the principles of heat transfer.

When a hot wire is immersed in a cooler fluid, heat will be transfered from the wire to the fluid. The rate of heat transfer is dependent upon the temperature differential between the wire and fluid, heat conductivity of the fluid, and the rate at which the fluid is moving past the wire. Thus, by measuring the rate of heat dissipation, a quantitative value for the local fluid velocity can be obtained.

In normal operation the tool is lowered into the drill by a wire line; the wireline housing the necessary electrical connection to surface equipment. Fluid is injected into the well at a constant rate and readings at various levels of interest are recorded. If the tool is located below a zone of lost circulation, a zero flow rate is recorded. By raising the tool into the zone and taking successive measurements, the extent and depth of the zone can be discovered.

Ability to Locate Lost Circulation Zones

The original tool has been used successfully to locate lost circulation zones in over 165 surveys. It appears to be a good tool for locating the zone, but large amounts of mud are required while running the survey.

Capability to Quantify Size of Zone and Rate of Loss

The tool is satisfactory for determining the vertical extent of the zone and provides a direct measure of the rate of loss. The width of the zone is undetermined.

Capability to Operate in Geothermal Well

Original tool could operate at temperatures up to 250°F. A high temperature version of the tool appears feasible. Able to operate in all drilling fluids.

Accuracy

Appears to have had good accuracy concerning the height determination although several logging analysts feel that the "skin effect" may preclude recording the actual in situ flow conditions.

Reliability

The tool is delicate due to the fineness of the sensing element.

Availability

The tool is not available.

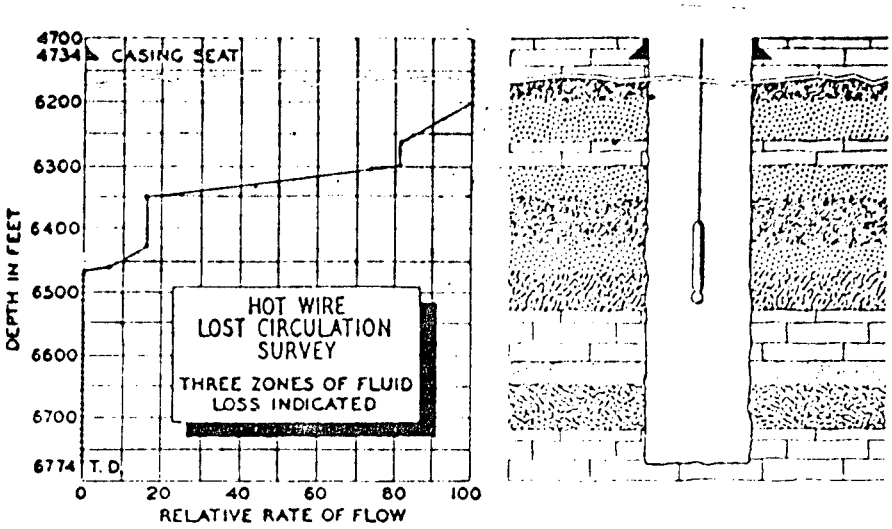


Figure 20. Hot Wire Survey

TOOL NAME - HOT WIRE SURVEY

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	8	80%	6.4				
• Determine orientation	1	20%	.2				
			6.6	22.5%	1.5		
Quantify zone size							
• Height	7	33%	2.3				
• Width	1	33%	.3				
• Flow rate into zone	8	34%	2.7				
			5.3	22.5%	1.2		
Operate in geothermal well							
• Temp. rating	4	33%	1.3				
• Pressure rating	8	33%	2.6				
• Mud wt/type	9	34%	3.1				
			7.0	22.5%	1.6		
Accuracy							
• Tool accuracy	9	50%	4.5				
• Locate zone	8	25%	2.0				
• Quantify zone	7	25%	1.8				
			8.3	22.5%	1.9		
Reliability	5	100%	5.0	10.0%	.5		
					6.7	X .50 =	3.4
RISK							
Stage of development							
• Temp. rating	5	45%	2.3				
• Pressure rating	8	45%	3.6				
• Mud wt/type	1	10%	.1				
			6.0	33.0%	2.0		
Design approach							
• Locate zone	9	50%	4.5				
• Quantify zone	7	50%	3.5				
			8.0	33.0%	2.6		
Experience/Testing	9	100%	9.0	34.0%	3.1		
					7.7	X .20 =	1.5
COST	NA	100%				X .10 =	
AVAILABILITY	NA	100%				X .20 =	

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

Final score 4.9

References

HOT WIRE SURVEY

1. Campbell, G. G., Scott, W. G., and Miller, J. S.; "Evaluation of Oil Shale Fracturing Tests near Rock Springs, Wyoming," Bureau of Mines Report of Inv. 7397, 1970.

2. Hamilton, R. G. and Myung, J. I.; Summary of Geophysical Well Logging, Seismograph Service Corporation.

3. Henderson, R. A.; "Hot Wire Tool Locates Lost Circulation," World Oil, pp. 187-188, October 1952.

4. Lamer, M.D.; "Measurement Requirements and Methods for Geothermal Reservoir System Parameters (An Apprasal)," Measurement Analysis Corporation, August 1979, MAC Tech Report No. 7806-01.

Name of Tool:	Impression Packers
Type:	Mechanical
Manufacturer:	Tam International, Lynes
Cost:	Approximately $3,100 per run plus orienting costs. The cost per run is based on 10-foot impression packers for use in 7" dia. open hole.
State of Development:	Tam International impression packers can operate at temperatures up to 250°F. According to Lynes, their packer can be run up to 550°F.

General Description:

Impression Packers can be used to obtain an imprint of the borehole wall. The impression is preserved in a soft rubber element. Impression packers are usually run into the hole on the end of the drill pipe. When the tool is at the proper depth, a ball is dropped to inflate the packer. Pressure is maintained at some level for a predetermined time. At this point, the pressure is increased to eject the ball and allow the packer to become deflated. A 360 degree, three dimensional impression of the borehole face can then be brought to the surface for visual inspection. Figure 21 shows the Tam International and Lynes impression packers.

Ability to Locate Lost Circulation Zones

Essentially it cannot determine a lost circulation zone due to limited length and, more importantly, its inability to determine if there is fluid escape.

If a zone is known to be losing circulation, use of this method allows the determining of the type of zone and, if it is a fracture, the width and orientation.

Capability to Quantify Size of Zone and Rate of Loss

Must be used selectively since each packer will cover only a limited length of borehole. Good tool for showing size and orientation of fractures and vugs intersecting borehole. Not good for quantifying magnitude of lost circulation into such zones.

Capability to Operate in Geothermal Well

Operational capability up to approximately 550°F. A higher temperature capability may be feasible. Able to operate in any drilling fluid so long as the fluid is non-corrosive to the rubber element.

Accuracy

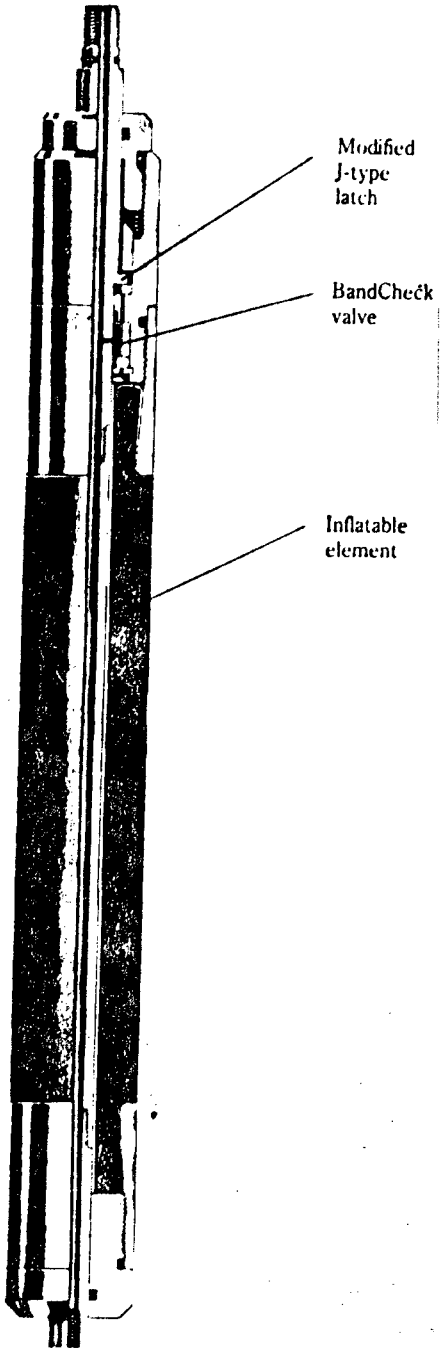
The rubber element accurately records the condition of the borehole wall.

Reliability

Very reliable due to its simplicity and function.

Availability

Tools are available from Tam International and Lynes.



Tam International

Lynes

Figure 21. Impression Packers

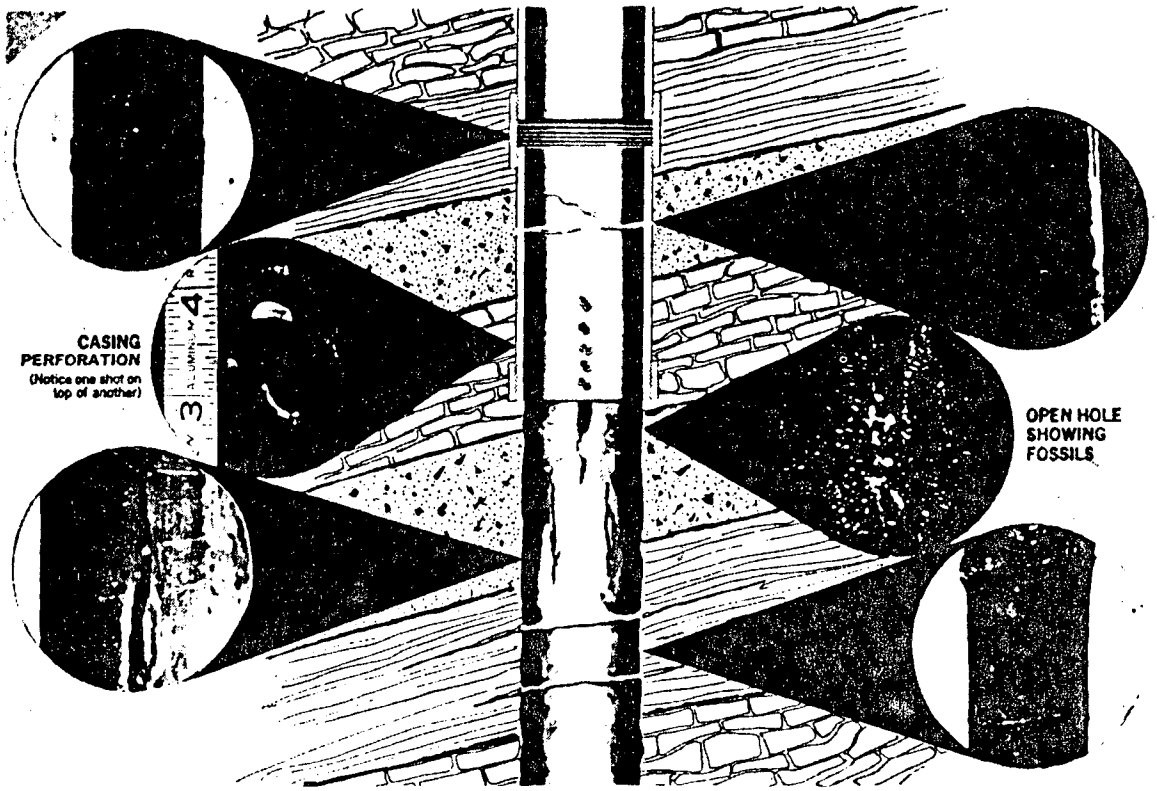


Figure 22. Impression Packer Records

Figure 22 shows packer impressions of six borehole conditions: 1) casing collar, 2) casing perforation, 3) open hole vertical fracture, 4) split casing, 5) fossils, and 6) bedding plans.

TOOL NAME - IMPRESSION PACKERS

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	1	80%	.8				
• Determine orientation	9	20%	1.8				
			2.6	22.5%	.6		
Quantify zone size							
• Height	9*	33%	3.0				
• Width	9	33%	3.0				
• Flow rate into zone	1	34%	.3				
			6.3	22.5%	1.4		
Operate in geothermal well							
• Temp. rating	9	33%	3.0				
• Pressure rating	9	33%	3.0				
• Mud wt/type	9	34%	3.1				
			9.1	22.5%	2.0		
Accuracy							
• Tool accuracy	9	50%	4.5				
• Locate zone	1	25%	.3				
• Quantify zone	7	25%	1.8				
			6.6	22.5%	1.5		
Reliability	9	100%	9.0	10.0%	.9		
					6.4	X .50 =	3.2
RISK							
Stage of development							
• Temp. rating	9	45%	4.1				
• Pressure rating	9	45%	4.1				
• Mud wt/type	9	10%	.9				
			9.1	33.0%	3.0		
Design approach							
• Locate zone	1	50%	.5				
• Quantify zone	7	50%	3.5				
			4.0	33.0%	1.3		
Experience/Testing	9	100%	9.0	34.0%	3.1		
					7.4	X .20 =	1.5
COST	9	100%				X .10 =	.9
AVAILABILITY	10	100%				X .20 =	2.0
						Final score	7.6

* when used selectively

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

Name of Tool: Induction Logs

Type: Electrical

Manufacturer: Birdwell, Dresser-Atlas, The GO Company, Halliburton, Pengo

Cost: $5,000 per run

State of Development: The majority of available tools operate at temperatures up to 325-400°F.

General Description:

Induction logs are used to obtain measurements on formation conductivity. The tool is composed of several transmitter and receiver coils. In operation, the formation is subjected to focused high frequency electromagnetic energy from the transmitters. This energy induces secondary currents in the formation which are detected by the receiver coils as receiver EMF's. The magnitude of the reciever EMF is proportional to the formation conductivity.

Historically, the main purpose of induction logs has been the determination of the relative percent of hydrocarbon saturation of the pore fluids. A special application of this tool is its use as a lost circulation detector. Lost circulation zones such as open fractures or permeable beds will appear as conductive anomalies. This discrepancy is due to the differences in conductivity between the drill mud and the formation and its associated fluids.

Ability to Locate Lost Circulation Zones

The Induction log's ability to locate lost circulation zones is directly related to:

- the vertical extent of the zone and
- the volume filled by mud, and
- the conductivity characteristics of the adjacent zones that bound it.

It is assumed that more than one induction log is run. Usually a shallow and a medium induction curve is obtained. Preferred embodiment is to run with a vertical reading device and correlate with prior induction or other resistivity device.

Ability to Locate Lost Circulation Zones (continued)

The tool can locate high conductivity pathways which may be indicative of the lost circulation zone. These high conductivity zones occur when fluid flows into a fractured or permeable zone that is bounded by low porosity rock. Many of the tools are unable to resolve thin permeable beds or fracture intervals less than 4 feet high. Induction logs usually respond better to horizontally oriented fractures that are filled with conductive mud.

Capability to Quantify Size of Zone and Rate of Loss

If the tool is run under conditions advantageous to its use in locating the lost zones as outlined above, it can usually locate the height of the zone to within the vertical resolution of the tool. The tool has no ability to determine the width of the zone nor can it provide information on the flow rate into the zone. But it can provide invasion depths.

Capability to Operate in Geothermal Well

Depending on manufacturer, the tool can be run at temperatures as high as 325-400°F. 500°F tools are available for service from Schlumberger but are in limited supply. Higher temperature capabilities are feasible. The tool works well in air, gas, oil-base and water-base muds, provided the mud is not too salty.

Accuracy

The accuracy of the measurements obtained is generally good when the tool is run in the proper muds. Very resistive formations can cause large errors in measurement (>20%) as conductivity approaches zero. The height of the zone can be determined to within about 5-10 feet in applicable situations.

Reliability

The tool is reliable in operation to the temperatures stated. Temperatures exceeding the rated value affect the tools performance.

Availability

Tool is widely available.

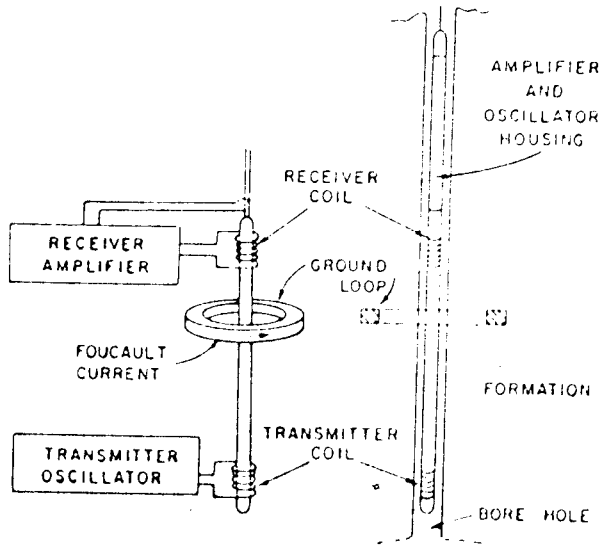


Figure 23. Simplified Schematic of Induction Log

TOOL NAME - INDUCTION LOGS

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	4	80%	3.2				
• Determine orientation	1	20%	.2				
			3.4	22.5%	.8		
Quantify zone size							
• Height	5	33%	1.7				
• Width	1	33%	.3				
• Flow rate into zone	1	34%	.3				
			2.3	22.5%	.5		
Operate in geothermal well							
• Temp. rating	8	33%	2.6				
• Pressure rating	9	33%	3.0				
• Mud wt/type	8	34%	.7				
			8.3	22.5%	1.9		
Accuracy							
• Tool accuracy	9	50%	4.5				
• Locate zone	5	25%	1.3				
• Quantify zone	2	25%	.5				
			6.3	22.5%	1.4		
Reliability	7	100%	7.0	10.0%	.7		
					5.3	X .50 =	2.7
RISK							
Stage of development							
• Temp. rating	9	45%	4.1				
• Pressure rating	9	45%	4.1				
• Mud wt/type	8	10%	.8				
			9.0	33.0%	3.0		
Design approach							
• Locate zone	4	50%	2.0				
• Quantify zone	2	50%	1.0				
			3.0	33.0%	1.0		
Experience/Testing	4	100%	4.0	34.0%	1.4		
					5.4	X .20 =	1.1
COST	8	100%				X .10 =	.8
AVAILABILITY	10	100%				X .20 =	2.0
						Final score	6.6

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

Name of Tool: Lost Circulation Detector

Type: Electrical

Manufacturer: California Research Corporation

Cost: Not available

State of Development: No longer in service. The model built and tested was for low temperature service (250°F).

General Description:

This method, which is run with a temperature survey, involves the injection of a slug of low resistivity fluid into the moving mud column and then detecting the flow of this slug past suitably placed electrode pairs.

The temperature survey is run going downhole and is used for the primary detection of the thief zone and determines which zones will be examined in detail.

The tool is then located just above this zone. The low resistivity fluid is injected into the mud column and its passage over the electrodes is recorded. If fluid movement is indicated past the bottom electrode pair, the tool is located above the zone of lost circulation. Conversely, if no fluid movement occurs, the tool is below the zone. By bracketing the zone, the extent of zone can be accurately defined.

Ability to Locate Lost Circulation Zones

A good tool specifically designed to pinpoint the location of the lost circulation zone. Mud flow is required for operation and the mud must be conductive if the tool is to operate correctly.

A poor tool for determining the orientation of the zone.

Capability to Quantify Size of Zone and Rate of Loss

A good tool for accurately determining the vertical extent of the lost circulation zone. A poor tool for determining the width of the zone. The tool provides the approximate rate of loss at any point.

Capability to Operate in Geothermal Well

The tool can operate in a wide range of mud resistivities.

The tool saw limited use in the 1950s. It is believed that the tool was a low temperature device since it was designed for the downhole temperatures normally encountered in oil and gas wells at that time.

Accuracy

Based on limited information, the overall accuracy of the tool appears to have been good.

Reliability

Good.

Availability

Not available.

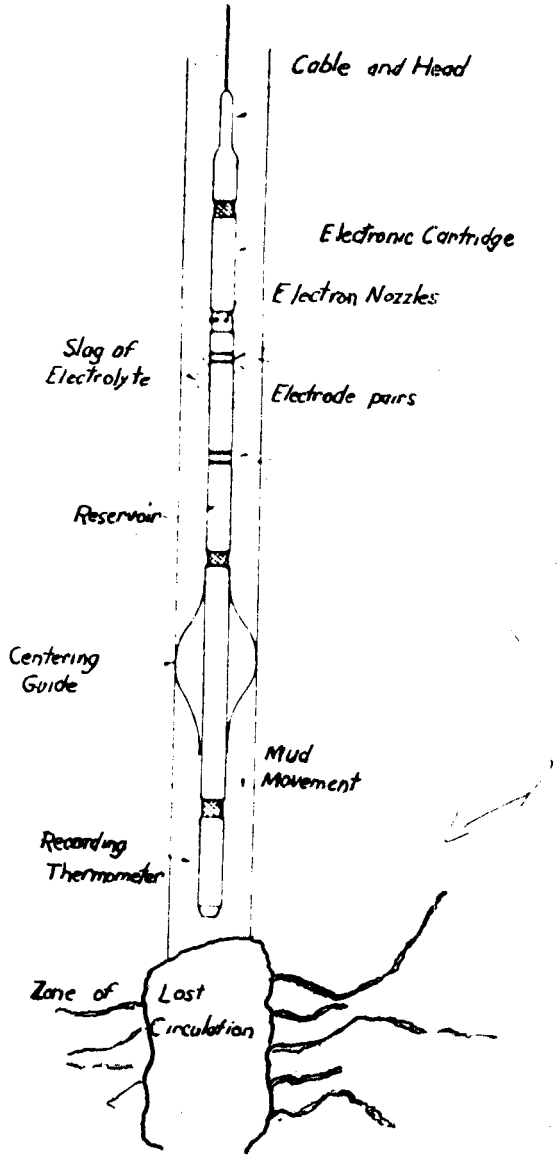


Figure 24. Lost Circulation Detector

TOOL NAME - LOST CIRCULATION DETECTOR

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	9	80%	7.2				
• Determine orientation	1	20%	.2				
			7.4	22.5%	1.7		
Quantify zone size							
• Height	8	33%	2.6				
• Width	1	33%	.3				
• Flow rate into zone	8	34%	2.7				
			5.6	22.5%	1.3		
Operate in geothermal well							
• Temp. rating	4	33%	1.3				
• Pressure rating	9	33%	3.0				
• Mud wt/type	7	34%	2.4				
			6.7	22.5%	1.5		
Accuracy							
• Tool accuracy	8	50%	4.0				
• Locate zone	8	25%	2.0				
• Quantify zone	7	25%	1.8				
			7.8	22.5%	1.8		
Reliability	7	100%	7.0	10.0%	.7		
					7.0	X .50 =	3.5
RISK							
Stage of development							
• Temp. rating	5	45%	2.3				
• Pressure rating	9	45%	4.1				
• Mud wt/type	1	10%	.1				
			6.5	33.0%	2.1		
Design approach							
• Locate zone	9	50%	4.5				
• Quantify zone	6	50%	3.0				
			7.5	33.0%	2.5		
Experience/Testing	5	100%	5.0	34.0%	1.7		
					6.3	X .20 =	1.3
COST	NA	100%				X .10 =	–
AVAILABILITY	NA	100%				X .20 =	–

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

Final score: 4.8

References

LOST CIRCULATION DETECTORS

1. Gallagher, C. F.; "Methods and Devices for Locating the Zone of Lost Circulation," API Paper No. 801-32C presented at the Spring Meeting of the Pacific Coast District, Div. of Prod., API, Los Angeles, CA, May 10 and 11, 1956.

2. Hamilton, R. G. and Myung, J. I.; Summary of Geophysical Well Logging, Seismograph Service Corporation.

Name of Tool: Microresistivity Logs

Type: Electrical

Manufacturer: Schlumberger, Halliburton, The GO Company, Dresser-Atlas

Cost: $5,100 per run

State of Development: Tool operates to temperatures up to 350°F

General Description:

Microresistivity tools measure the resistivity of the flushed zone and delineate permeable beds by detecting the mud cake. The tool has the necessary mechanics to press a rubber pad against the borehole wall. In the face of this pad are located the tool's sensing elements, small electrodes, usually between 3 and 6, spaced a short distance apart. The tool examines the wall to a depth of one to four inches. Four-arm microresistivity tools compare all four sides of the wellbore simultaneously and are used to detect fractures.

When a permeable zone is encountered, the four logs track one another. Whereas when nonhorizontal fractures are encountered, the pads located 90 degrees apart give different reponses. This behavior is caused by the fluid in the fracture. When horizontal fractures are encountered the tool's response is characterized by sharp, low resistivity spikes on all four pads simultaneously. Figure 25 shows a four-arm microresistivity log in which several fractures between 11,015 and 11,065 ft. were located.

Ability to Locate Lost Circulation Zones

The tool is helpful in locating lost circulation zones occurring in low porosity and low permeability fractured intervals. In a permeable formation, the tool's shallow depth of investigation will respond similarly to normal mud filtrate and whole mud loss zones. It may miss entirely fractures that cause lost circulation, seeing them as high conductivity anomalies because the average porosity in the small volume of investigation is large, or the local saturation of conductive drilling fluid is high.

It can derive the general inclination of the fractures.

Capability to Quantify Size of Zone and Rate of Loss

The tool can provide information on the height of the zone. The width of the zone and the rate of loss are undetermined by this method.

Capability to Operate in Geothermal Well

It can be run in environments where the temperature does not exceed 350°F. Can operate in fresh and salt base muds. Not useful for air-drilled holes.

Accuracy

The tool is accurate, with good logs obtained even in low porosity formations. Poor results in rugose holes where wall contact is difficult to maintain. Height determinations are fair. Better results are achieved if the tool follows the fracture path and the bounding zones have different characteristics.

Reliability

The tool is reliable although the retractable arm may be damaged in out-of-round holes.

Availability

High.

Figure shows several fractures at depths of 11,015 to 11,065 ft.

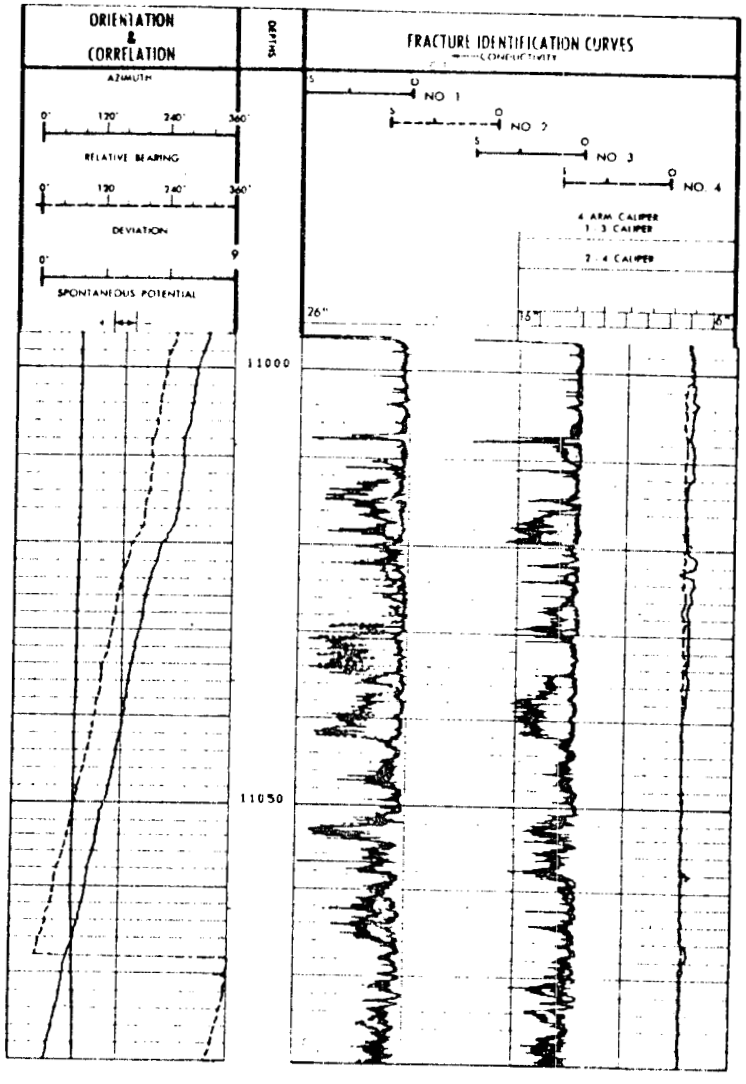
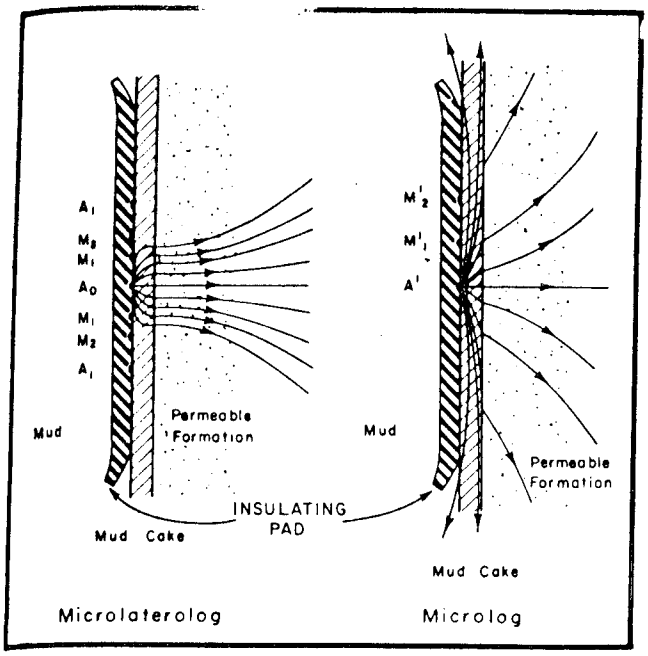


Figure 25. Four-Arm Microresistivity Log of Fractures



Comparative distribution of current lines of Microlaterolog and Microlog.

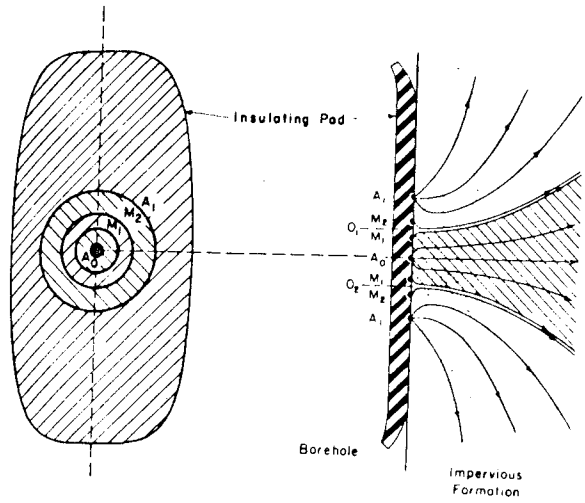


Figure 26. Current Lines Distribution of Some Microresistivity Devices

TOOL NAME - MICRORESISTIVITY LOGS

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	3	80%	2.4				
• Determine orientation	6	20%	1.2				
			3.6	22.5%	.8		
Quantify zone size							
• Height	6	33%	2.0				
• Width	1	33%	.3				
• Flow rate into zone	1	34%	.3				
			2.6	22.5%	.6		
Operate in geothermal well							
• Temp. rating	6	33%	2.0				
• Pressure rating	9	33%	3.0				
• Mud wt/type	6	34%	2.0				
			7.0	22.5%	1.6		
Accuracy							
• Tool accuracy	9	50%	4.5				
• Locate zone	3	25%	.8				
• Quantify zone	2	25%	.5				
			5.8	22.5%	1.3		
Reliability	7	100%	7.0	10.0%	.7		
					5.0	X .50 =	2.5
RISK							
Stage of development							
• Temp. rating	6	45%	2.7				
• Pressure rating	9	45%	4.1				
• Mud wt/type	8	10%	.8				
			7.6	33.0%	2.5		
Design approach							
• Locate zone	4	50%	2.0				
• Quantify zone	3	50%	1.5				
			3.5	33.0%	1.2		
Experience/Testing	4	100%	4.0	34.0%	1.4		
					5.1	X .20 =	1.0
COST	8	100%				X .10 =	.8
AVAILABILITY	10	100%				X .20 =	2.0
						Final score	6.3

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

References

MICRORESISTIVITY LOGS

1. Log Review I, Dresser-Atlas, 1974

2. Log Interpretation - Vol. I, Principles, New York, New York, ... Schlumberger, 1972.

3. Suau, J., and Gartner, J.; "Fracture Detection from Well Logs," Log Analyst, pp. 3-13, March - April 1960.

4. Tixier, M. P.; "Fundamentals of Logging," University of Kansas, Petro. Eng. Conf., pp. 43-66, 1956.

Name of Tool:	Neutron Log
Type:	Radiation
Manufacturer:	Birdwell, DIA-Log, Schlumberger, Halliburton, Dresser-Atlas, The GO Company
Cost:	Approximately $4,700 plus orienting costs
State of Development:	Operates at temperatures up to 400°F, 15,000 -20,000 psi. The Schlumberger HEL tool is rated at 500°F, 25,000 psi and available in limited supply. Higher temperature capabilities are feasible.

General Description:

Neutron logs are used to delineate and quantify formation porosity. The tool consist of a Pu-Be or Am-Be chemical neutron source that emits neutrons into the formation. These neutrons collide with nuclei of the formation material losing energy with each collosion. The amount of energy lost per collision is a function of the relative mass of the nucleus with which the neutron collides. The closer the nucleus is in mass to the neutron the greater the energy loss. Hence, the majority of tools are sensitive to hydrogen concentration.

Within a few micro-seconds of emittance, the energy of the neutrons has been reduced through successive collisions to thermal velocities. These thermal neutrons diffuse randomly until capture by the nuclei of atoms such as chlorine. Upon capturing the thermal neutron, the excited nuclei emit gamma radiation.

Depending on the type of neutron logging tool, the thermal neutrons and/or gamma rays are counted by a detector(s) spaced a nominal distance from the source. Accordingly, the counting rate determines the porosity of the formation. Because chlorine has a large thermal neutron capture cross-section and is present in large amounts in the water contained in most formations, neutron logs with gamma ray detectors are often called chlorine logs.

The tool is usually run with a caliper device to provide corrections for hole geometry effects.

A possible application of neutron logging is its use as a lost circulation detector. It is believed this method can be used if

- there is a large salinity differential between the mud and formation fluids, or
- the relative difference in hydrogen concentrations in the formation and drill fluid is sufficiently large enough to cause a measurable change in counting rate. This condition is considered extremely unusual. Use sidewall tool.

General Description (continued):

These two conditions rely on the differences in absorption rates due to dissimilar concentrations of chlorine and hydrogen, respectively, with the resulting changes in both gamma ray and thermal neutron counting rates.

Ability to Locate Lost Circulation Zones

Can possibly locate lost circulation when run under the conditions detailed in the General Description, provided normal invasion is not too deep, less than 3 inches. Field testing and further research is needed to determine the actual usefulness of the method. Work is currently underway to examine the fracture-finding capabilities of the epithermal-thermal neutron logging combination. Results are not yet available.

Capability to Quantify Size of Zone and Rate of Loss

Vertical resolution of the tool is good, but the width and the rate of loss into the zone are beyond the capabilities of the tool.

Capability to Operate in Geothermal Well

As stated, the tool can be used in any borehole fluid (gas, oil, water or mud) at temperatures as high as 400°F. High density muds increase the neutron counting rate and require correction.

Accuracy

Radioactive measurements are statisical in nature. Good quality logs can be obtained by adjusting the time-constant setting and the logging speed so that enough counts are recorded. The tool's accuracy in locating and quantifying the zone is undetermined at this time. The chlorine log is sensitive to salinities above 40,000 ppm. The neutron log reads higher than normal porosities in shaly environments.

Reliability

The tool is quite reliable in operation.

Availability

The tool is widely available in 350-400°F temperature range. 500°F tools from Schlumberger and Dresser-Atlas are in limited supply.

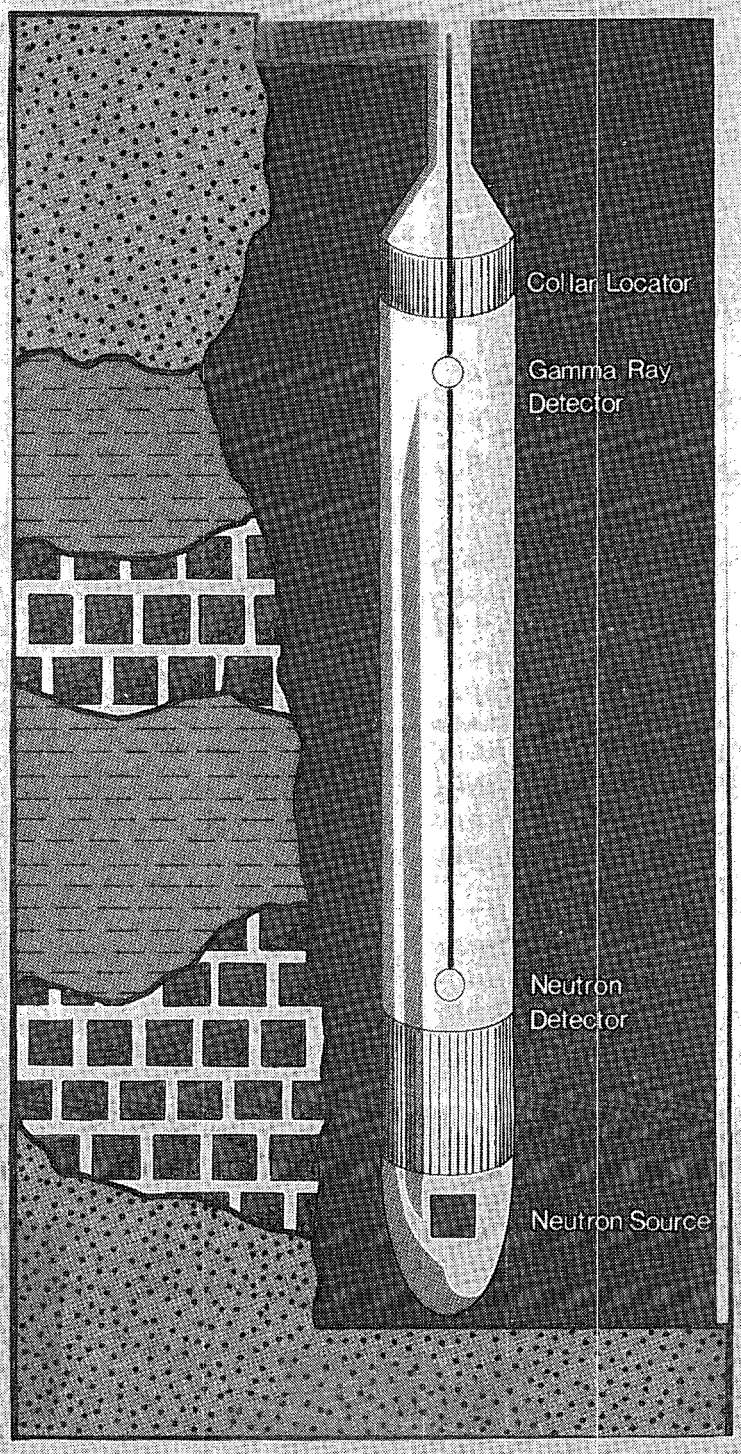


Figure 27. Physical Arrangements of Neutron-Gamma Ray Logger

TOOL NAME - NEUTRON-LOG

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	1	80%	.8				
• Determine orientation	1	20%	.2				
			1.0	22.5%	.2		
Quantify zone size							
• Height	3	33%	1.0				
• Width	1	33%	.3				
• Flow rate into zone	1	34%	.3				
			1.6	22.5%	.4		
Operate in geothermal well							
• Temp. rating	9	33%	3.0				
• Pressure rating	9	33%	3.0				
• Mud wt/type	9	34%	3.1				
			9.1	22.5%	2.0		
Accuracy							
• Tool accuracy	7	50%	3.5				
• Locate zone	2	25%	.5				
• Quantify zone	2	25%	.5				
			4.5	22.5%	1.0		
Reliability	7	100%	7.0	10.0%	.7		
					4.3	X .50 =	2.2
RISK							
Stage of development							
• Temp. rating	9	45%	4.1				
• Pressure rating	9	45%	4.1				
• Mud wt/type	9	10%	.9				
			9.1	33.0%	3.0		
Design approach							
• Locate zone	2	50%	1.0				
• Quantify zone	1	50%	.5				
			1.5	33.0%	.5		
Experience/Testing	1	100%	1.0	34.0%	.3		
					3.8	X .20 =	.8
COST	7	100%				X .10 =	.7
AVAILABILITY	10	100%				X .20 =	2.0
						Final score	5.7

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

References

NEUTRON LOGS

1. Hoyer, W.A., et al.; "Pulsed Neutron Logging," SPWLA Reprint Vol., March 1976.

2. Logging Manual, NL McCullough, Houston, TX, 1980.

3. "Neutron Lifetime Log Interpretation," Dresser-Atlas, Tech Rep. 3319, May, 1978.

Name of Tool: Neutron-Sonic Porosity Log

Type: Combination

Manufacturer: Schlumberger, Dresser-Atlas, The GO Company, Welex

Cost: Approximately $6,200 per run

State of Development: Operates up to 350°F

General Description:

The Dual-Porosity Neutron-Sonic logging combination provides a better means of evaluating lithologies and formation porosities than either tool alone. In this application, the sonic log measures only the matrix porosity and the neutron log records the total porosity, the difference being a measure of the fracture porosity. The method has been successfully used to detect fractures that may be indicative of lost circulation.

For a more detailed description, the reader is referred to the separate sections on Neutron and Sonic Logs in this appendix.

Ability to Locate Lost Circulation Zones

This combination device can provide the following information which, depending on circumstances, can either locate directly or aid in the location of lost circulation zones:

- locate fractured and vuggy zones
- determine relative strengths of the various zones, and
- discriminate in salinity differentials between mud and formation fluids.

Capability to Quantify Size of Zone and Rate of Loss

It can provide a good estimation of the height of the zone when all th information is taken together. Has no ability to provide the width or flow rate in the zone. It does, however, provide fracture porosity which is an extremely useful substitute.

Capability to Operate in Geothermal Well

Currently limited by the low temperature capabilities of the sonic tool. Higher temperature capabilities are feasible. Able to operate in all drilling fluids.

Accuracy

The tools are reasonably accurate. Main basis for the interpretation is differences in response between the tools. Therefore, so long as calibration and set-up procedures are carefully followed, the tools do not have to give good porosity estimates in order to provide useful information.

Reliability

Reliability is good to rated temperature. Operator familiarity is usually good, which leads to better recognition of problems when they occur.

Availability

Widely available.

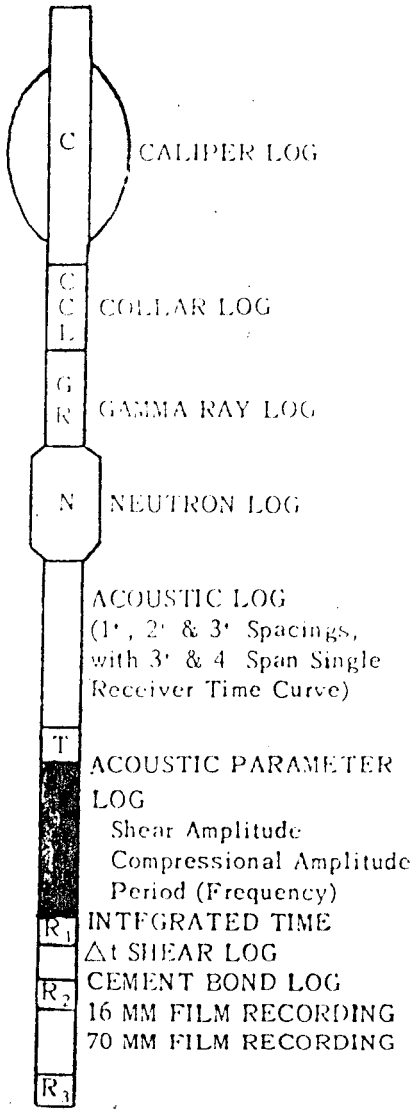


Figure 28. Schematic of Dual Porosity Logger

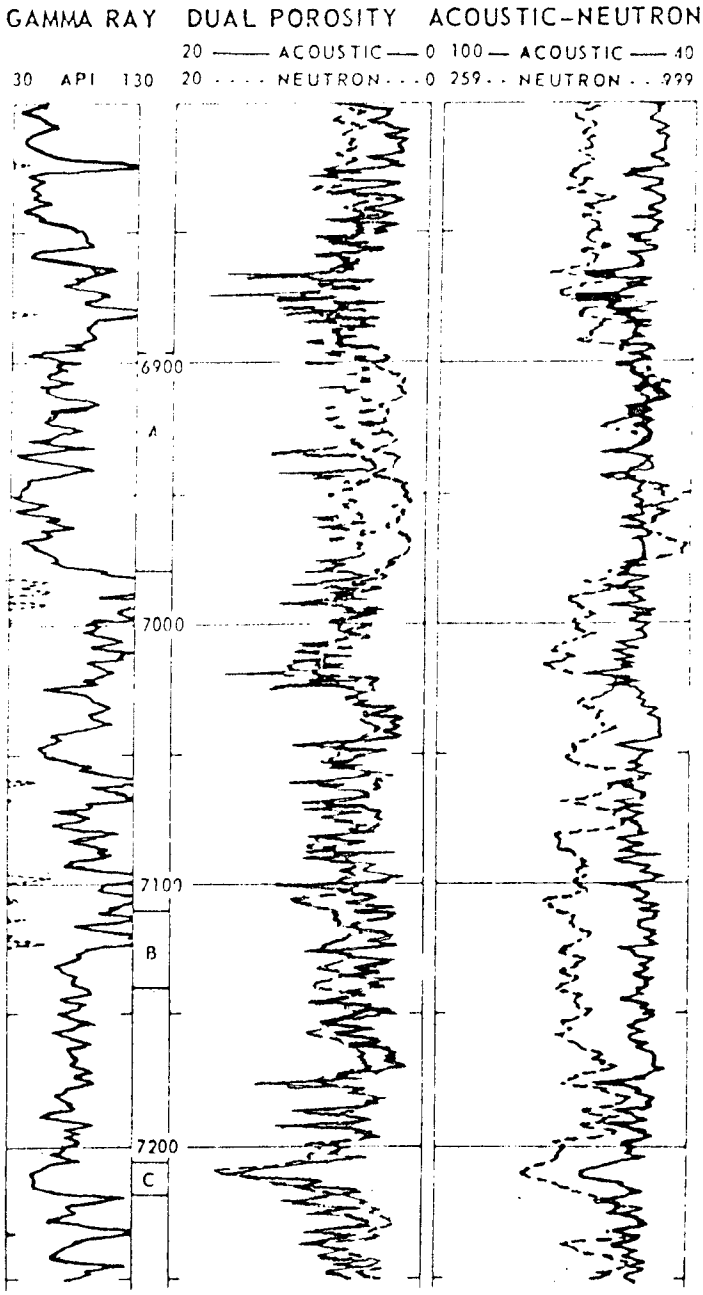


Figure 29. Example of the fracture finding capabilities of the Neutron-Acoustic Dual porosity log. Zone B is fractured as displayed by the marked anomalies between the acoustic and neutron curves.

TOOL NAME - NEUTRON-SONIC POROSITY LOG

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	4	80%	3.2				
• Determine orientation	1	20%	.2				
			3.4	22.5%	.8		
Quantify zone size							
• Height	6	33%	2.0				
• Width	1	33%	.3				
• Flow rate into zone	1	34%	.3				
			2.6	22.5%	.6		
Operate in geothermal well							
• Temp. rating	6	33%	2.0				
• Pressure rating	9	33%	3.0				
• Mud wt/type	8	34%	2.7				
			7.7	22.5%	1.7		
Accuracy							
• Tool accuracy	8	50%	4.0				
• Locate zone	3	25%	.8				
• Quantify zone	4	25%	1.0				
			5.8	22.5%	1.3		
Reliability	7	100%	7.0	10.0%	.7		
					5.1	X .50 =	2.6
RISK							
Stage of development							
• Temp. rating	6	45%	2.7				
• Pressure rating	9	45%	4.1				
• Mud wt/type	8	10%	.8				
			7.6	33.0%	2.5		
Design approach							
• Locate zone	3	50%	1.5				
• Quantify zone	4	50%	2.0				
			3.5	33.0%	1.2		
Experience/Testing	4	100%	4.0	34.0%	1.4		
					5.1	X .20 =	1.0
COST	6	100%				X .10 =	.6
AVAILABILITY	10	100%				X .20 =	2.0
						Final score	6.2

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

References

NEUTRON-SONIC (DUAL) POROSITY LOGS

1. Zoeller, W. A.; "Dual Porosity Logging - A Means to Better Evaluation of Porosity and Lithology in the Permian Basin." P.G.A.C., Midland, TX, Feb. 3, 1966.

Name of Tool: Radioactive Tracer Log

Type: Radioactive

Manufacturer: DIA-LOG, Dresser-Atlas,The GO Company, Pengo, Schlumberger, NL McCullough

Cost: Approximately $4,200 per run. Orientation costs and hauling operations are extra.

State of Development: Depending on manufacturer, the tool operates up to 300-350°F, 15,000 psi.

General Description:

The radioactive tracer survey is used for the identification of various well problems. The method consists of mixing small quantities of short half-life radioactive isotopes, such as Iodine 131, with mud at the surface or injecting it into the downhole mud stream with an ejector tool at some point above the zone of interest. Most downhole injection systems cannot be used in heavy muds or deep formations because the ejector motor cannot overcome the hydrostatic pressure of the mud on the plunger assembly.

The tagged fluid is pumped down the borehole where its movement into the formation is later detected by a gamma ray logging tool. Zones of lost circulation initially appear as higher levels of radioactivity, followed by dissipation or stabilization when compared to adjacent portions of the borehole. With time the tracer will decay or the radioactive mud will be pumped away into the formation and cannot be detected by the gamma ray log. In permeable zones the material may plate to the face of the zone.

Readings are correlated and compared with a gamma log run prior to introducing radioactive material into the well. It is worth noting that it may be necessary to pump the radioactive material down both the annulus and the drill pipe before the zone is located.

Quantitative evaluation of the mud flow rate into the formation can be obtained by measuring the time it takes the radioactive isotope to move past two gamma ray detectors of a known distance of separation. This type of system is superior to the ejector/single gamma ray log technique which depends on knowing the time of ejection. In both cases, the separation between the detectors and/or source can be selected. Such information, when coupled with the volumetric rate of loss recorded at the surface, (among other pertinent factors) provides a computer generated flow profile.

Ability to Locate Lost Circulation Zones

The Tracer Log is a good tool for locating the depth of lost circulation zones. However, it is recommended for use in low to moderate rate of loss situations only. In high rate of loss situations, the radioactive material may be carried deep into the formation and be undetectable by the time the gamma log is run at that level.

It provides no information on the orientation of the zone.

Capability to Quantify Size of Zone and Rate of Loss

The survey provides information on the height and rate of loss into the lost circulation zone. Poor tool for determining the width of the zone.

Capability to Operate in Geothermal Well

Operational capability up to 350°F, 15,000 psi. The tool can be run in any medium capable of transporting the radioactive material. Included in the fluids with such characteristics are oil, fresh and salt water-base muds.

Accuracy

Time measurements recorded for the determination of flow velocity into the zone can be measured to the nearest .01 second[1] by certain systems.

The accuracy of the height determination is generally good.

Reliability

Tool is very reliable.

Availability

Tool is readily available.

---

[1] Dresser-Atlas, "Nuclear Flolog/Tracerlog"

Figure 30 shows a lost circulation zone detected at a depth of 4,144 feet using radioactive tracers. The gamma ray signal was much higher at this depth because of the radioactivity of the fluid which had leaked off into the lost circulation.

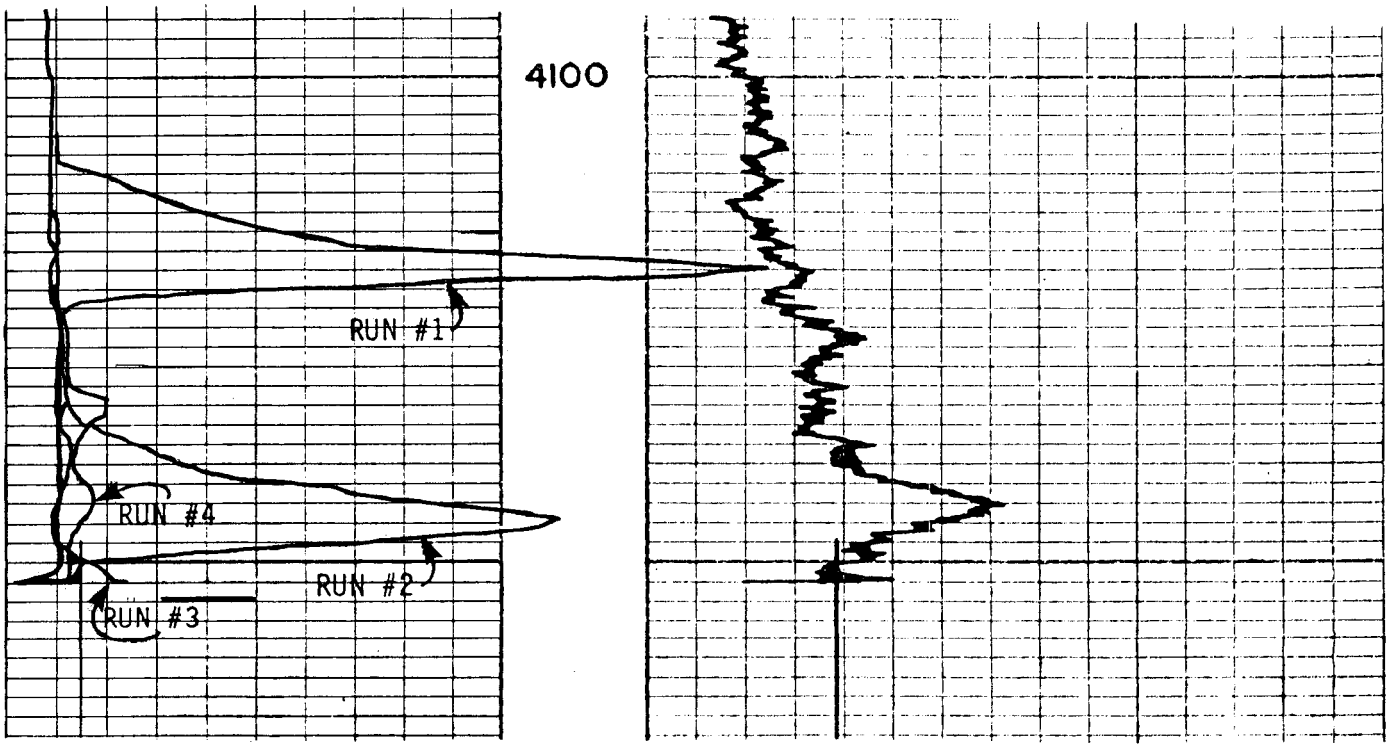


Figure 30. Radioactive Tracer Survey

TOOL NAME - RADIOACTIVE TRACER LOG

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	7	80%	5.6				
• Determine orientation	1	20%	.2				
			5.8	22.5%	1.3		
Quantify zone size							
• Height	8	33%	2.6				
• Width	1	33%	.3				
• Flow rate into zone	7	34%	2.4				
			5.3	22.5%	1.2		
Operate in geothermal well							
• Temp. rating	6	33%	2.0				
• Pressure rating	9	33%	3.0				
• Mud wt/type	8	34%	2.7				
			7.7	22.5%	1.7		
Accuracy							
• Tool accuracy	8	50%	4.0				
• Locate zone	7	25%	1.8				
• Quantify zone	6	25%	1.5				
			7.3	22.5%	1.6		
Reliability	7	100%	7.0	10.0%	.7		
					6.5	X .50 =	3.3
RISK							
Stage of development							
• Temp. rating	6	45%	2.7				
• Pressure rating	8	45%	3.6				
• Mud wt/type	7	10%	.7				
			7.0	33.0%	2.3		
Design approach							
• Locate zone	9	50%	4.5				
• Quantify zone	7	50%	3.5				
			8.0	33.0%	2.6		
Experience/Testing	8	100%	8.0	34.0%	2.7		
					7.6	X .20 =	1.5
COST	9	100%				X .10 =	.9
AVAILABILITY	10	100%				X .20 =	2.0
						Final score	7.7

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

References

RADIOACTIVE TRACER LOG

1. Messenger, J. U.; "Lost-Circulation Techniques," Oil and Gas Journal, pp. 94-98, May 27, 1968.

2. Production Log Interpretation, Schlumberger, Houston, TX, 1973.

3. "Tracer Survey - Ejector," Dia-Log, Technical Report, Internal Report, (No Date).

Name of Tool:	Spinner Survey
Type:	Mechanical
Manufacturer:	Baker Production Services, The GO Company, Schlumberger, Dresser-Atlas, NL McCullough, Pengo, Kuster, Worth Systems
Cost:	Approximately $3,300 per run
State of Development:	Available in models that operate at temperatures to 500°F. The majority of tools operate at 350-400°F, 18,000 psi. The 500°F tools of Dresser-Atlas, Kuster, and Schlumberger require special cable. The Go Company has scheduled testing of 550°F prototype for late 1980. If successful the tool will be introduced commercially.

General Description:

The Spinner Survey is carried out by running a small, centralized spinner attachment into the borehole on a conductor cable in such a way that the low inertia impeller turns or spins if there is any motion in the mud. The rotational velocity of the moving impeller is proportional to the velocity of the fluid and is related to the volumetric flow rate.

Lost circulation zones can be located by two methods: running the tool through the flow stream or recording stationary measurements.

The first technique requires that the direction of tool travel be with the fluid flow at high velocities and against the fluid flow in low fluid velocities. Zones are located when there are changes in spinner speed from 100% flow or changes in absolute flow rate. 100% flow is established near the surface at a point where the diameter of the hole and flow rate are accurately known.

The second technique provides the most accurate results. The spinner is lowered into the hole to a given depth. A packing gland is closed around the line. Mud is then pumped into the casing at pressures sufficient to cause fluid loss. If rotation of the spinner is recorded, the point of loss is below the tool.

By raising and lowering the position of tool, followed by the pumping procedure, the zone can be located to within a foot or two.

Spinner surveys can be run in open and cased holes. They are accurate in single phase flow. Multi-phase flow can lead to erroneous interpretation because of the different rotational energies of the phases.

Ability to Locate Lost Circulation Zones

A good tool for locating lost circulation zones provided the amount of lost circulation material in the mud is small. Large, flaky, fibrous material can clog the impeller with the result of false information.

The tool has no capability to determine the orientation of the zone taking mud.

Capability to Quantify Size of Zone and Rate of Loss

The tool gives the height of the zone and the magnitude of flow into the zone.

A poor tool for deriving width of the zone.

Capability to Operate in Geothermal Well

Due to the mechanical nature of the tool and the success of high temperature wire line, most tools can withstand temperatures up to 500°F. Sandia has a 550°F prototype flowmeter. Tool can operate in any liquid drilling fluid or liquid/gas fluid although the two phase system affords less accurate information.

Accuracy

Depending on the manufacturer, the tool's sensitivity to single phase flow ranges from 10 ft/min to 1 ft/min. These sensitivites are for optimal conditions. The accuracy of measurements obtained and the sensitivity of the tool are strongly dependent upon several factors and are, therefore, variable. Among these are:

- velocity of fluid vs. hole size
- viscosity of the fluid, and
- condition of the borehole wall.

Multi-phase flow requires much higher threshold flow rates if useful measurements are to be obtained. Volumetric flow rates into the loss zones are much more accurate in casing than in open hole. All open hole logs should be correlated with a caliper log run over the same intervals.

Reliability

The tool is reliable when run in clean, clear fluids inside casing. Reliability is reduced in open hole use. The tool is susceptable to clogging by material added to the mud in order to plug lost circulation zones or from the build up of cuttings associated with lost circulation.

Availability

Widely available.

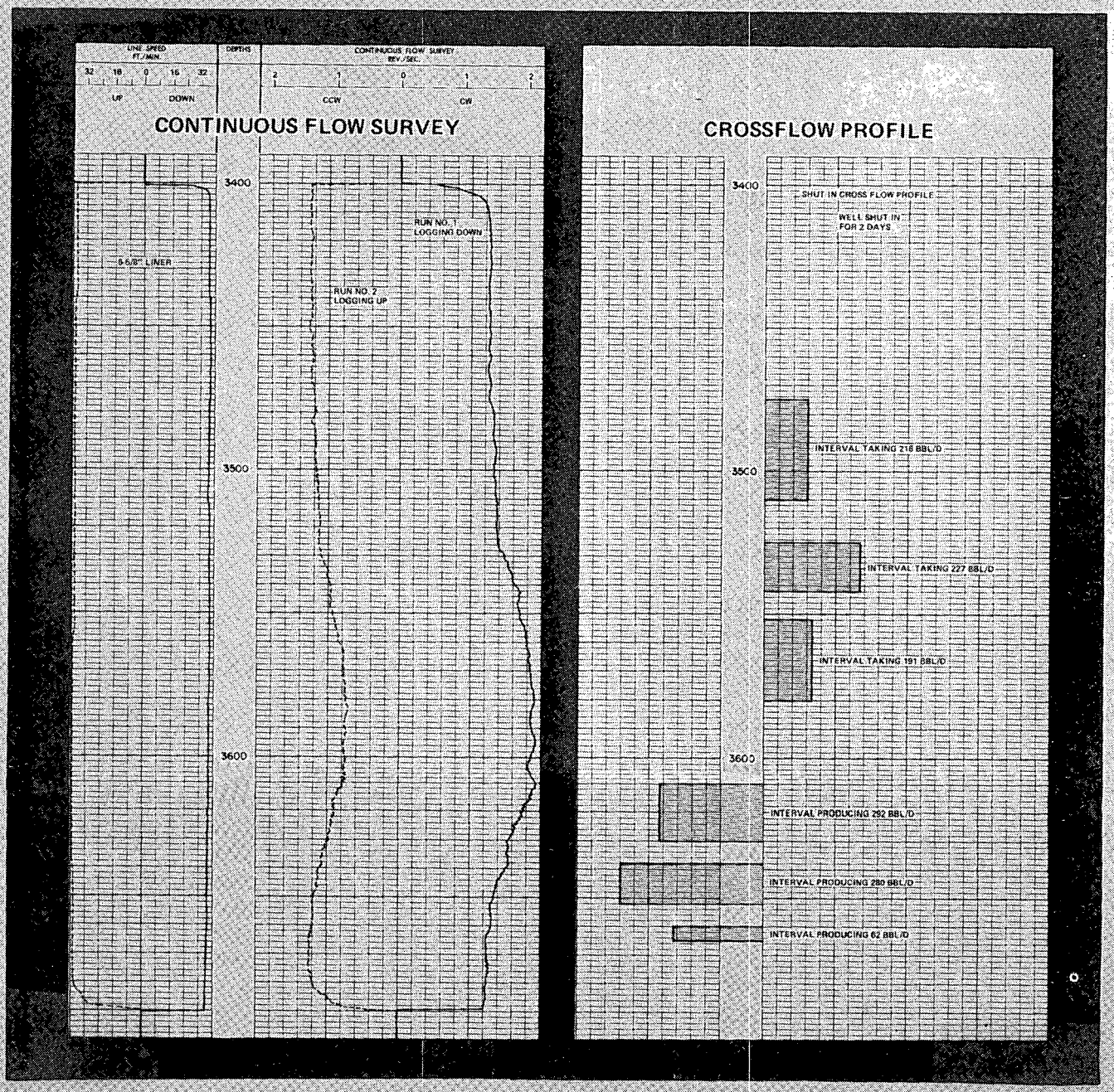


Figure 31. Spinner survey showing crossflow occurring in water disposal well. The procedure for locating these zones is analogous to that used in locating lost circulation zones.

TOOL NAME - SPINNER SURVEY

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	7	80%	5.6				
• Determine orientation	1	20%	.2				
			5.8	22.5%	1.3		
Quantify zone size							
• Height	8	33%	2.6				
• Width	1	33%	.3				
• Flow rate into zone	9	34%	3.1				
			6.0	22.5%	1.4		
Operate in geothermal well							
• Temp. rating	9	33%	3.0				
• Pressure rating	9	33%	3.0				
• Mud wt/type	5	34%	1.7				
			7.7	22.5%	1.7		
Accuracy							
• Tool accuracy	8	50%	4.0				
• Locate zone	8	25%	2.0				
• Quantify zone	7	25%	1.8				
			7.8	22.5%	1.8		
Reliability	6	100%	6.0	10.0%	.6		
					6.8	X .50 =	3.4
RISK							
Stage of development							
• Temp. rating	9	45%	4.1				
• Pressure rating	9	45%	4.1				
• Mud wt/type	9	10%	.9				
			9.1	33.0%	3.0		
Design approach							
• Locate zone	9	50%	4.5				
• Quantify zone	7	50%	3.5				
			8.0	33.0%	2.6		
Experience/Testing	8	100%	8.0	34.0%	2.7		
					8.3	X .20 =	1.7
COST	9	100%				X .10 =	.9
AVAILABILITY	10	100%				X .20 =	2.0
						Final score	8.0

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

Name of Tool: Spinner-Temperature Survey

Type: Combination, Mechanical and Electrical

Manufacturer: Kuster, DIA-LOG, Dresser-Atlas, The GO Company, NL McCullough, Schlumberger, Worth Systems

Cost: $3,800 per run

State of Development: Systems available that operate up to 500°F, 20,000 psi

General Description:

The Spinner-Temperature Survey combination provides measurements of two downhole parameters, temperature and fluid velocity. These parameters can be measured simultaneously or sequentially, at stations or under dynamic conditions. The technique for locating and quantifying zones of loss is essentially the marriage of the techniques used in the independent operations of the two tools. For further details, see temperature log and spinner surveys in this appendix.

Ability to Locate Lost Circulation Zones

A good tool for locating lost circulation zones. Superior to either an independent temperature or spinner survey. The information each tool provides enhances the interpretation of the other.

Capability to Quantify Size of Zone and Rate of Loss

The survey determines the height and flow rate into the zone. The width of the zone is unresolved.

Capability to Operate in Geothermal Well

Operations up to 500°F or higher temperature capabilities are feasible with 525-570°F tools under development. Spinner is not recommended for use when lost circulation material has been added to the mud.

Accuracy

See temperature logs and spinner surveys for accuracy of the components.

The accuracy of the height determination is very good.

Reliability

The temperature survey is very reliable. While the reliability of the spinner survey is dependent upon the conditions of the borehole. See spinner survey.

Availability

Widely available as a production stock system.

TOOL NAME - SPINNER TEMPERATURE SURVEY

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	8	80%	6.4				
• Determine orientation	1	20%	.2				
			6.6	22.5%	1.5		
Quantify zone size							
• Height	8	33%	2.6				
• Width	1	33%	.3				
• Flow rate into zone	9	34%	3.1				
			6.0	22.5%	1.4		
Operate in geothermal well							
• Temp. rating	9	33%	3.0				
• Pressure rating	9	33%	3.0				
• Mud wt/type	5	34%	1.7				
			7.7	22.5%	1.7		
Accuracy							
• Tool accuracy	9	50%	4.5				
• Locate zone	9	25%	2.3				
• Quantify zone	7	25%	1.8				
			8.6	22.5%	1.9		
Reliability	7	100%	7.0	10.0%	.7		
					7.2	X .50 =	3.6
RISK							
Stage of development							
• Temp. rating	9	45%	4.1				
• Pressure rating	9	45%	4.1				
• Mud wt/type	9	10%	.9				
			9.1	33.0%	3.0		
Design approach							
• Locate zone	9	50%	4.5				
• Quantify zone	7	50%	3.5				
			8.0	33.0%	2.6		
Experience/Testing	9	100%	9.0	34.0%	3.1		
					8.7	X .20 =	1.7
COST	8	100%				X .10 =	.8
AVAILABILITY	10	100%				X .20 =	2.0

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

Final score 8.1

References

SPINNER - TEMPERATURE SURVEY

1. Hamilton, R. G. and Myung, J. I.; Summary of Geophysical Well Logging, Seismograph Serv. Corp., Tulsa, OK.

2. Peacock, D. R.; "What You Can Learn from Temperature Logs," Pet. Eng Vol. 37, No. 1096.

3. Pierce, A. E., et al.; "Temperature Surveys - New Use for an Old Tool," World Oil, pp. 136-139, June 1966.

Name of Tool: Spontaneous Potential Logs

Type: Electrical

Manufacturer: Birdwell, Dresser-Atlas, Gearhart-Owen, Halliburton, Schlumberger

Cost: Lithologic log run with other tools.

State of Development: Essentially no temperature limitations. Can be run up to the temperatures limitations of the cable.

General Description:

The Spontaneous Potential (SP) Log, measures the potential difference between a movable downhole electrode and a fixed potential surface electrode. It can only be used in uncased portions of a hole. For SP operation, the borehole must be filled with conductive mud to provide electrical continuity between electrode and formation and to provide ions. Furthermore, the differences between mud and formation resistivities must be large if sufficient feature is to be displayed on the graph.

To date, the SP logs primary use has been to differentiate rock formations and provide correlation with other survey equipment. Unconventional applications include fracture detection and possible identification of lost circulation zones.

Fractures filled with conductive mud, that may be associated with lost circulation, often result in erratic behavior of the SP. In hard formations, the SP is often not reliable and should only be used as a check of other fracture indicators.

SP logs can possibly be used to locate lost circulation zones by measuring the algerbraic sum of electrokinetic, electro-chemical, telluric and electrode potentials. The technique could consist of the following steps.

The first step is to survey the well when the mud is being pumped down at a constant rate. The well is logged up and down until the SP results are repeatable to within 3 mv. Logging speed should be fast - 100 ft/min - to reduce drift caused by relative fluid movement past the tool and also to reduce the probability of recording spurious noise.

The next step requires logging the well under stabilized static fluid conditions.

General Description (continued):

The SP log detects lost circulation zones by measuring the change in the electrokinetic potential caused by fluid flow from the wellbore into the formation. This potential is the only potential affected by fluid flow. Hence, the difference in the measurements between Step 1 and Step 2 yields a value for the induced electrokinetic voltage and the location of the zone responsible for this voltage.

Another variation of this method is to make two runs, while applying pressure at the wellhead, under different heads of fluid. This also allows the electrokinetic contribution to the SP to be isolated and examined.

The SP tool is run on wire line. The above technique requires a prior SP base log for comparison purposes.

Ability to Locate Lost Circulation Zones

Under the proper conditions, the SP log may be able to locate lost circulation zones. Its behavior in front of fracture zones, that may be the cause of lost circulation, is well documented. Additionally, the SP has been used to locate zones taking fluids in injection wells. This situation is quite similar to lost circulation detection and lends plausibility to this application.

Capability to Quantify Size of Zone and Rate of Loss

May provide information on the vertical extent of the zone. Field testing is required to confirm this capability. The width of the zone is undetermined by this method. No general correlation exists between the SP_K and flow rate since the proportionality constant responds to changes in permeability, bed thickness and a host of other formation factors.

Capability to Operate in Geothermal Well

Capable of operating up to the temperature limitations of the cable. Able to operate in all fluids that exhibit sufficient conductivity required for operation. But it may not be run in oil-base muds, gas or air.

Accuracy

The technique has detected flow rates as low as 70 bbl/day in the Wasson San Andres field, and appears to have the sensitivity to indicate major lost circulation zones. The SP, however, is related linearly to the resistivity value of the drilling fluid. Accordingly, the lower the resistivity the higher the minimum detectable flow rate.

Reliability

SP has no moving parts and is not subject to breakdown.

Availability

Widely available.

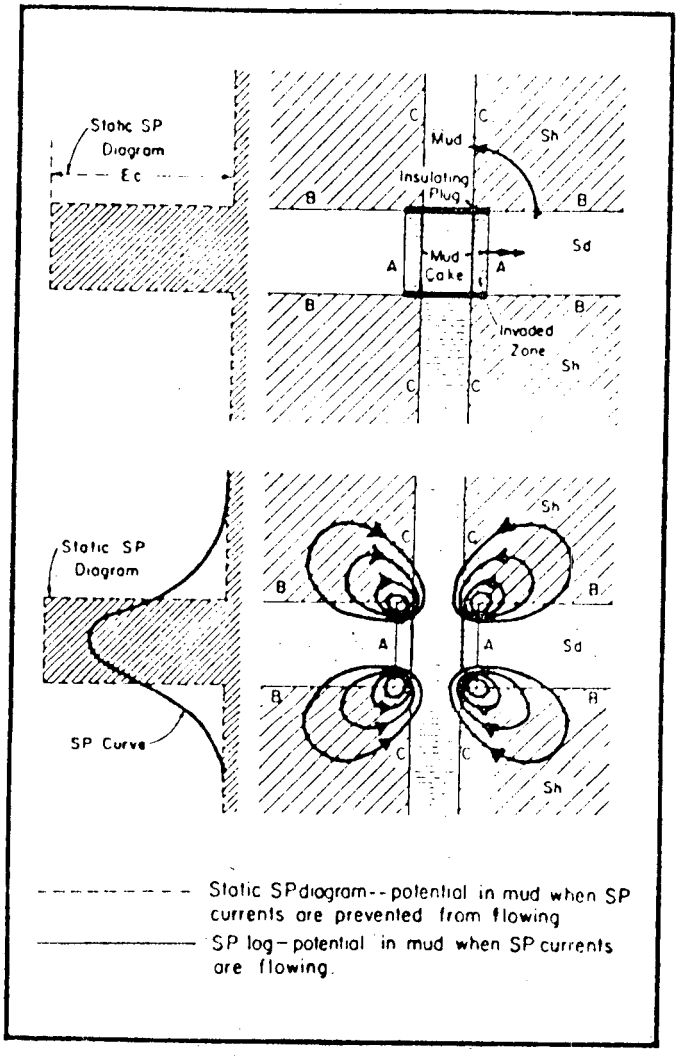


Figure 32. Schematic of SP Log

These currents are the result of the "battery effect" caused by salinity differences and electrolyte movement through permeable membranes.

TOOL NAME - SPONTANEOUS POTENTIAL LOGS

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	4	80%	3.2				
• Determine orientation	1	20%	.2				
			3.4	22.5%	.8		
Quantify zone size							
• Height	5	33%	1.7				
• Width	1	33%	.3				
• Flow rate into zone	3	34%	1.0				
			3.0	22.5%	.7		
Operate in geothermal well							
• Temp. rating	9	33%	3.0				
• Pressure rating	9	33%	3.0				
• Mud wt/type	6	34%	2.0				
			8.0	22.5%	1.8		
Accuracy							
• Tool accuracy	8	50%	4.0				
• Locate zone	4	25%	1.0				
• Quantify zone	2	25%	.5				
			5.5	22.5%	1.2		
Reliability	8	100%	8.0	10.0%	.8		
					5.3	X .50 =	2.7
RISK							
Stage of development							
• Temp. rating	9	45%	4.1				
• Pressure rating	9	45%	4.1				
• Mud wt/type	9	10%	.9				
			9.1	33.0%	3.0		
Design approach							
• Locate zone	3	50%	1.5				
• Quantify zone	2	50%	1.0				
			2.5	33.0%	.8		
Experience/Testing	3	100%	3.0	34.0%	1.0		
					4.8	X .20 =	1.0
COST	10	100%				X .10 =	1.0
AVAILABILITY	10	100%				X .20 =	2.0

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

Final score: 6.7

References

SPONTANEOUS POTENTIAL LOGS

1. Gillingham, W. J.; "Electrical Logging in the Appalachian Fields," Bull. 21, Pennsylvania State College Mineral Industries Experiment Station, pp. 30-52, 1937.

2. Hallenburg, J. K.; "A Resume of Spontaneous Potential Measurements," SPWLA Twelfth Annual Logging Symposium, Dallas, Texas, May 2-5, 1971.

3. Log Interpretation, Vol. I - Principles, Schlumerger Ltd., New York, New York, 1972.

4. Log Review 1, Dresser-Atlas, Houston, Texas, 1974.

5. Suau, J. and Gartner, J.; "Fracture Detection from Well Logs," The Log Analyst, pp. 3-13, March-April, 1980.

6. Traugott, M. O.; "Use of SP Log in Waterflood Surveillance," J. Pet Tech., pp. 151-153, February 1972.

Name of Tool:	Straddle Packer
Type:	Mechanical
Manufacturer:	Arrow Oil Tools,* Baker Service Tools,* Brown Oil Tools,* Johnson Div. of Schlumberger,* Lynes,[1] OTIS,* Tam International
Cost:	$2,000 for cased holes and approximately $3,000 for open hole use
State of Development:	Most packers are rated for temperatures up to 250°F. Lynes Straddle packer operates up to 350°F for periods not exceeding 5-10 hours. Tam is developing a new inflatable straddle packer with a goal of 500°F.

General Description:

The general description primarily applies to the Lynes tool as well as does the information under the headings that follow.

Straddle packers are used for above-tool and below-tool treatment operations and for locating leaks, thief zones and water.

Externally, the straddle packer consists of two steel reinforced rubber packers mounted on a ported steel housing. These packers are inflated with fluid and make a positive seal with the borehole wall, which is made tighter as more differential pressure is exerted across the ends of the elements.

Inside the housing, a ported mandrel extends the length of the tool.

A hydraulic positioning device located above and below each packer element provides the means by which the mandrel may be moved and locked into five in-line positions. These positions permit the inflation of the packers, allow each port to be opened individually to the wellbore (above, below, and between the elements), and finally allow the tool to be unset by deflation of the elements.

The technique for locating lost circulation zones is straightforward. The tool is run to the point of interest and the packers inflated to set the tool and isolate the zone. During the inflation process, it is desirable to choose a system that allows the developing "squeeze pressure" to be bled off. This pressure, caused by the force the inflating packers exert on the trapped fluid column, can damage the

---

* These tools use weight-set compression packers. These elements are recommended for use in cased hole. In open hole, their narrow sealing width and lack of sufficient elasticity can result in poor sealing performance.

[1] The Lynes Inflatable Treating and Testing Tool has special features in design and in capabilities not found in most other tools.

General Description (continued):

formation to the point of breaking it down, if not relieved. The mandrel is then pulled up and locked in the position that allows fluid flow between the packers. Fluid is then slowly pumped through the tool into the zone at pressures comparable to those normally associated at that point during circulation, or at slightly greater values. If the zone will take fluid, a measurable pressure drop will occur. Knowing the rate of pumping and the size of the injection ports, the rate of loss can be determined. The height of the zone can be bracketed to within the length of spacing between the packers.

In normal operations, the tool is run on tubing or drill pipe and can be used in both open and cased holes.

Ability to Locate Lost Circulation Zones

A good tool for locating lost circulation zones in both open and cased holes.

Capability to Quantify Size of Zone and Rate of Loss

The tool can bracket the height of the zone to within the spacing between the packers. Spacing is variable, but cannot be changed downhole. Provides good estimation of the rate of loss into the zone. Unable to determine the width of the zone.

Capability to Operate in Geothermal Well

Operates at temperatures up to 350°F for a limited period of time. May be run in any drilling fluid.

Accuracy

Good, for application stated.

Reliability

The tool is mechanical in design and is reliable in operation.

The major problem associated with packers, becoming stuck in the borehole, has been minimized by providing greater clearance between the wall and the outer housing of the tool.

Availability

Widely available in both compression and inflation designs.

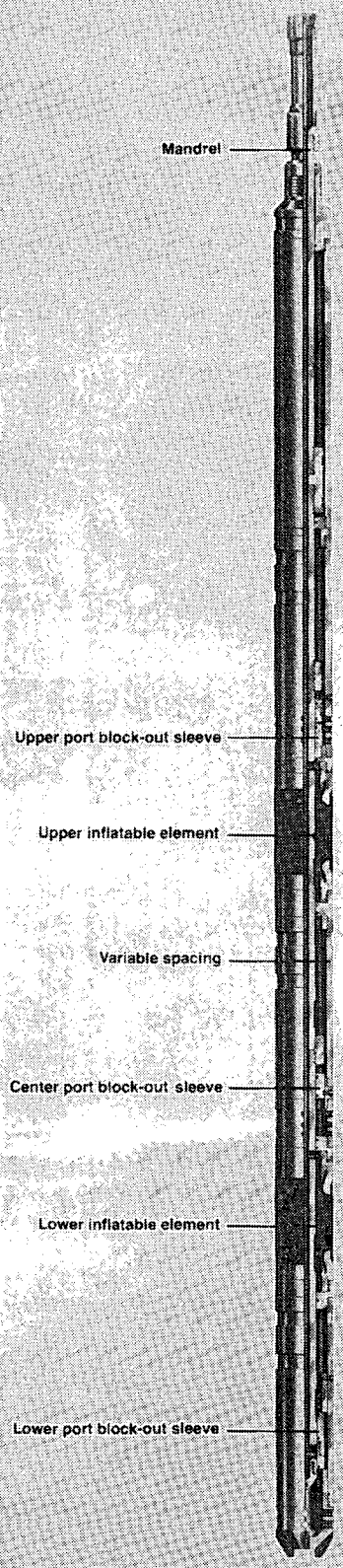


Figure 33. Schematic of Lynes Treating and Testing Tool

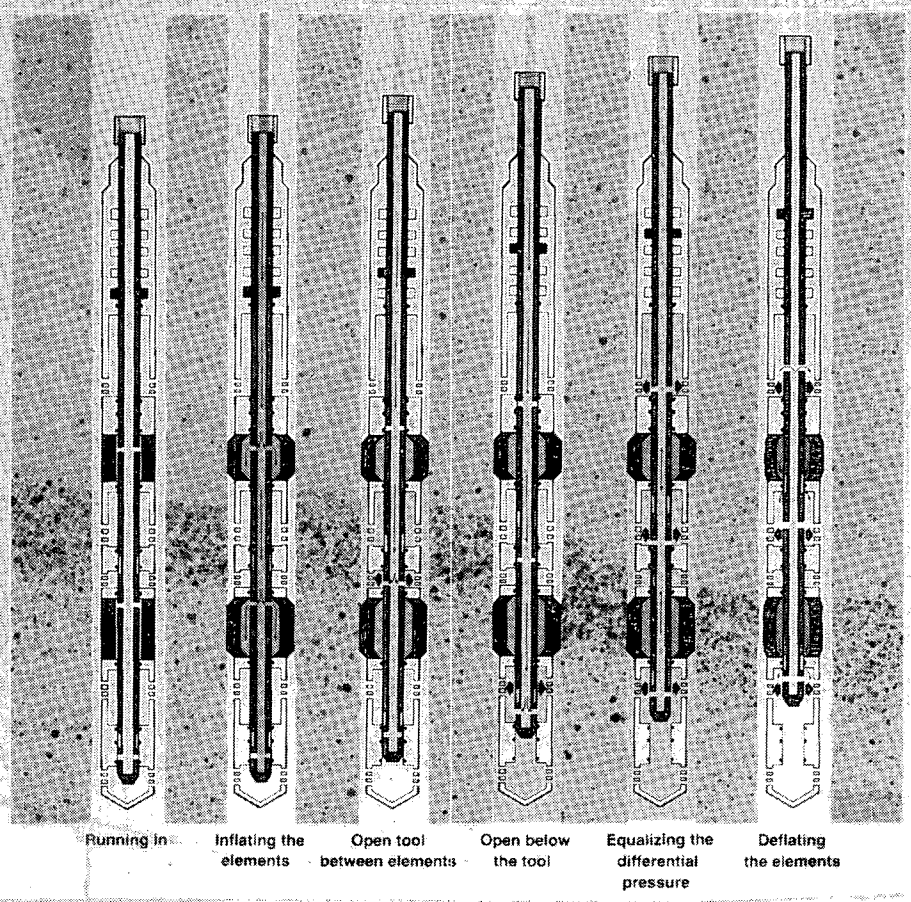


Figure 34. Running the Inflatable Treating and Testing Tool. Figure shows the five in-line positions.

TOOL NAME - STRADDLE PACKER

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	7	80%	5.6				
• Determine orientation	1	20%	.2				
			5.8	22.5%	1.3		
Quantify zone size							
• Height	7	33%	2.3				
• Width	1	33%	.3				
• Flow rate into zone	8	34%	2.7				
			5.3	22.5%	1.2		
Operate in geothermal well							
• Temp. rating	5	33%	1.7				
• Pressure rating	8	33%	2.6				
• Mud wt/type	9	34%	3.1				
			7.4	22.5%	1.7		
Accuracy							
• Tool accuracy	9	50%	4.5				
• Locate zone	7	25%	1.8				
• Quantify zone	6	25%	1.5				
			7.8	22.5%	1.8		
Reliability	9	100%	9.0	10.0%	.9		
					6.9	X .50 =	3.5
RISK							
Stage of development							
• Temp. rating	5	45%	2.3				
• Pressure rating	8	45%	3.6				
• Mud wt/type	5	10%	.5				
			6.4	33.0%	2.1		
Design approach							
• Locate zone	8	50%	4.0				
• Quantify zone	6	50%	3.0				
			7.0	33.0%	2.3		
Experience/Testing	8	100%	8.0	34.0%	2.7		
					7.1	X .20 =	1.4
COST	9	100%				X .10 =	.9
AVAILABILITY	10	100%				X .20 =	2.0

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

Final score 7.8

Name of Tool:	Temperature Log
Type:	Electrical
Manufacturer:	Baker Production Services, Birdwell, DIA-LOG, Dresser-Atlas, The GO Company, Geophysical Research, Halliburton, Kuster, NL McCullough, Pengo, Schlumberger
Cost:	$3,200 per run
State of Development:	The majority of temperature logging devices are effective up to 400°F, 15-20,000 psi. Systems are available that can operate up to 500°F, 20,000 psi. The Dresser-Atlas tool has a 550°F temperature log. The Go Company will offer a 550°F tool by 1981.

General Description:

The use of temperature logs to locate lost circulation zones is a technique that is both well understood and widely practiced. The tool is composed of a highly sensitive element which continuously measures the temperature of the drill hole. Information is sent up-hole on wire line where a record of the absolute and differential temperature (both plotted vs. depth) is obtained.

The general method for locating lost circulation zones requires two temperature surveys. The first survey is used to determine the temperature gradient of the well when mud and formation are in temperature equilibrium. Cool mud is then pumped into the well. Pressure is applied, if necessary, to force some of the mud into the formation. A second temperature log is immediately run thereafter. Zones of lost circulation will appear as temperature deviations from the base run. These anomalies are due to the cooling effect of the mud as it invades the formation. The instrument can be run in open and cased holes and its operation is unaffected by lost circulation material in the mud. Figure 35 shows schematic of the Gearhart-Owen temperature logging tool and surface module.

Ability to Locate Lost Circulation Zones

Good tool for the primary location of lost circulation zones. Should be used when the rate of loss is substantial. Provides no information on the orientation of the zone.

Capability to Quantify Size of Zone and Rate of Loss

The tools' ability to define the height of the zone is dependent upon several factors. Important among these are:

- the way in which fluid enters and is subsequently distributed in the zone, and
- the magnitude of the anomaly.

The tool has been run in wells to locate lost circulation problems with the following results.

- upper level of the zone of lost circulation indicated
- only lower level indicated
- the height of the zone is accurately determined

It suffices to say that all these situations can occur in any particular well, although clean, well behaved sands probably offer the most accurate height determinations.

The tool can provide qualitative results of the flow rate into the zone. Temperature flow profiling and computer programming can be used in certain circumstances and provide better flow rate estimates.

In open hole there exists no temperature logging device which can provide width determinations. In cased hole, an approximate width of the lost circulation zone (a zone accepting fluid through casing leaks or in communication with open hole zone taking fluid) is feasible with the Radial Differential Temperature Log.

Capability to Operate in Geothermal Well

Operational capability up to 500°F. Tool can be run in any drilling fluid and is unaffected by materials added to the mud in order to try to effect a cure of lost circulation. Higher temperature capabilities are feasible.

Accuracy

Tool accuracy varies with manufacturer. Commonly the range of accuracies is from ±0.01° to ± 2°F. Resolution is excellent. As stated above, height and flow rate determinations are variable in accuracy; the latter tending to be much more qualitative than quantitive.

Reliability

The tool is very reliable, insensitive to most downhole conditions.

Availability

The tool is probably the most easily obtained logging device in the industry.

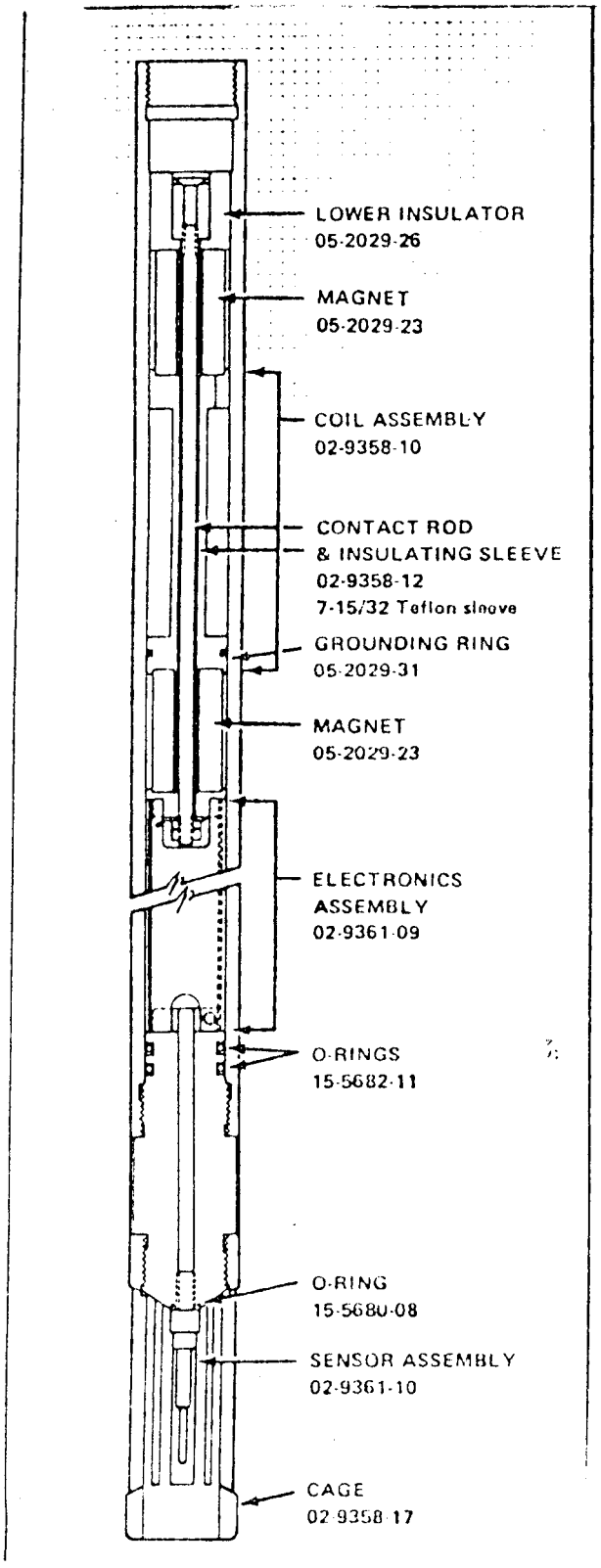


Figure 35. Gearhart-Owen Logging Tool and Surface Model

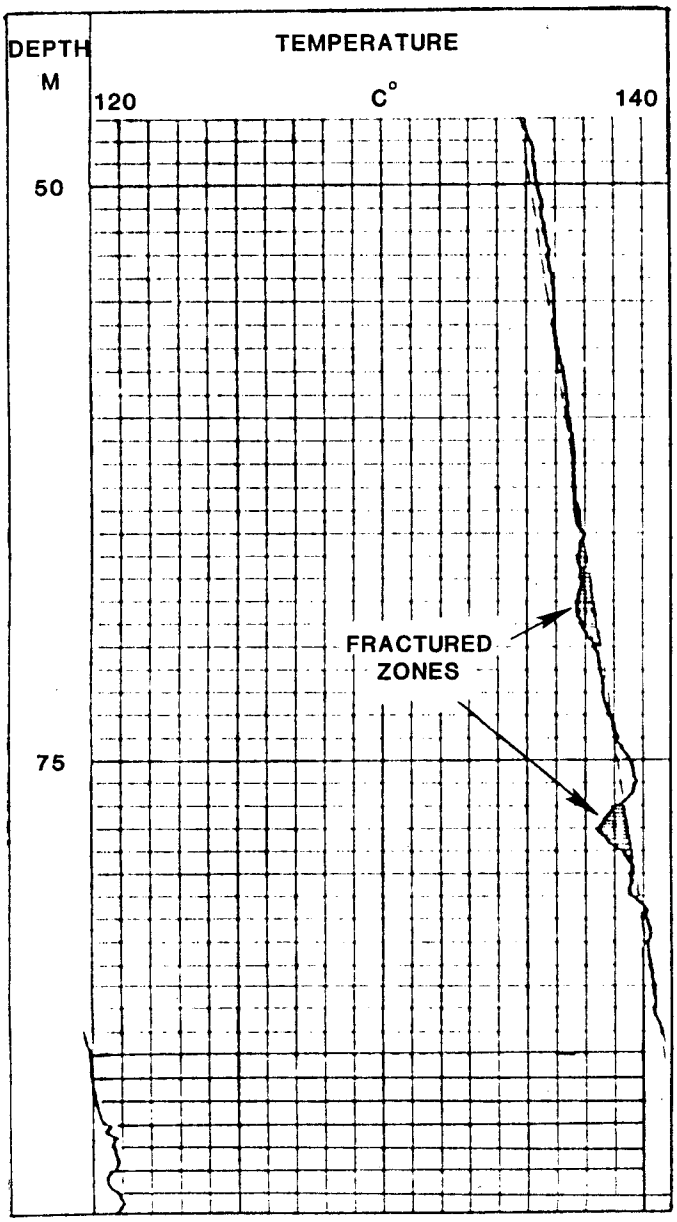


Figure 36.
Temperature log anomalies in front of fractured zones. Mud invasion causes this cooling effect.

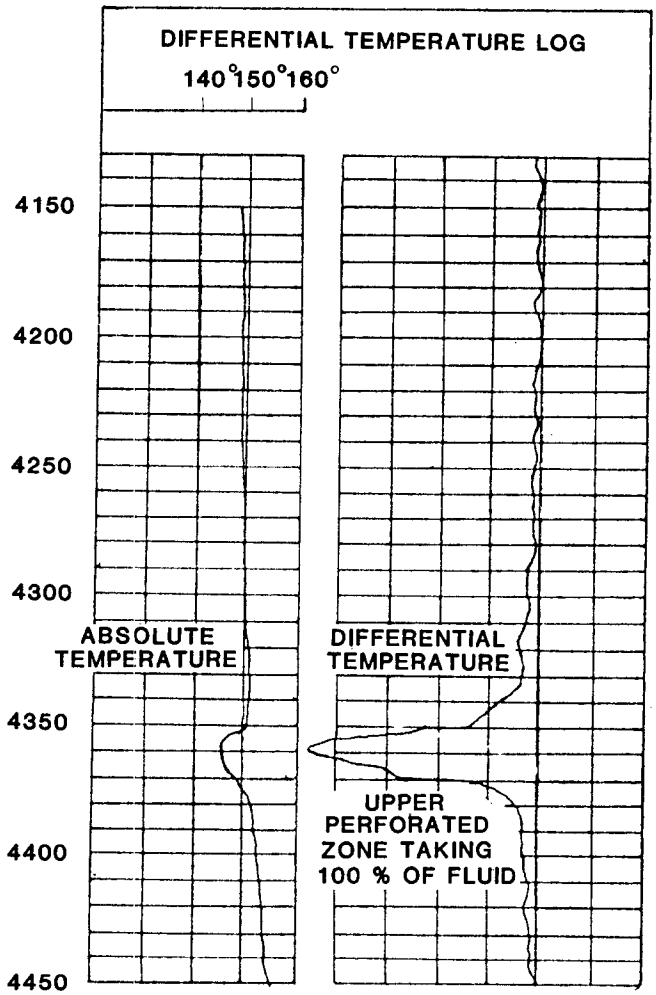


Figure 37.
Use of temperature logs to check the flow through perforations.

TOOL NAME - TEMPERATURE LOG

Criteria	Raw Score	Subelement Weight	Subelement Weighted Score	Element Weight	Element Weighted Score	Category Weight	Category Score
PERFORMANCE							
Locate lost circulation zone							
• Find depth	7	80%	5.6				
• Determine orientation	1	20%	.2				
			5.8	22.5%	1.3		
Quantify zone size							
• Height	6	33%	2.0				
• Width	1	33%	.3				
• Flow rate into zone	3	34%	1.0				
			3.3	22.5%	.7		
Operate in geothermal well							
• Temp. rating	9	33%	3.0				
• Pressure rating	9	33%	3.0				
• Mud wt/type	9	34%	3.1				
			9.1	22.5%	2.0		
Accuracy							
• Tool accuracy	9	50%	4.5				
• Locate zone	7	25%	1.8				
• Quantify zone	4	25%	1.0				
			7.3	22.5%	1.6		
Reliability	8	100%	8.0	10.0%	.8		
					6.4	X .50 =	3.2
RISK							
Stage of development							
• Temp. rating	9	45%	4.1				
• Pressure rating	9	45%	4.1				
• Mud wt/type	9	10%	.9				
			9.1	33.0%	3.0		
Design approach							
• Locate zone	9	50%	4.5				
• Quantify zone	4	50%	2.0				
			6.5	33.0%	2.1		
Experience/Testing	8	100%	8.0	34.0%	2.7		
					7.8	X .20 =	1.6
COST	9	100%				X .10 =	.9
AVAILABILITY	10	100%				X .20 =	2.0
						Final score	7.7

Raw score range		
Poor	Medium	Good
0 - 3	4 - 7	8 - 10

References

TEMPERATURE LOG

1. Hamilton, R. G. and Myung, J. I.; Summary of Geophysical Well Logging, Seismograph Serv. Corp., Tulsa, OK.

2. Peacock, D. R.; "What You Can Learn from Temperature Logs," Pet. Eng. Vol. 37, No. 1096.

3. Pierce, A. E., et al; "Temperature Surveys - New Use for an Old Tool," World Oil, pp. 136-139, June 1966.

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