

Building a Successful Company in Superconductivity

Ronald E. Sager
Quantum Design, Inc.

The “Quantum Way”

(Small Company Viewpoint)

- * Biased in favor of small companies
- * Biased against venture capital investment
- * Biased against public offerings

Quantum Design, Inc.

(Incorporated April 13, 1982)

Founders

- * Dave Cox, B.S. Video Engineering
 - Cryogenic Design and Fabrication
- * Barry Lindgren, B.S. Physics
 - Sales, Management, Administration
- * Ron Sager, Ph.D. Physics
 - Research, Product Development
- * Mike Simmonds, Ph.D. Physics
 - Research, Product Development

Why We Started Quantum Design

- * QD founders were S.H.E. employees
- * “Rules of Thumb”
 - \$100K - \$140K/man year
 - 2-3 month cash / credit reserve (revenues)
 - Debt to equity ratio (< 1)
 - Prompt payment of payables
- * S.H.E. in 1982
 - Overstaffed (105 people - \$3.5M revenue)
 - Payables (> 90 days)
 - Bad management decisions - struggle to meet payroll

Quantum Design, Inc. - Day 1

(Incorporated April 13, 1982)

- * Assets: One bay, 4 keys, \$8,000,
 4 warm bodies
- * Liabilities: \$15,000 3-year lease



QUANTUM DESIGN

**Helping to bridge the gap
between theory and application**

Call Quantum Design for expert consultation or
engineering support in any of the following areas:

-
- ☐ Cryogenic engineering and electronic design
 - ☐ Superconducting instrumentation
 - ☐ Ultra-low noise magnetic and electrical measurements
 - ☐ Josephson junction physics and SQUID devices
 - ☐ Experimental solid-state physics.
-

Meet the QUANTUM Design team

Four highly qualified
specialists ready to help
you meet your design
goals within affordable
time/cost parameters.



Michael Simmonds

Dr. Simmonds has extensive experience in the design and development of superconducting instrumentation, advanced quantum interference devices and electronic control systems. He has been heavily involved in both fundamental research and product development, is intimately familiar with all aspects of cryogenic measuring techniques, and has designed optically pumped and flux-gate magnetometers.



Ronald Sager

Dr. Sager has acquired a broad background in both theoretical and experimental disciplines. He has supervised the development of a low-power cryocooler designed to reach temperatures below 10K, has experience in oceanographic applications of cryogenic detectors and has studied noise suppression in magnetic gradiometers using both empirical measurements and computer modeling.



David Cox

Dave Cox is a specialist in the engineering aspects of superconducting devices and cryogenic design. He has the unique ability to express difficult concepts in working prototypes and to provide Quantum Design customers with thoroughly tested, reliable instrumentation. Among many projects, Dave has to his credit the successful fabrication of several prototype instruments for biomagnetic research.



Barry Lindgren

Our general manager is your contact at Quantum Design—the person to call to discuss a new research, design or development project. He has a strong background in cryogenics, experience in both laboratory and field instrumentation and is well attuned to our customers' need for application support.



**QUANTUM
DESIGN**



QUANTUM DESIGN

**Helping to bridge the gap
between theory and reality.**

Call Quantum for rapid and extremely effective consulting
and assistance in the following areas of applied physics

-
- ☐ Cryogenic Engineering ☐ Ultra-low noise magnetic and electrical measurements ☐ Application and design of SQUID amplifier-based equipment and Josephson junction physics ☐ Experimental solid-state physics design, engineering, and hardware development.
-

Meet the QUANTUM Design team

Four highly qualified
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goals within affordable
time/cost parameters.



**QUANTUM
DESIGN**



Michael Simmonds

Dr. Simmonds has extensive experience in the design and application of superconducting instruments, including magnetometers, gradiometers, and susceptometers. He has been heavily involved in the design and fabrication of advanced quantum interference devices. Dr. Simmonds has also designed optically pumped and fluxgate magnetometers.



Ronald Sager

Development of 4.2K cryocooler, research and development of hybrid SQUID devices, and oceanographic application of SQUID sensors. Also noise suppression in magnetic sensors and computer modeling. Assisted in cesium magnetometer development.



David Cox

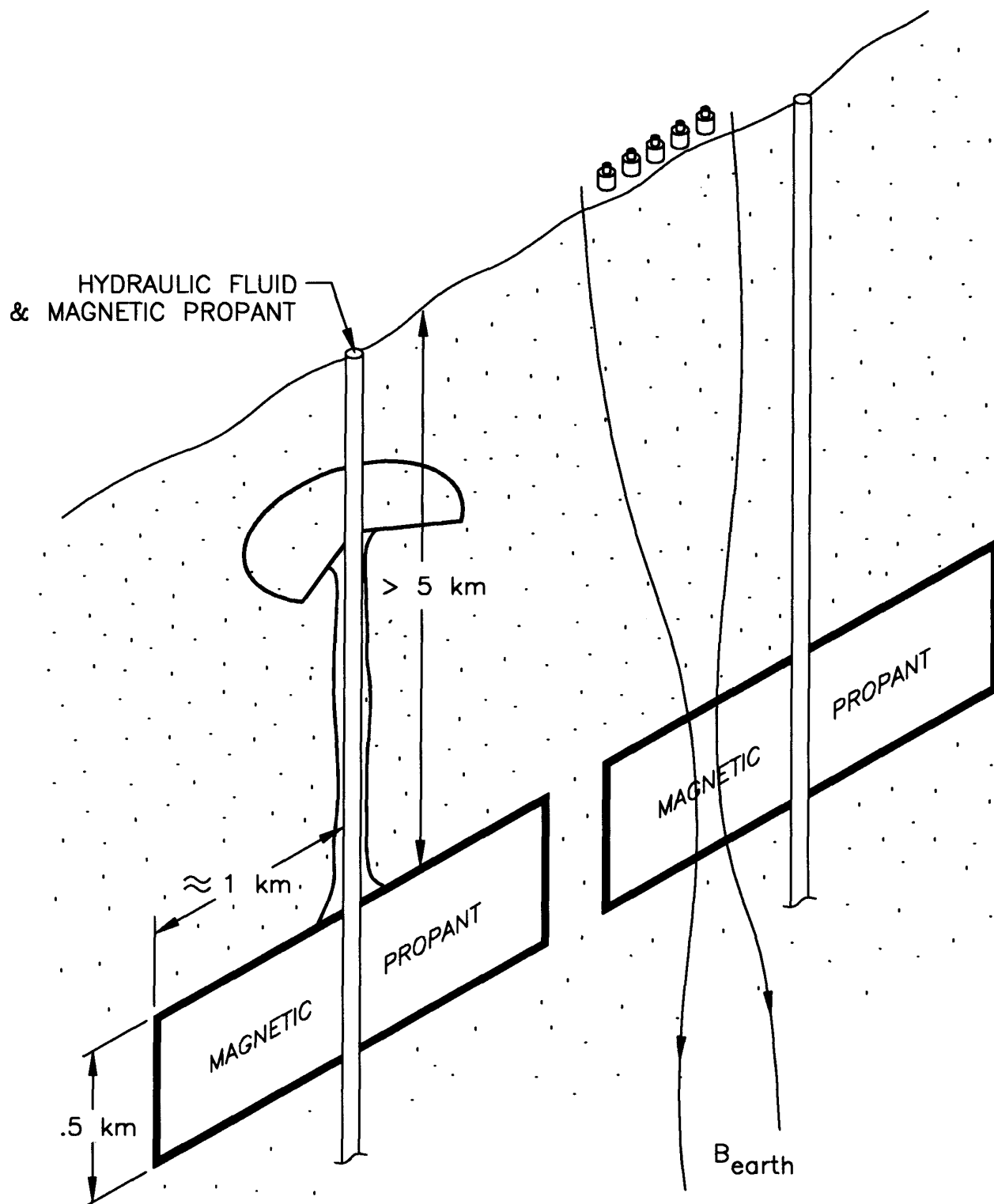
Specialist in the design of superconducting instruments — hands-on ability to rapidly fabricate concept into application .. such as one-of-a-kind gradiometers for medical research.



Barry Lindgren

Our general manager is your contact at Quantum Design — the person to call to discuss a new research, design or development project. With a strong cryogenic background, as well as extensive experience with ultra-low temperature refrigeration systems and superconducting magnetometer/gradiometers for field use, Barry is well attuned to your applications support needs.

"FRACING" GAS WELLS



SPE/DOE 11612

Fracture Proppant Mapping by use of Surface Superconducting Magnetometers

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M.B. Smith,* *Amoco Production Co.*; R.L. Abbott,* *Dowell Division of Dow Chemical U.S.A.*
D. Cox, *Quantum Design Inc.*; and P. O'Shea,* *Gas Research Inst.*

* Member SPE-AIME

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This paper was presented at the 1983 SPE/DOE Symposium on Low Permeability held in Denver, Colorado, March 14-16, 1983. The material is subject to correction by the author. Permission to copy is restricted to an abstract of not more than 300 words. Write SPE, 6200 North Central Expressway, Drawer 64706, Dallas, Texas 75206.

ABSTRACT

A surface array of sensitive superconducting magnetometers was deployed in the first set of a planned series of field tests and successfully mapped a shallow, magnetically tagged proppant in a horizontal fracture. In the project, a coordinated GRI-Hunter-Amoco-Dowell effort, the magnetometer array was supported by tiltmeters, borehole television, and stimulation pressure/flow data to analyze a complex vertical-horizontal fracture formation process. The horizontal propped disk radius was determined to be 60 feet at shut-in, with disk center offset to the east-northeast of the wellbore. The complexity of fracture formation and proppant deposition during the initial field tests emphasized the importance of using a well-coordinated set of complementary geophysical instruments for future proppant mapping tests at greater depths.

INTRODUCTION

Low-permeability gas reservoirs contain vast amounts of potentially recoverable gas resources [1,2]. Massive hydraulic fracturing (MHF) has been found to be a viable method for increasing production in low-permeability reservoirs [3,4]. Optimal application of this type of stimulation requires detailed knowledge of the results of the in-situ fracturing process. In recent years, several geophysical techniques have been applied with the goal of determining information about fracture azimuth, including surface electric potential surveys [5, 6, 7, 8], passive and active seismic monitoring [6, 9, 10], pressure transient testing [11], and surface deformation measurements [3, 5, 12, 13, 14]. Of these, surface electrical potential and surface deformation surveys (using tiltmeters) have been shown to be viable at 8000-foot depths in the Wattenberg gas field north of Denver, Colorado [7, 12, 13, 15].

Even if the geometry of the hydraulic fracture can be identified, optimal stimulation performance depends on proppant transport and final propped geometry [16, 17]. Thus the ability to map the propped region of a hydraulic fracture is of primary importance. Proppant mapping goes a step beyond measuring azimuth to determination of propped fracture length and orientation. In 1982 Hunter Geophysics entered into a contract with the Gas Research Institute to develop a surface superconducting magnetometer field system for application in fracture proppant mapping. Amoco Production Company and Dowell Division of Dow Chemical U.S.A. agreed to become industry partners and to provide resources and field support to the research program. To date Hunter has developed field hardware and software for an array of magnetometers, and has supplied an ancillary array of tiltmeters for mapping of fracture azimuth. Two field experiments have been carried out at an Amoco research site near the Port of Catoosa, Tulsa, Oklahoma. This paper will focus on the results of the second tests, called "Catoosa II Tests," with emphasis on magnetometer measurements of proppant dimensions. Ancillary results from measurements by an array of surface tiltmeters, borehole television camera observations, and pressure/flow data will also be presented.

APPROACH OF THE PROPPANT MAPPING PROJECT

The methodology presented in this paper is the result of the first phase of a broad-based fracture/proppant diagnostics program which presently involves a joint GRI-Hunter-Amoco-Dowell effort. The program will be expanded in the near future to incorporate other supplementary geophysical methodologies. The present approach involves use of a surface array of highly sensitive cryogenic magnetometers to detect the anomalous spatial magnetic field of a magnetically tagged proppant. From the characteristics of the anomalous vector magnetic field, proppant dimensions were inferred using

HUNTER GEOPHYSICS
DATA ACQUISITION TRAILERS

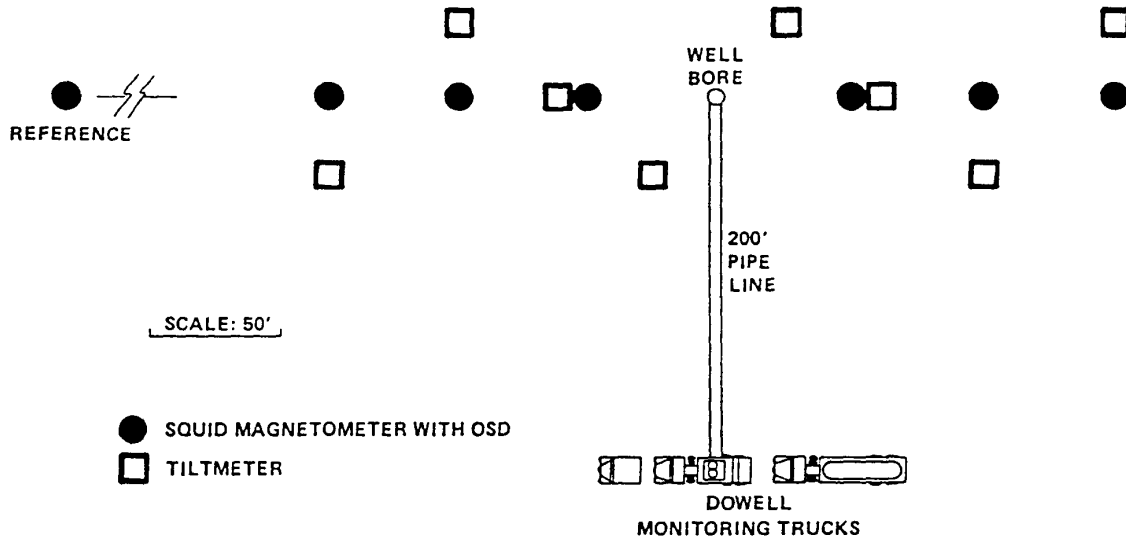


FIGURE 1. INSTRUMENT ARRAYS: CATOOSA II TESTS.

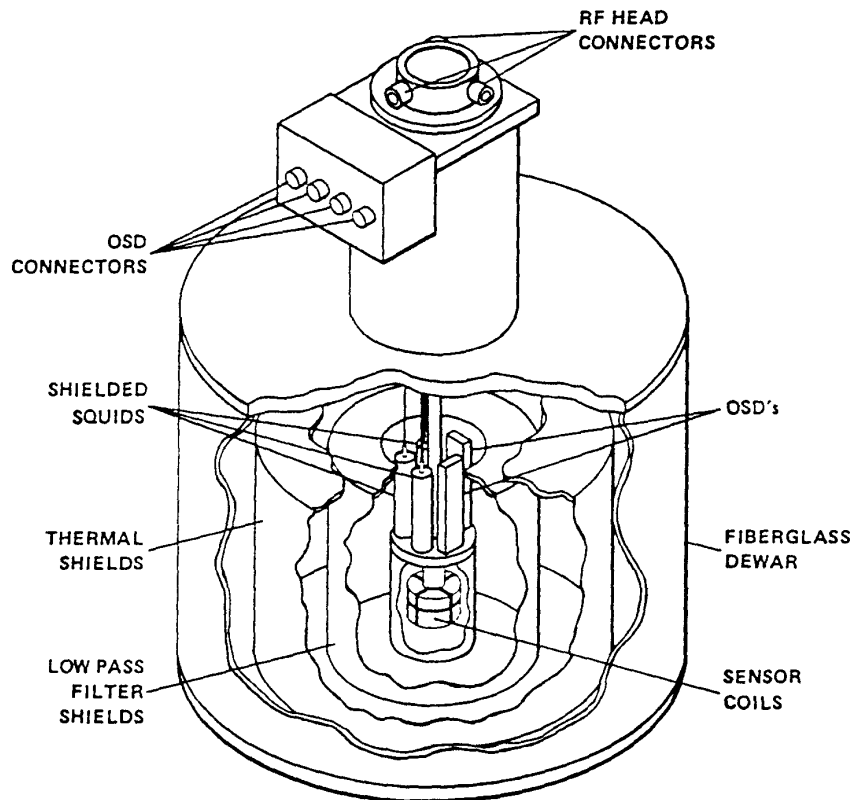


FIGURE 2. SQUID MAGNETOMETER.

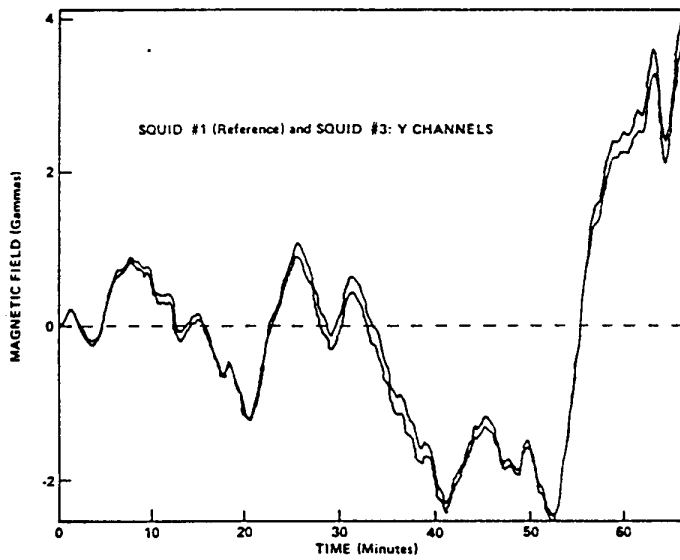


FIGURE 9. SIMULTANEOUS MEASUREMENTS OF BACKGROUND MAGNETIC FIELD (Raw Data).

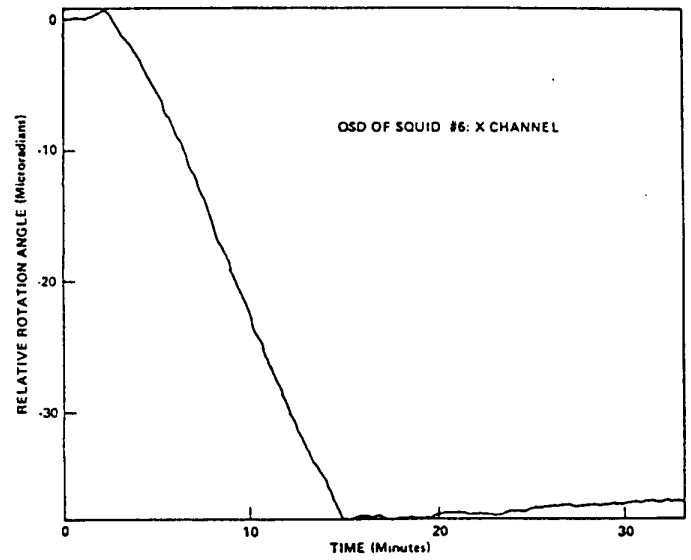


FIGURE 10. SQUID MAGNETOMETER ROTATION DURING INJECTION, AS RECORDED BY INTERNAL ORIENTATION SENSING DEVICES (OSD's) (Raw Data).

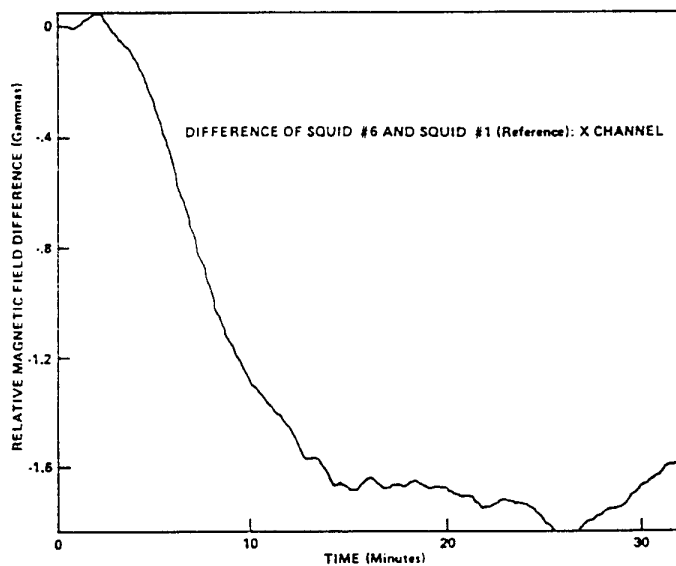


FIGURE 11. MAGNETIC FIELD DIFFERENCES DURING INJECTION (Raw Data).

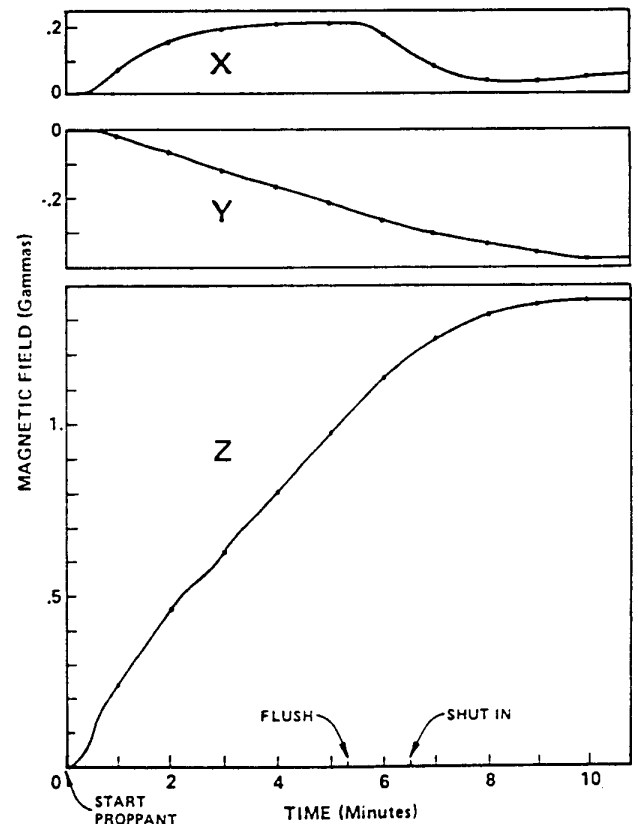


FIGURE 12. MAGNETIC FIELD RESIDUALS AS A FUNCTION OF TIME AT SQUID #5.

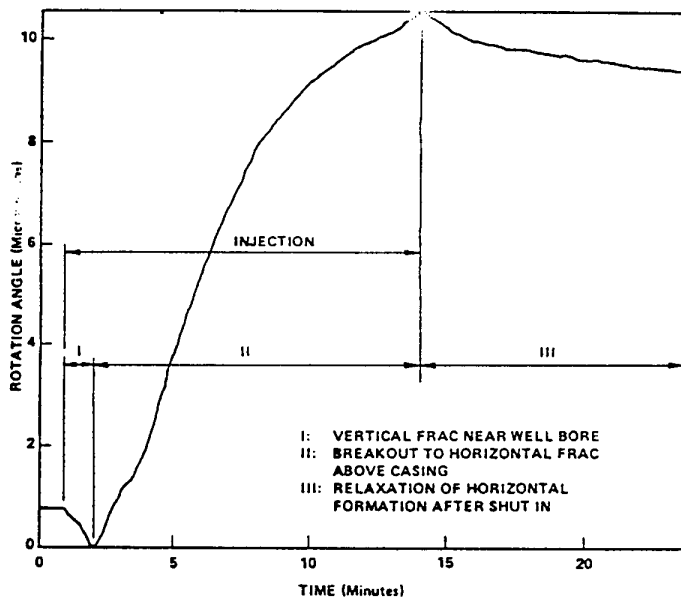


FIGURE 5. THREE STAGES OF FRACTURE FORMATION (During and After Fluid Injection, as Recorded by Array Tiltmeter).

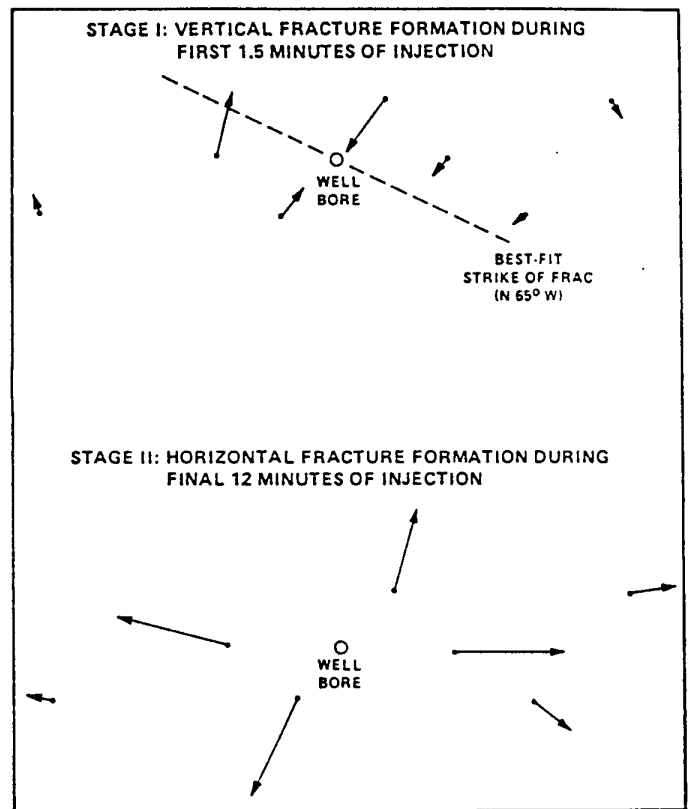


FIGURE 6. MEASURED TILT PROFILES DURING STAGES I AND II OF FRACTURE FORMATION.

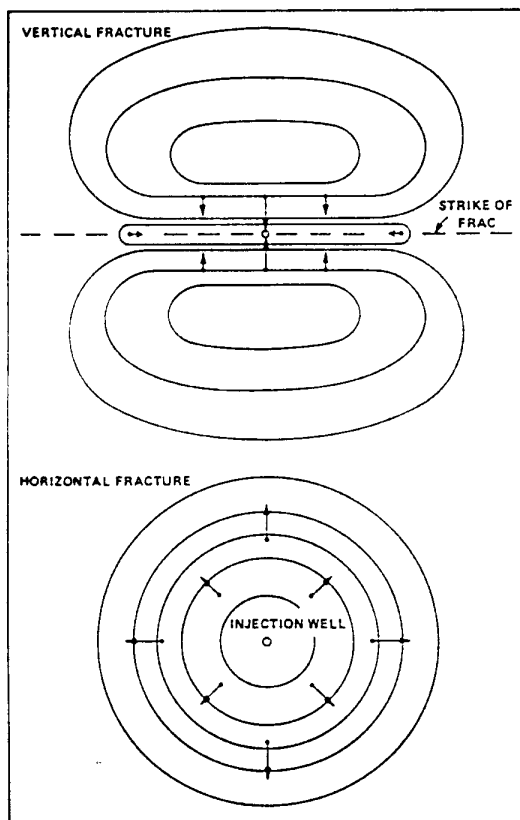


FIGURE 7. THEORETICAL TILT VECTOR AND SURFACE DEFORMATION PATTERNS.

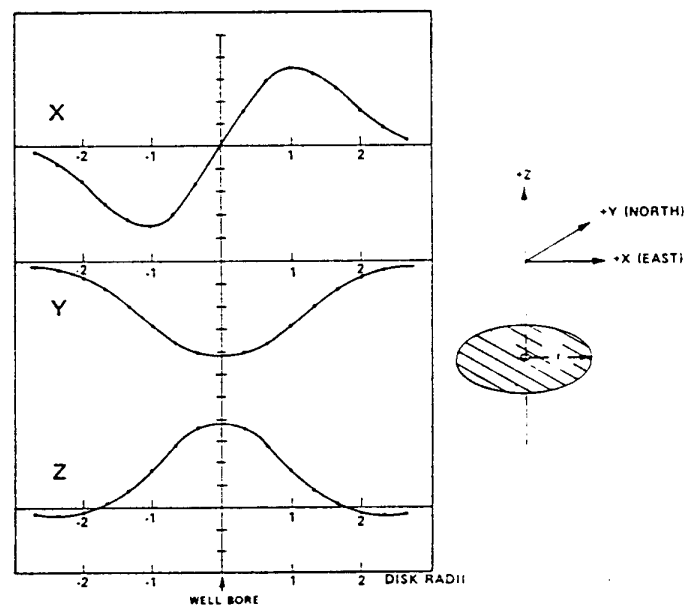


FIGURE 8. MAGNETIC FIELD PROFILES FOR HORIZONTAL DISK PROPPANT (Empirical Data from Scale Model. Magnetic Field Components are in Relative Units.)

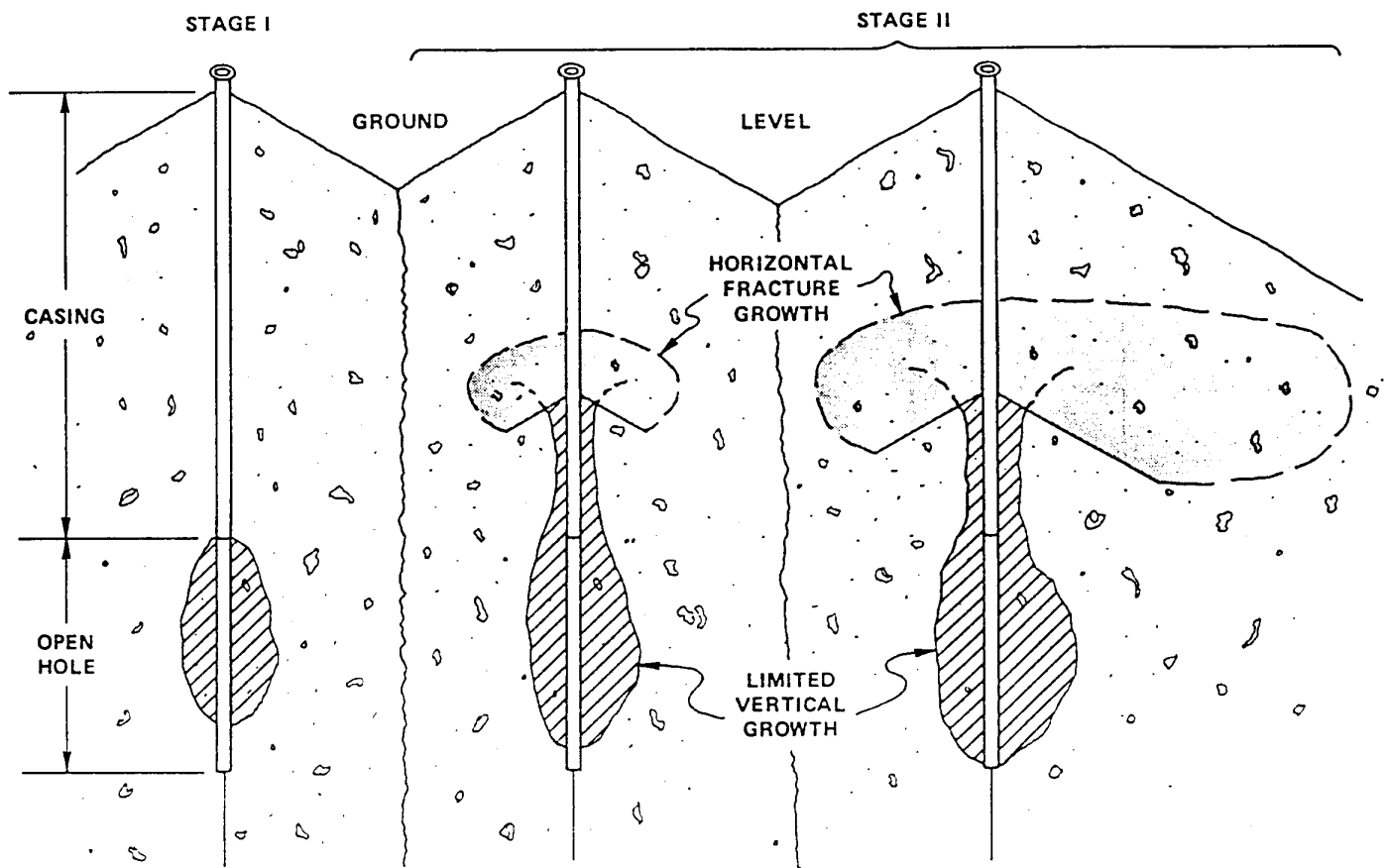


FIGURE 15. SCENARIO FOR PROPPED FRACTURE EVOLUTION: CATOOSA II TESTS.

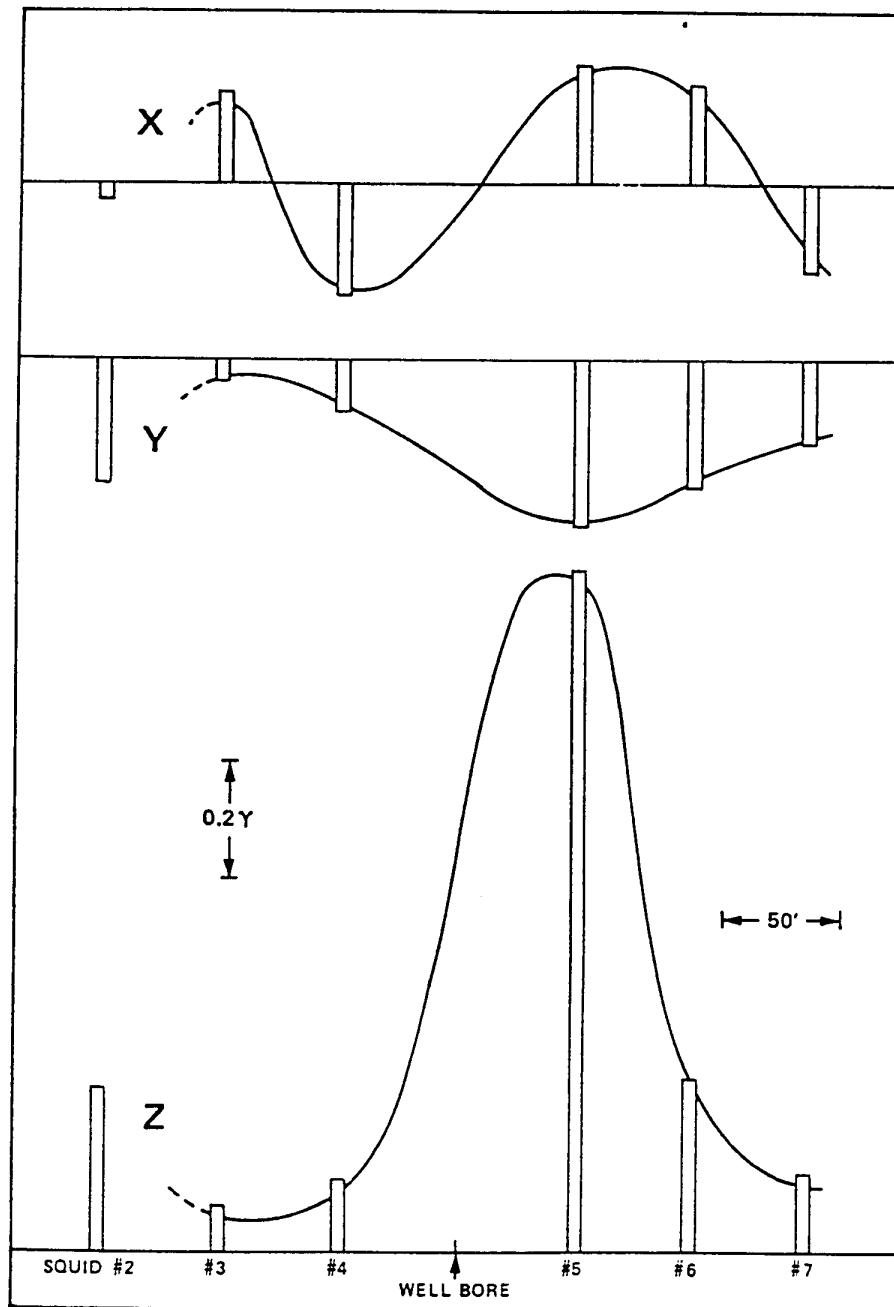


FIGURE 13. MAGNETIC RESIDUALS AT SHUT-IN, AS A FUNCTION OF SQUID MAGNETOMETER LOCATION EAST AND WEST OF WELLBORE.

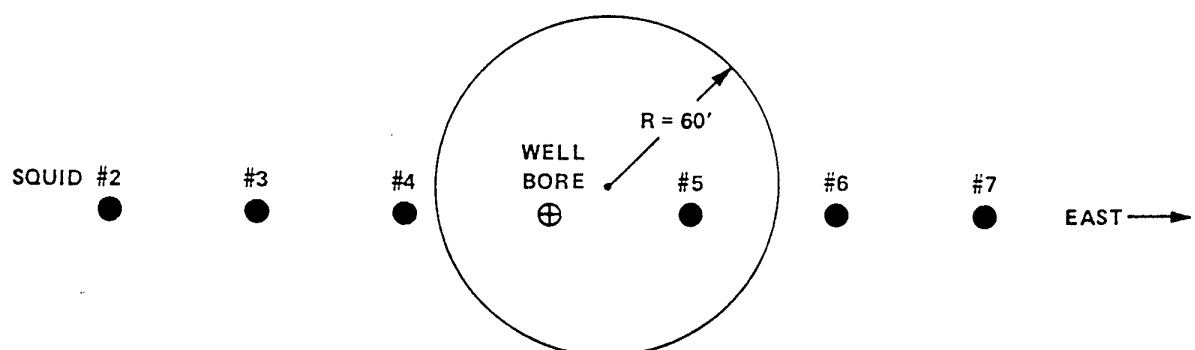
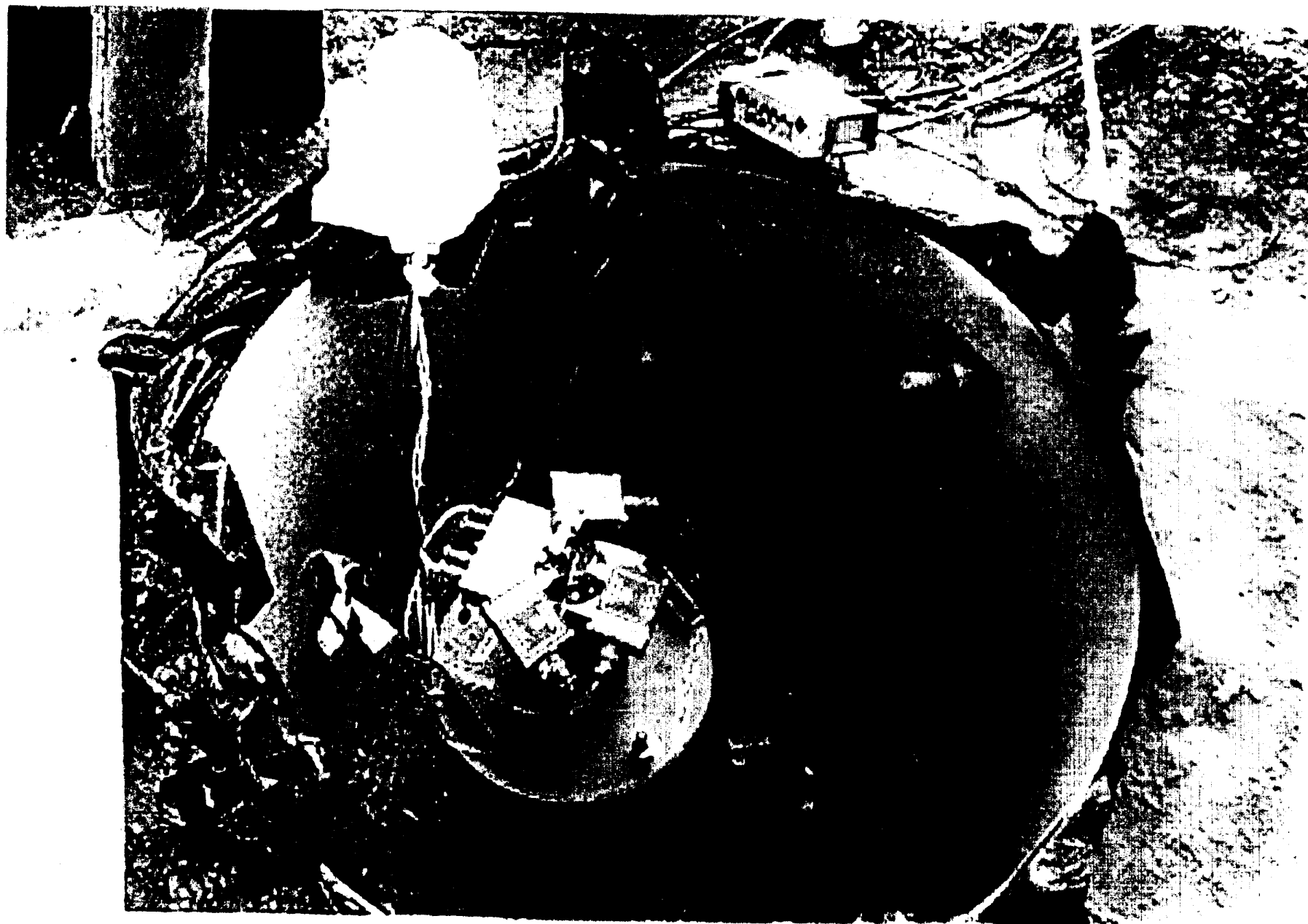
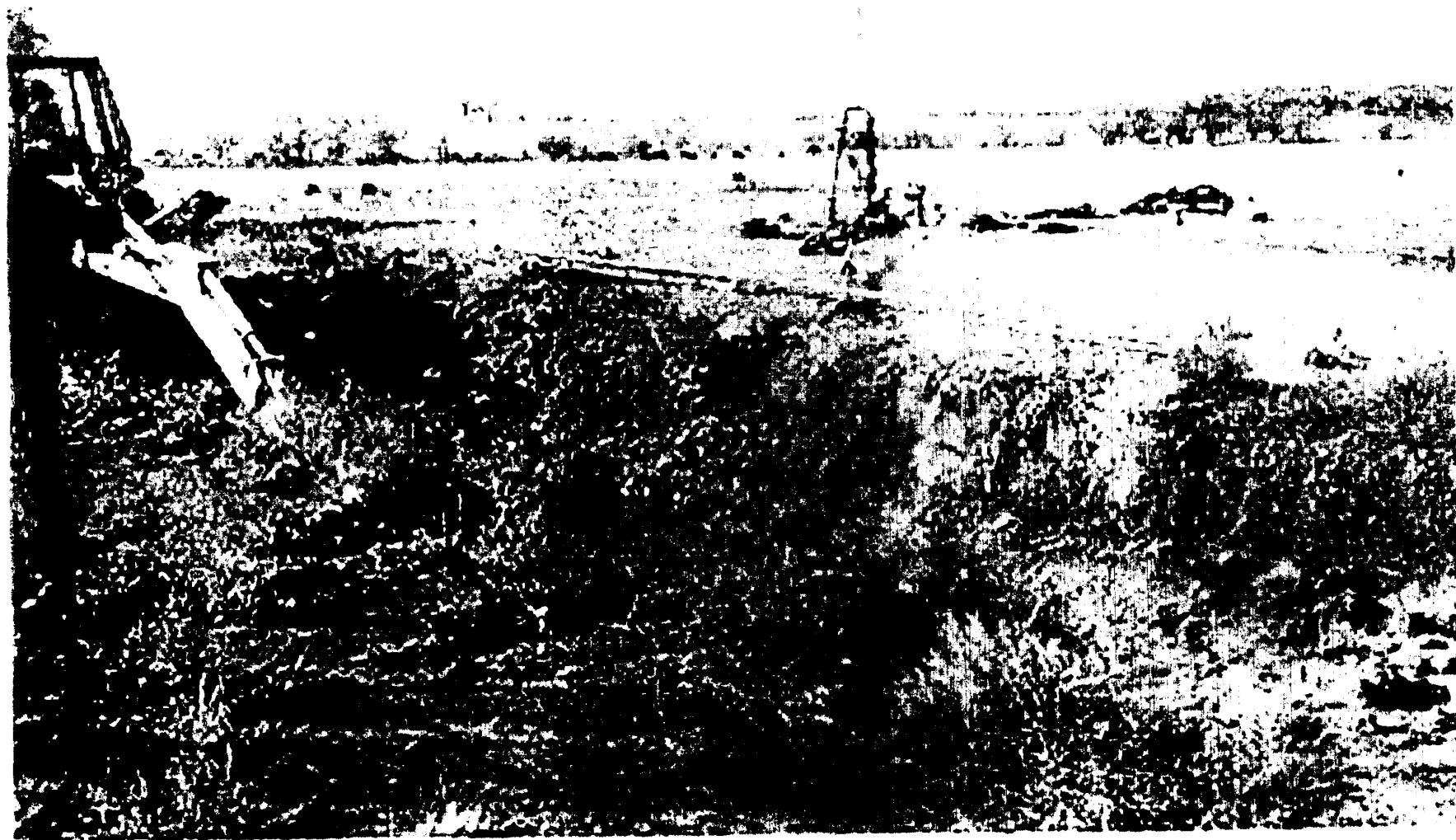


FIGURE 14. DIMENSIONS OF FRACTURE PROPPANT.







What Makes A Good Product?

What Makes a Good Product?

- * Many people want to buy it
- * You can sell it for a profit

Why Do People Want To Buy It?

- * Personal enjoyment
- * Provides convenience
- * Solves a problem
- * Helps make or save money
- * Cost is commensurate with benefit
- * Good economics

What Makes a Good Instrument?

- * Performs a needed measurement
- * Easy to use
- * Reliable
- * Well-supported by manufacturer

Commercial Encounters...

- * OF THE FIRST KIND

- You get a government contract to build one

- * OF THE SECOND KIND

- You sell a couple to your friends

- * OF THE THIRD KIND

- You manufacture dozens for a wide range of users

For a Commercial Product

- * Engineered for manufacturing and testing
 - * Entire manufacturing process is documented
 - * Intuitive and forgiving for wide range of users
 - * Backed by professional service and support
-
- * Useful enough to be bought with your own money

Quantum Design's Goals

- * Keep your customers happy.
- * Make a profit.
- * Create an enjoyable place to work.

Contributing Factors

- * Good products
- * Good Service
- * Good financial management
- * Good personnel management

Thermal Management Workshop

October 1995

University of Minnesota

WHY USE CRYOGENIC SYSTEMS?

VERY LARGE MAGNETIC FIELDS

LABORATORY MEASUREMENTS/SCIENTIFIC MEASUREMENTS

MAGNETIC FUSION PLASMA CONFINEMENT

HIGH SENSITIVITY DETECTORS

QUANTUM MECHANICAL DEVICES (SQUIDS)

REDUCED THERMAL NOISE

HIGH SPEED ELECTRONICS

HIGH SPEED SWITCHING OF JOSEPHSON JUNCTIONS

FASTER CONVENTIONAL ELECTRONICS

SCIENTIFIC INVESTIGATIONS

SUPERCONDUCTIVITY

SUPERFLUIDS

GENERAL QUANTUM MECHANICAL PHENOMENA

TYPICAL REFRIGERATION SYSTEMS

CYCLE	G-M	BOREAS	G-M / JT
MINIMUM TEMPERATURE	7-12K	<4K	4.1K
COOLING POWER	1-10 W @ 10K	1W @ 4.2K	1-10W @ 4.2K
INPUT POWER	2.2-5.0 KW	2.9 KW	5-10 KW
COST	\$15,000 - \$20,000	\$38,000 - \$50,000	>\$30,000

Josephson Junction Computers

Good News:

January 1992, *Science*, S. Hasuo (Vol.255, P.301)

4-bit Josephson Computer - 1988.

1841 Modified Variable Threshold Logic (MVTL) Gates

MVTL Gate: 1-2 psec Switching @ 12 μ Watts

5 mm x 5 mm Chip - AM 2901

Device	Clock (MHz)	Pwr Dis. (W)
Silicon	30	1.4
GaAs	72	2.2
Josephson	770	0.005

(Leads - 1-2W, Cryostat - 1.5W)

1990: 8-bit Josephson DSP Chip

6300 MVTL Gates, 4 bytes Memory

Memory: 500 psec Access Time

100X Faster than CMOS Version

Josephson MVTL Gate Theoretical Limit ~ 0.2 psec.

$$\Delta t \sim h/\Delta E$$

ΔE = Energy Gap

h = Plancks Const.

Josephson Junction Computers

Bad News:

Existing computers require 4.2K temperature

Reliable Nb technology

Low power dissipation

Liquid helium required

Cryocoolers cost in excess of \$30,000

High- T_c Materials - Good News

Some reports of reproducible JJs in High- T_c

Operate at 77K

Operate with cryocoolers which are much cheaper

High- T_c Materials - Bad News

Dissipation will be 250X greater at 77K

(V and I are both proportional to temperature)

Device	Temp (K)	Power (μ W)	Freq (Mhz)	Voltage (V)
Nb JJ	4.2K	5	1,000	
Tl JJ	77	1,300	1,000	
1 μ CMOS	77	10	50	3.3
1 μ CMOS	77	200	1,000	3.3 (freq-scaled)

Low T_c Materials - Bad News

IBM JJ computer (1960s) - Goal was 70 MIPS.

Today - Silicon has far surpassed this

Josephson Junction Computers

More Bad News:

Density of Components

Silicon now at $0.35 - 0.25\mu$ dimensions

JJ memory cells are limited in size

$$\phi_0 = 2 \times 10^{-15} \text{ webers } (\phi_0 = LI_c)$$

Maximum $I_c \sim 1$ mamp

Minimum $L/d \sim 5 \times 10^{-8}$ H/M

Minimum loop area $\sim 1,000 \mu^2$ ($30\mu \times 30\mu$)

To prevent cross talk: $80\mu \times 80\mu$

Rapid single flux Quantum (RSFQ) Logic

Similar problem with scaling down size

Present Status of Speed

JJs now at about 3 GHz - Possibly get to 100 GHz?

Silicon now at about 300 Mhz - 2 GHz in 10 years

(silicon is on track to do this)

Problems of Implementation

Hybrid systems - interface problems (interconnects)

Heat dissipation at cryogenic temperatures

Impedance matching

JJ High Speed - problems similar to silicon (not heat)

Impedance matching difficulties

Propagation times

Josephson Junction Computers

Hasuo's Conclusions

- 1) “Both density and speed of transistors will saturate in the near future, independent of material” (??)
- 2) “Bioelectric or optical computers will be developed, but at present they are still primitive. The Josephson computer will most likely be the solution.”
- 3) “Commercially, the development of the Josephson computer relies on finding a market.....”
- 4) “If a full Josephson computer having powerful processors could be developed soon, a large market would be available.”
- 5) Hasuo suggests several possible uses:
 - Radio astronomy
 - Medicine (neuromagnetometers) - 160 SQUIDs
 - Possibly 1,000 SQUIDs

References:

- 1) Kroger & Ghoshal, *IEEE Trans. Appl. Superconductivity*, Vol.3, No.1, March 1993 (P.1307 & P.2315).
- 2) S. Hasuo, *Internat. J. High Speed Elect.*, Vol.3, P.13 (1992).
- 3) Kroger, Hilbert, et al., *Proc IEEE*, Vol.77, No.8, August 1989.

A Tale of Two Conferences

- * Cryocooler Workshop - 1981
- * Cryocooler Workshop - 1995

Cryocooler Workshop Attendees

- * Government Funding Agents
- * Government Scientists
- * Academic Community
- * Small Cryogenic Research Companies
- * Cryocooler Manufacturers

Cryocoolers - 1981

- * Cryocoolers will expand superconductivity markets
- * Present cryocoolers are too expensive
- * Larger demand → high volume manufacturing
- * Large volume → reduce cost of cryocoolers
- * Cheaper cryocoolers will help superconductivity

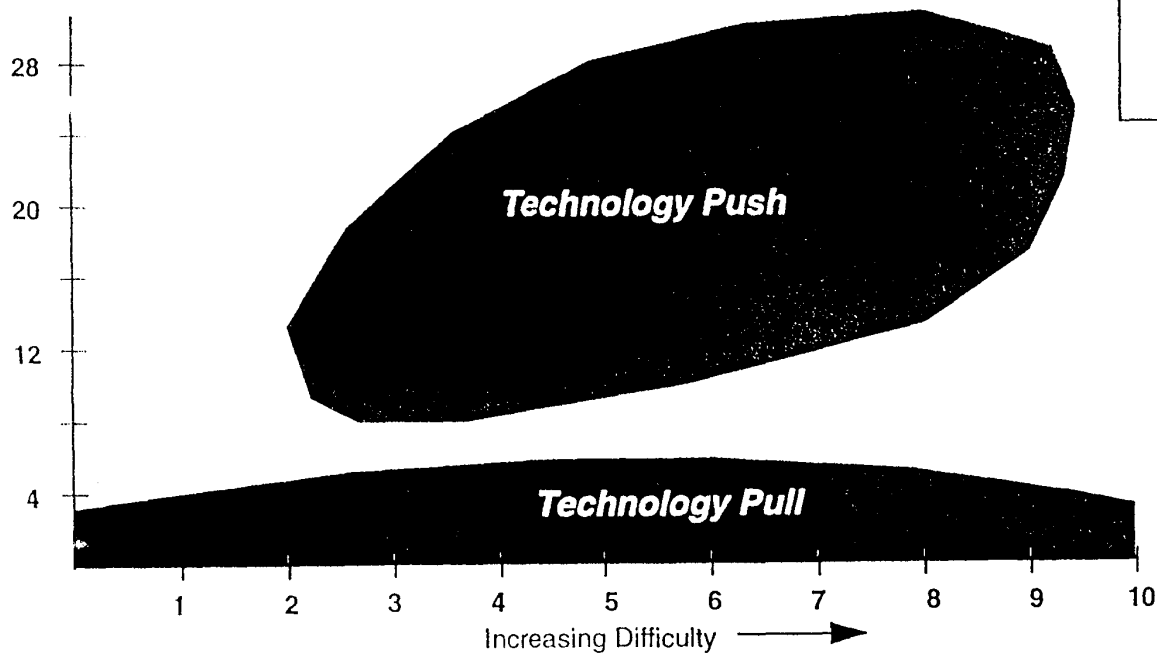
Cryocoolers - 1995

- * Cryocoolers will expand superconductivity markets
- * Present cryocoolers are too expensive
- * Larger demand → high volume manufacturing
- * Large volume → reduce cost of cryocoolers
- * Cheaper cryocoolers will help superconductivity



Mechanical Technologies Market "Pull" & "Push" Experience

Duration to
introduction
(Years)



- 43 Mechanical technologies
- Insertion only after end-user pull identified
- If 'pull' exists, 2-6 years to introduction regardless of difficulty