KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 90-29

FIELD TRIP FOR KANSAS CORPORATION COMMISSION STAFF TO ZENITH FIELD, AUGUST 20, 1990

ZENITH FIELD—A FIELD DEMONSTRATION PROJECT FOR IMPROVED EFFICIENCY FOR OIL AND GAS RECOVERY IN KANSAS

conducted by

Kansas Geological Survey and Tertiary Oil Recovery Project
University of Kansas, Lawrence, Kansas

in cooperation with Hallwood Petroleum
funded in part by the Kansas Corporation Commission

compiled by Lynn Watney

Kansas Geological Survey
1930 Constant Avenue
University of Kansas
Lawrence, KS 66047-3726

KGS OF

Field Trip for Kansas Corporation Commission staff
to Zenith Field, August 20, 1990

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TABLE OF CONTENTS

Separate poster presentations to be exhibited during the field trip:

1. Computer generated structural cross sections across Zenith field by J.C. Wong, Kansas Geological Survey

2. Geologic investigations of the Misener Limestone Reservoir by Kevin Cunningham, Kansas Geological Survey

3. Geological characterization of Zenith field by Dave Newell and J.C. Wong, Kansas Geological Survey

Acknowledgements: Thanks is extended to Renate Hensiek for assistance in preparation of posters.

ITINERARY, ZENITH FIELD VISIT
KANSAS CORPORATION FIELD TRIP
AUGUST 20, 1990

A. <u>TOUR OF SURFACE FACILITIES</u>

1. Injection plant
2. Injection well
3. Producing well, surface pump jack
4. Producing well, submersible pump
5. Tank battery

B. <u>LUNCH AT CAFE IN STAFFORD</u>

C. <u>VISIT TO STAFFORD COUNTY MUSEUM</u>

Include briefing on Zenith field
(one hour total, five minute summaries)

(1) Lynn Watney -- introductions, overview

(2) Wendell Weatherbie -- assembly of completion and production data

(3) Dave Newell -- geologic reservoir characterization

(4) J.C. Wong -- mapping and cross sections

(5) Kevin Cunningham -- geological studies of Misener Limestone reservoir

(7) Rodney Reynolds -- drilling and completion history, current well status

(8) Lanny Schoeling -- development of reservoir management plan

(9) Comments by staff of Hallwood Petroleum

D. <u>RETURN TO FIELD TO SEE DEMONSTRATION OF ECHOMETER SURVEY ON WELL ZU-36</u>

GENERAL STATEMENT OF OBJECTIVES AND IMPACT OF INTERDISCIPLINARY STUDIES OF KANSAS PETROLEUM RESERVOIRS

by Lynn Watney, Kansas Geological Survey

Fundamental energy conservation can be initiated by increased efficiency and reduction of waste in the extraction of oil and gas from existing reservoirs. Integrated geoscience research can provide an increased return of oil from existing reservoirs and pools, increase success rates and decrease costs per barrel of extracted oil.

Targeted beneficiary groups are the small independent petroleum producers, the rural, agricultural mineral owners, and the small businesses which depend upon successful independent oil operators for their livelihood.

Significant amounts of this oil still remaining in existing fields will not be recovered if many of the mature older fields are abandoned. Timely action is needed to identify bypassed oil and to develop remedial actions to boost production and extend the life of active fields, to optimize drilling, and to reduce the waste caused by reservoir abandonment.

While proven oil reserves stabilized over the period of 1978 through 1985, these proven reserves have plummeted 26% from 1985 levels to 312 million barrels at the end of 1986. Proven gas reserves as of the end of 1986 increased 11% to 11 trillion cubic feet. Depleting reserves reflect, in part, premature plugging of small fields as a consequence of low production rates compounded by severe price drops.

The national experience has shown that recovery efficiency of all reservoirs at the present level of development is only about 35% of the original oil-in-place (Science, 26 June 1987, Volume 235, at p. 1633), compared to only 33% of the original-oil-in-place in existing Kansas fields. Average recovery efficiencies of original oil in place of 55% should be achievable in similar reservoirs according to the same article. An additional 3.7 billion barrels would be recovered in Kansas if recovery efficiency could be increased to 55% through improved geological and engineering characterization of reservoirs. Another estimate (BPO/TORIS, 1987) indicates that 2.4 billion barrels of unswept mobile oil and 8.7 billion barrels of residual oil (immobile) are potentially extractable through application of improved oil recovery using today's technology in Kansas.

New cost effective methods are needed to locate and extract mobile oil now locked in the reservoirs due to heterogeneity and inability of existing wells to contact all areas of the reservoir. Predictive geologic models are needed to site wells with greater accuracy to minimize energy waste during field development. Interdisciplinary efforts can help to improve knowledge of reservoir definition, development of geologic models to aid in predicting the locations of undrained reserves in existing fields, and tailor new extraction procedures to specific geologic conditions of the reservoir.

A lease in a field is abandoned when production rates and/or prices have diminished to a level where returns are less than costs. This is the economic limit. Two-hundred-and-five net fields were abandoned in Kansas between when the price began to fall in December 1985 and late 1987. A total of 1462 net wells were abandoned during 1989. Once fields are abandoned and wells are plugged, opportunities to economically redrill wells and produce remaining oil becomes diminished and reserves are effectively lost or wasted. Many leases are approaching their economic limit as the rates of production diminish. Effective and timely action is warranted to limit this loss.

The independent petroleum industry is a vital element in the rural economies of western, central, and southeastern Kansas. Approximately 1200 independent petroleum operators drill 97% of all the wells in Kansas. Total payroll for the petroleum industry in Kansas was nearly $240 million in 1986. Drilling costs, a fraction of overall operating costs, are estimated to be $362 million in 1988 based on the completion of 4600 wells. Nearly eight million acres of Kansas farm and rangelands are also producing oil and gas leases. An estimated $91 million in royalty went to landowners in 1988, most of whom are farmers or ranchers living on the property. In comparison, royalties are estimated to have been $573 million in 1983.

The rural communities and the independent petroleum industry are dependent on each other for their success. The rural communities provide the infrastructure to support petroleum developmental activities. Accordingly, improvements in efficiency and elimination of waste will help sustain both sectors to weather the economic uncertainty of the future. Maintaining a secure source of locally derived energy will also benefit the farmer and rancher.

The independent petroleum industry does not have the staff nor the broad base of expertise to conduct needed interdisciplinary research to improve production efficiency and to minimize waste. However, our experience has shown that they are receptive to the application of new concepts, methods, and new technology, provided that applications are timely and cost effective. Accelerated and more intensive efforts to transfer knowledge and apply new technology is needed.

The collapse of the world price for crude oil in late 1985 and its persistence until the summer 1990 has created a crisis for these small businesses as reflected by many bankruptcies and marked decline in proven reserves of crude oil. This coupled with the farm loan situation has created considerable hardship in the rural areas. Because of the unpredictability of the oil price for the foreseeable future, the viability of remaining small independent oil producers will be determined primarily by improved efficiency of operation by minimizing unnecessary drilling and unsuccessful wells. Conservation of resources through efficient development and avoiding the potential waste of the resource through abatement in the abandonment of fields will impact the entire rural community.

EXECUTIVE SUMMARY
(from proposal submitted to KCC)

Many fields in central Kansas have extremely high water volumes associated with their oil production. The percentage of water recovered in the total fluid produced commonly exceeds 95%. Considerable energy must be used to pump this fluid to the surface, to reinject the water into the reservoir, or to dispose of the produced water in a disposal well.

Opportunities for energy efficiency in the operation of oil and gas recovery can be substantial. A team of geologists from the Kansas Geological Survey and engineers from the Tertiary Oil Recovery Project at the University of Kansas propose a collaborative study to demonstrate cost-effective methods to increase the energy efficiency of production in mature oil fields in central Kansas. Results of this study will be useful to small independent oil operators to help them evaluate their operations and reduce energy consumption.

Water is injected into the reservoir to maintain natural reservoir pressure and drive additional oil from the injection well to the producing wells. Water production inevitability increases and oil production declines as this process continues, as in many of these fields. This secondary recovery program becomes uneconomical when increasing operating costs exceed the income from the oil field. Remedial action can be prescribed for some reservoirs to decrease the amount of produced water and actually restore some of the oil volume. The net result is improved energy efficiency.

The proposed study will be conducted in the Zenith Field in Stafford County, Kansas. Production in this field is from the rock intervals called the Viola Limestone, Maquoketa Dolomite, and Misener Sandstone. Other fields in central Kansas produce from these same reservoir rocks in analogous geologic settings. What is revealed in this study should be directly transferable to these other fields.

The Zenith Field has a history of water injection on one sector of the field with very mixed results. Engineering appraisals of the field indicate substantial remaining reserves but the field has responded poorly to water injection. Oil production rates have declined in spite of these efforts. Current oil production rate is 187 barrels per day. Large amounts of water (11,000 bbls/day) must be produced to sustain this production rate. As with many fields along this trend, energy costs to extract the remaining oil are becoming prohibitive for continued operation. In the Zenith Field, electricity costs are about $23,000/month and gas costs are $4,000/month.

Oil recovery to date in this field is 16.8% of the original oil in place while the average for the State of Kansas is on the order of 33%. A considerable amount of oil apparently is being bypassed in the reservoir. Injected water may, in fact, be flowing through pathways of least resistance (such as fractures) to the producing wells without contacting and moving oil outside these pathways. There is reason to believe that once the relationship of the pathways to the overall pore system is established, improved oil recovery and increased energy efficiency will be realized.

The project involves two separate phases extending over a two-year period: a reservoir evaluation study during the first year and implementation of remedial actions during the second year, if deemed feasible during the reservoir evaluation phase of the study. The focus of this proposal is a one-year collaborative investigation of the Zenith Field involving engineers and geologists to define the geological heterogeneity of this reservoir and to possibly recommend engineering remedial action that will minimize water production and increase oil recovery rates.

Prior research at the University of Kansas has shown that high-permeable zones that transport water so rapidly to producing wells can be shut down through novel well-completion technology involving chemical gel systems. Strategic wells can be treated and injection programs devised to reorient waterflooding to increase recovery efficiency. In some cases water can also be treated by the addition of polymers to increase its capability to sweep oil from the reservoir more effectively. If these measures are applicable to the Zenith field, they could extend the productive life of the field in an energy-efficient way for the well-being of the operator, the local economy, and the state.

Results of the first year of this proposed study will be two-fold:

1) to demonstrate the procedures and benefits used to define reservoir heterogeneity in reservoirs using collaborative engineering and geological efforts that can be utilized by the independent petroleum industry;

2) to propose a range of cost-efficient remedial actions that could be undertaken in the second year of the project to increase production efficiency.

KANSAS OIL AND GAS PRODUCTION STATISTICS

* 5,634 oil and gas fields, 3,500 field still active

* 1.6 million productive acres of oil; 5.6 million productive acres of natural gas in Kansas

* an estimated 235,000 wells drilled during 130 years of production; 6 billion bbls. total oil production and 30 billion cubic feet of natural gas

* 48,000 oil wells and 11,300 gas wells producing in 1986 compared to 45,470 oil wells and 14,043 gas wells producing in 1989 (1462 oil wells abandoned in 1989)

* well completions (see graph)

* daily production (barrels of oil, billion cu. ft. of natural gas):

	oil	gas
1986	186,000	1.
1987	162,000	
1988		
1989	154,221	1.6

(compared to daily world oil production of: 63 million barrels/day
daily U.S. oil demand of: 17.4 " "
daily domestic oil production of: 7 " "
daily production from average
Middle East oil well: approx. 100,000 barrels/day)

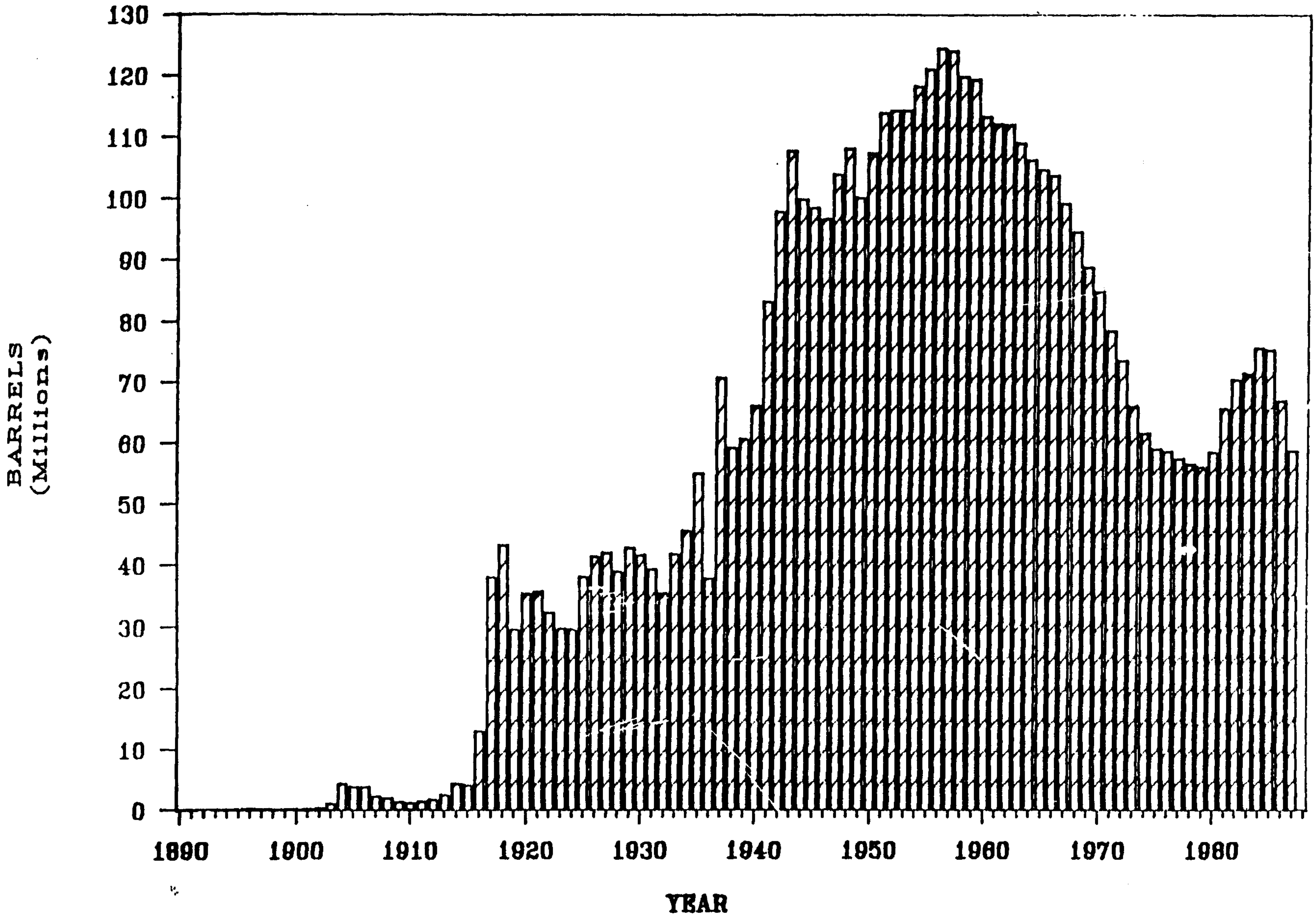
* oil and gas reserves (millions of barrels, trillion cu. ft.):

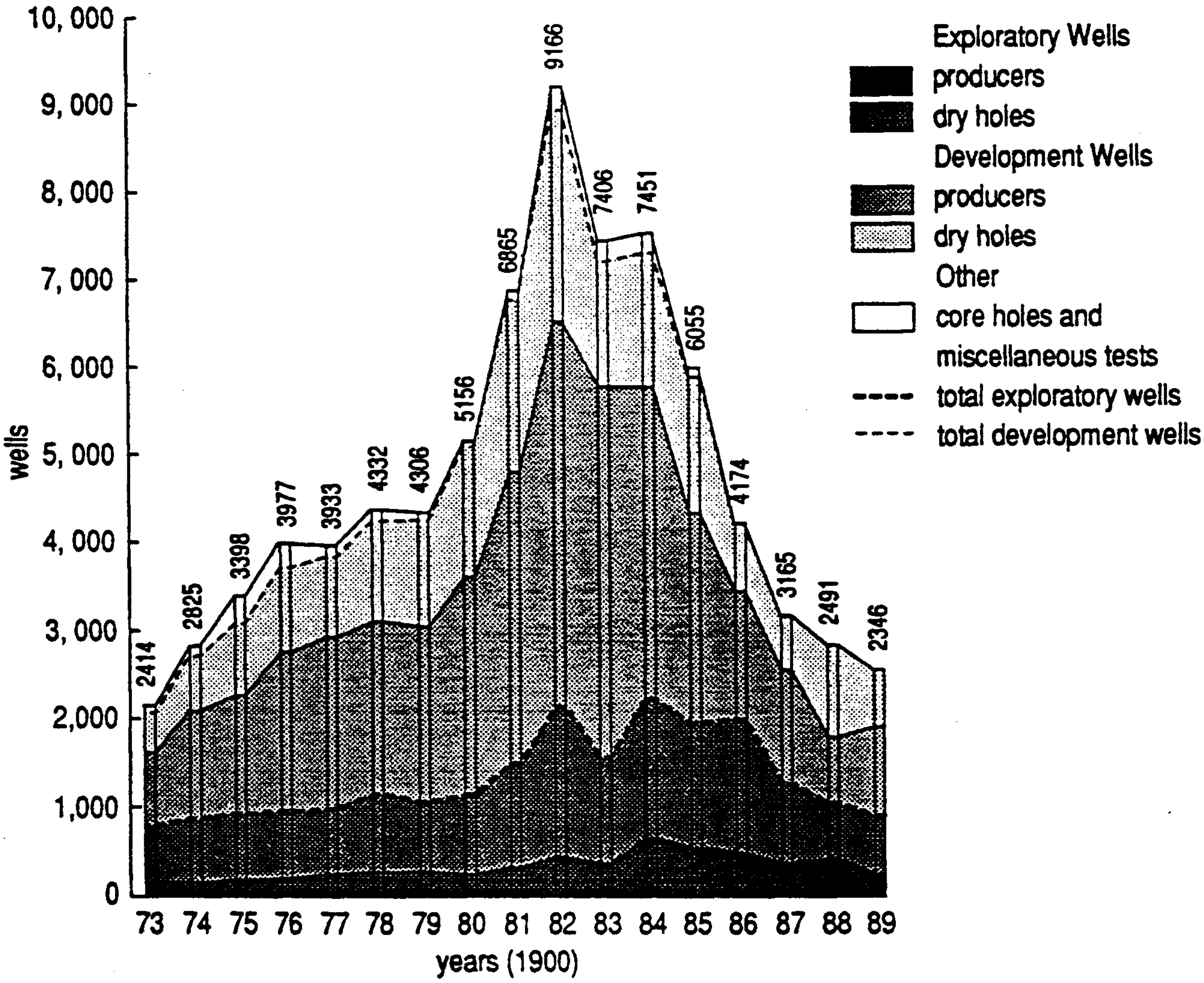
	oil	gas
end 1987	357	11
end 1988	327	10.5

* 11 billion bbls. of oil still in existing fields roughly 2/3 of what was originally in the reservoirs; if oil recovery increased in existing fields from 34% to 55% of original oil in place, this would translate to 3.4 billion barrels

(Kansas generally ranks 3rd or 4th in number of wells drilled and 7th or 8th in oil and gas reserves)

KANSAS ANNUAL OIL PRODUCTION



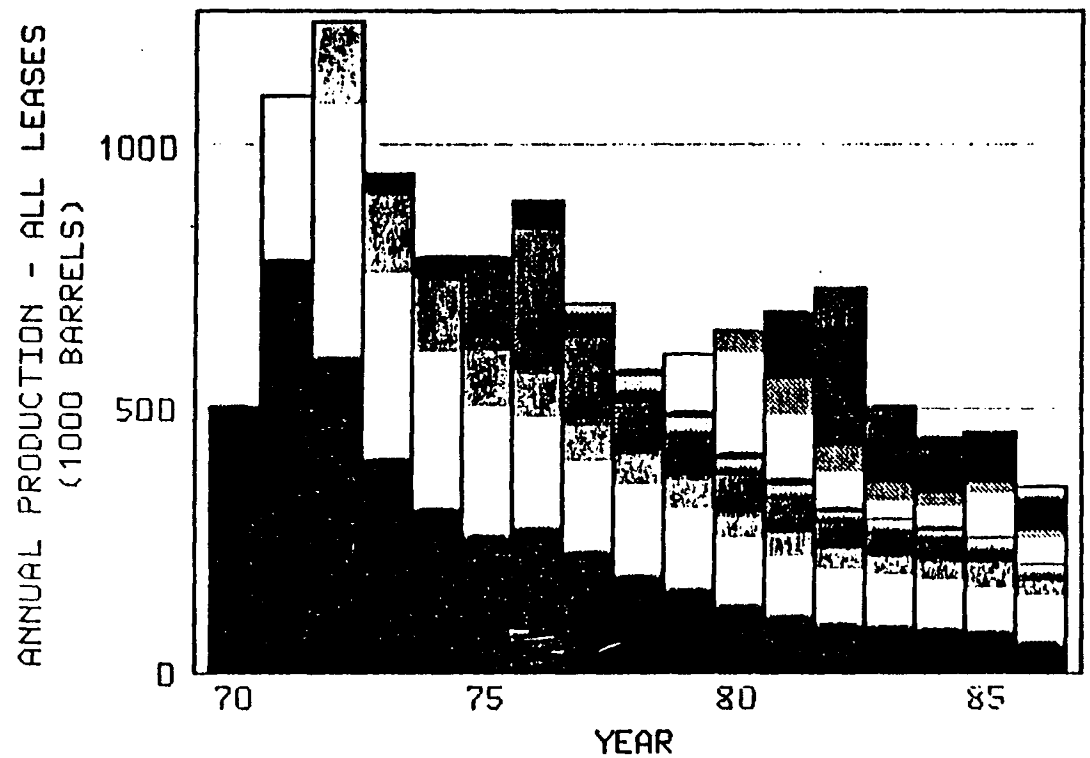


Graph showing number of wells drilled annually from 1973 through 1989.

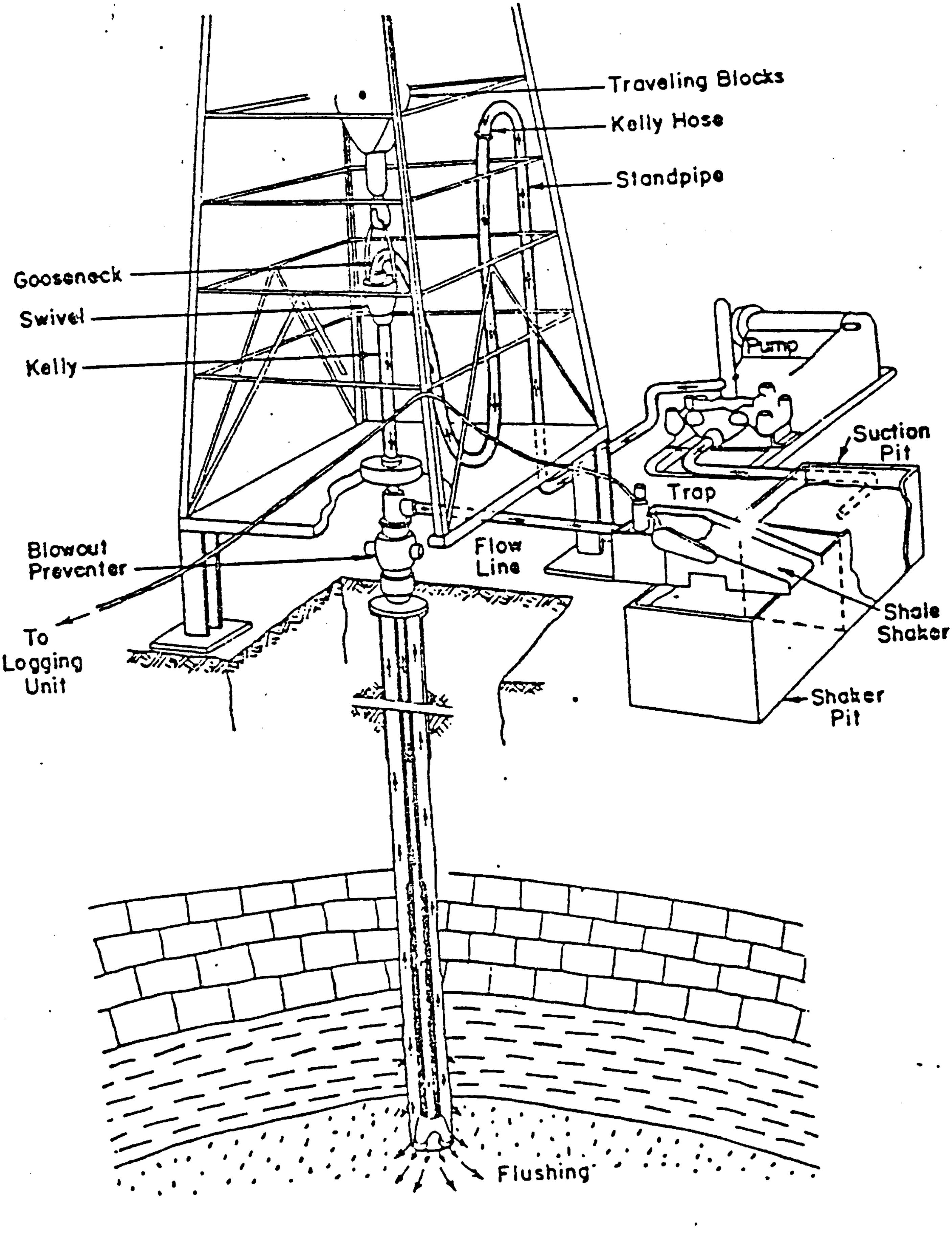
S. Paul, petroleum geologist-Kansas Geological Survey

NEW OIL PRODUCTION -- RESPONSE TO ECONOMIC INCENTIVE

PRODUCTION FROM KANSAS OIL FIELDS DISCOVERED IN 1970
LEASES GROUPED BY FIRST YEAR OF PRODUCTION

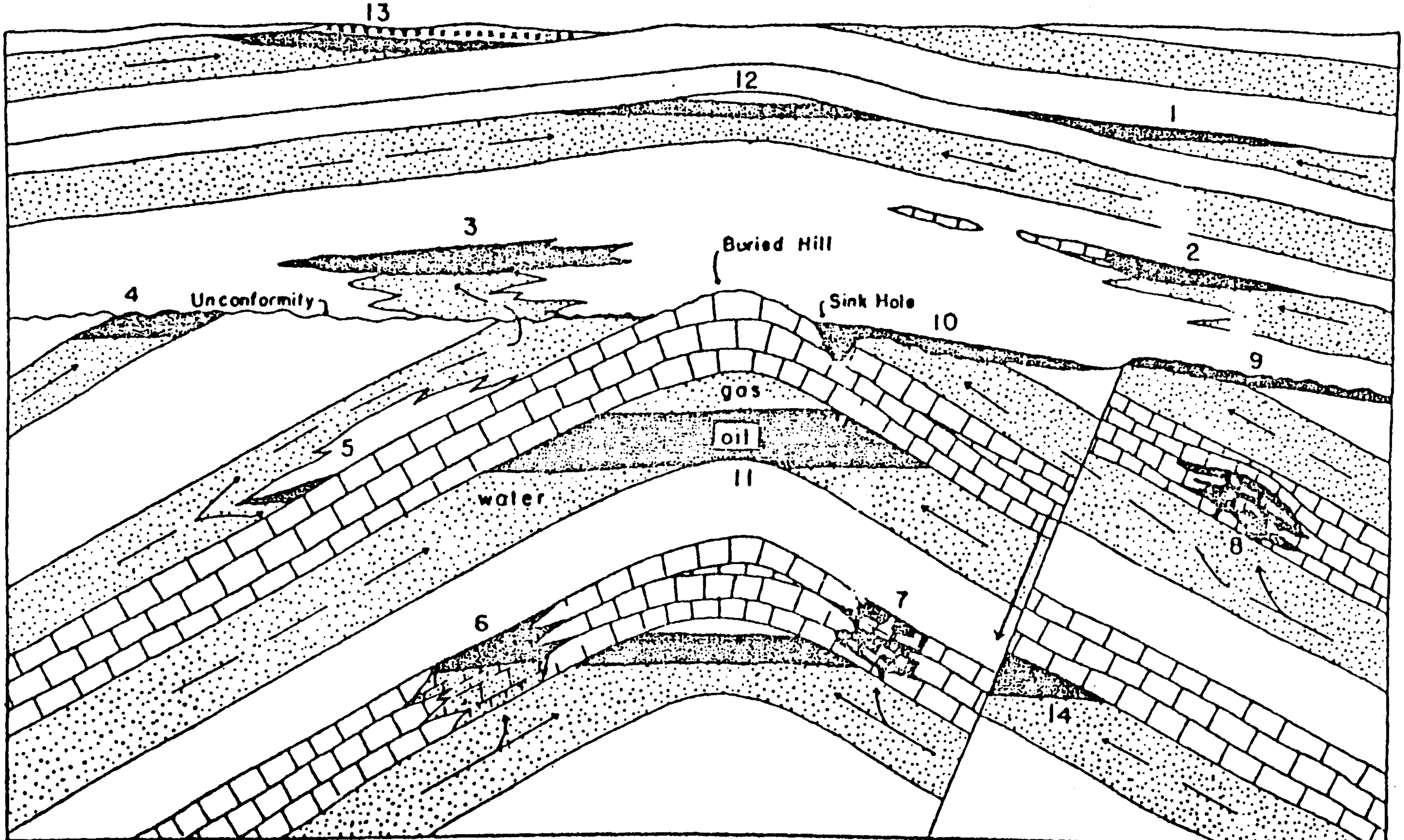


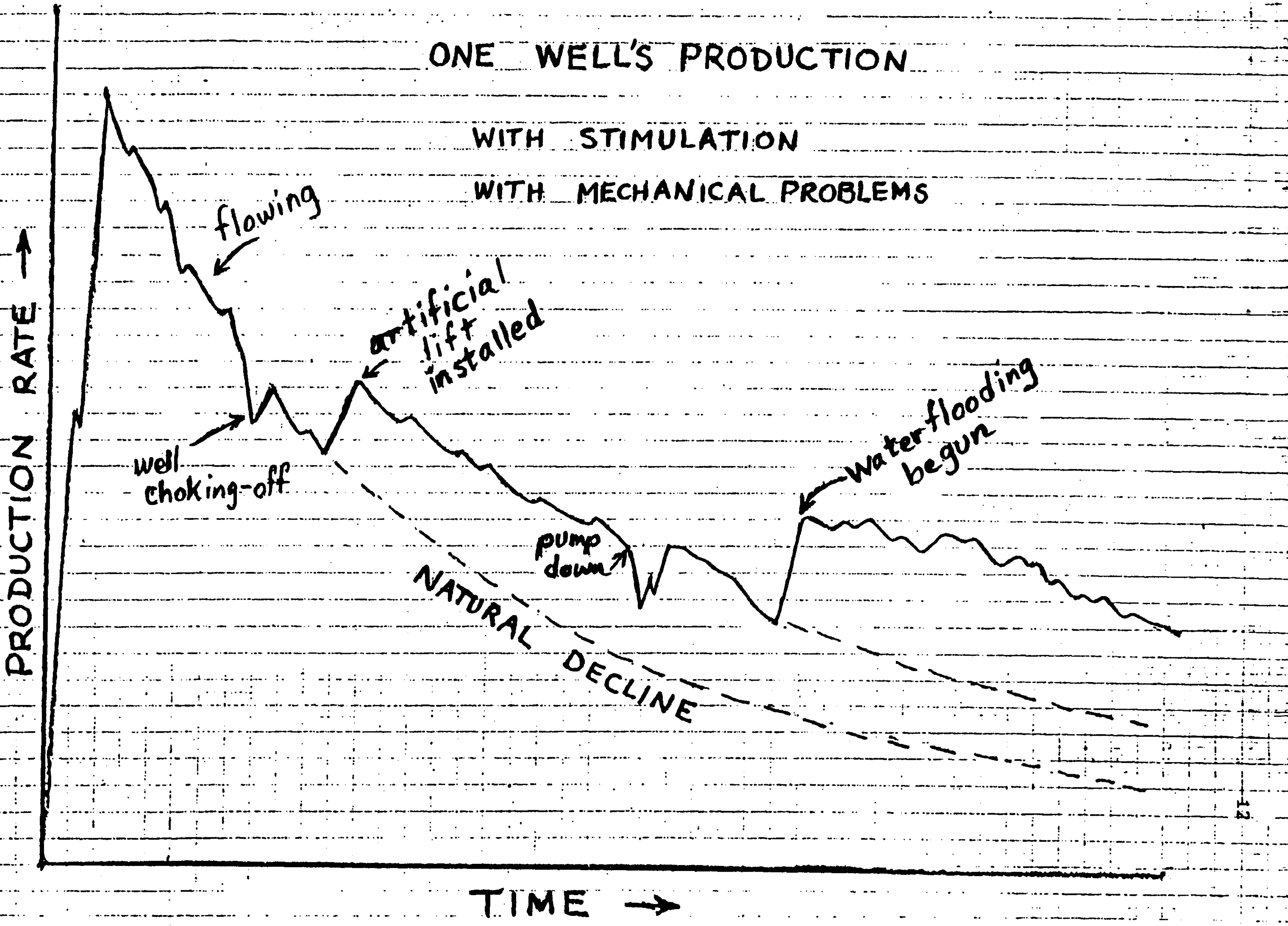
Notable increases in oil recovery from fields discovered in 1970 have come mainly from new leases, i.e., extensions to existing fields. There appears to be plenty of room for improving oil recovery in older established leases. We obviously have to do things different than in the past in order to substantially increase oil recovery in this setting. Integrated studies such as exhibited in this demonstration project may be the vehicle for this objective to be accomplished.



Diagrammatic sketch of drilling well.

Geologic cross section showing common traps for oil and gas.




ONE WELL'S PRODUCTION
WITH STIMULATION
WITH MECHANICAL PROBLEMS
flowing
artificial lift installed
well choking-off
pump down
waterflooding begun
NATURAL DECLINE
PRODUCTION RATE →
TIME →

STATISTICS ON ZENITH FIELD

Discovery date: 1937

Oil Production: 23 million barrels cumulative production of 41 API-gravity oil; rapid development on 10-20 acre spacing with initial potentials ranging upward to 26,000 barrels of oil per day; some 350 wells initially completed in Zenith; Peak production in 1942 then more than 3.3 million barrels of oil were sold; 1942 also year with peak daily production of 10,000 barrels per day.

Primary oil recovery: Primary production as solution gas drive with some water drive in southern part of field; primary recovery mostly before 1946 with rapid decline in oil recovered and in reservoir pressures (loss of energy); only 36 producing wells by 1953.

Secondary recovery: Waterflooding was initiated in 1966 to increase reservoir pressures and drive oil to producing wells. The waterflood has performed poorly with high water/oil ratios. Seventy-three wells have been drilled since 1966, many with modern logging suites, aiding in recorrelating, mapping, and volumetrically reevaluating the field for new enhanced oil recovery procedures. Approximately 20 wells currently produce in Zenith field, all of which have high water cuts (approx. 96% water). The present average daily oil production is approximately 150 barrels per day. Total daily water injected into the field has been upwards of 11,000 barrels and associated energy costs have been $27,000 per month (during operation of the field by Striker Petroleum).

Size: 3 miles wide and 14 miles long

Geological setting (please refer to illustrations):

Zenith field is located on the southeast end of the prolific Central Kansas uplift. The field trends northeast-southwest paralleling the Peace Creek fault zone. The field is dominated by a broad south-southwestward plunging anticlinal fold. The oil-filled reservoirs pinch out northward beneath impermeable shales and conglomerates at a prominent erosional surface called the basal Pennsylvanian unconformity. These reservoirs terminate to the east against Peace Creek fault zone. Oil accumulation is limited in the southern part of Zenith field by an oil-water contact that is common to all reservoirs in the field.

There are five reservoirs in Zenith field. The lower Viola Limestone contains two of the reservoirs. The Viola reservoirs consist of cherty porous dolomite. The Viola is the most laterally extensive reservoir in the field. The overlying Maquoketa dolomite, and Misener sandstone and limestone are not universally present over the study area. The internal properties and spatial distribution of these reservoirs play critical roles in the performance of wells in the field.

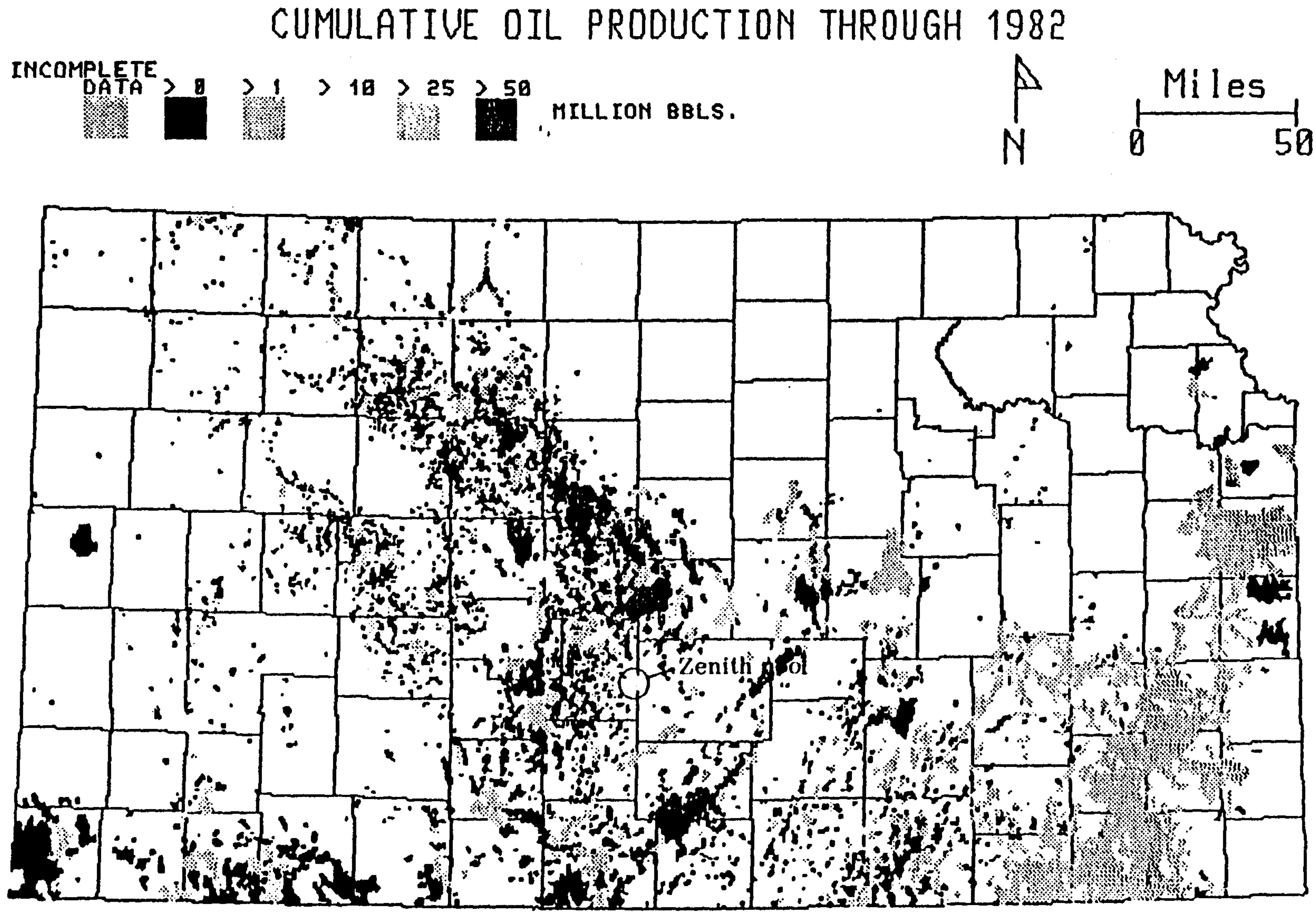


FIGURE 1. LOCATION MAP

Kansas Geological Survey
1930 Constant Avenue, Campus West
The University of Kansas
Lawrence, Kansas 66046-2598
(913) 864-3965

1988

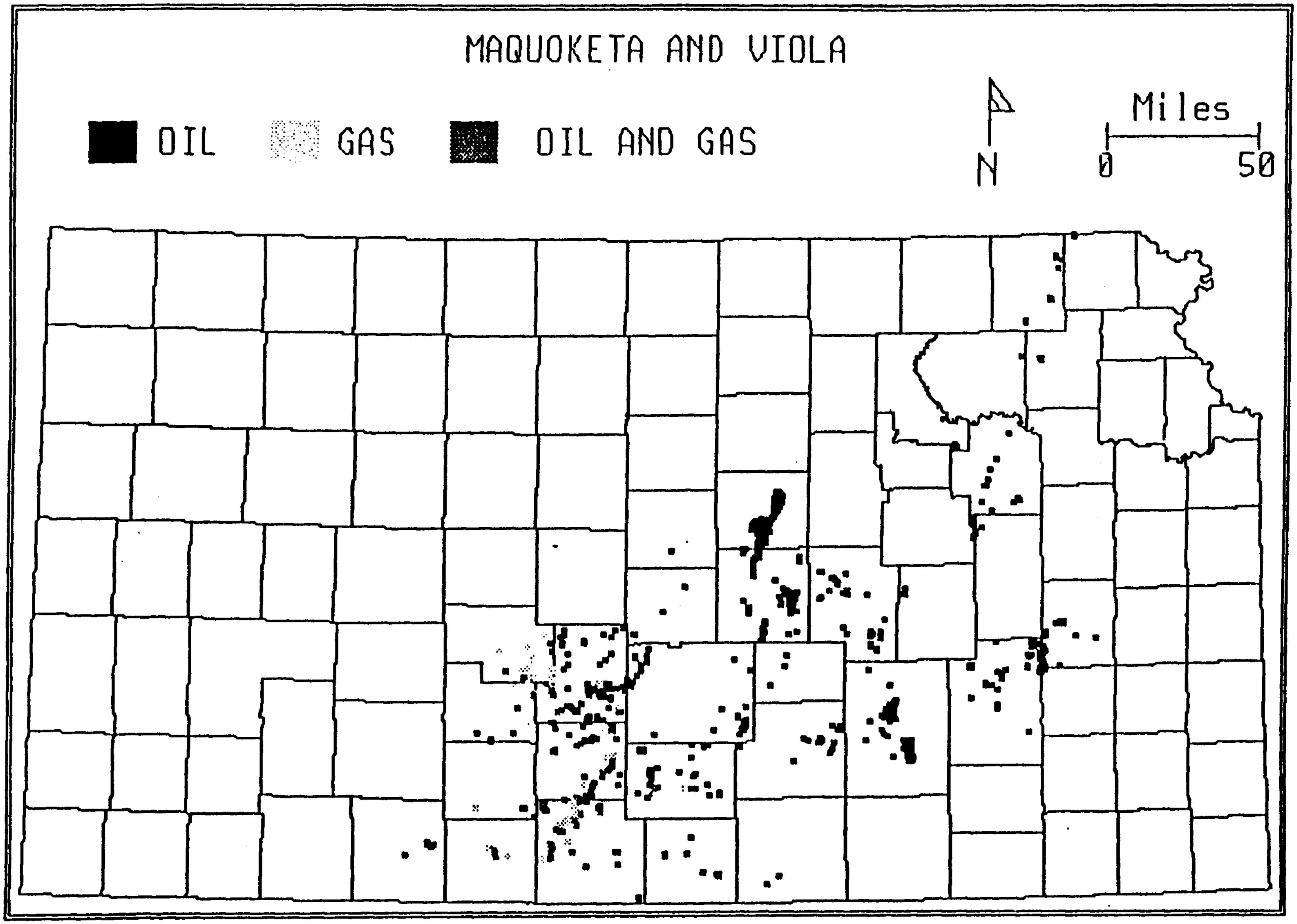


Figure 2

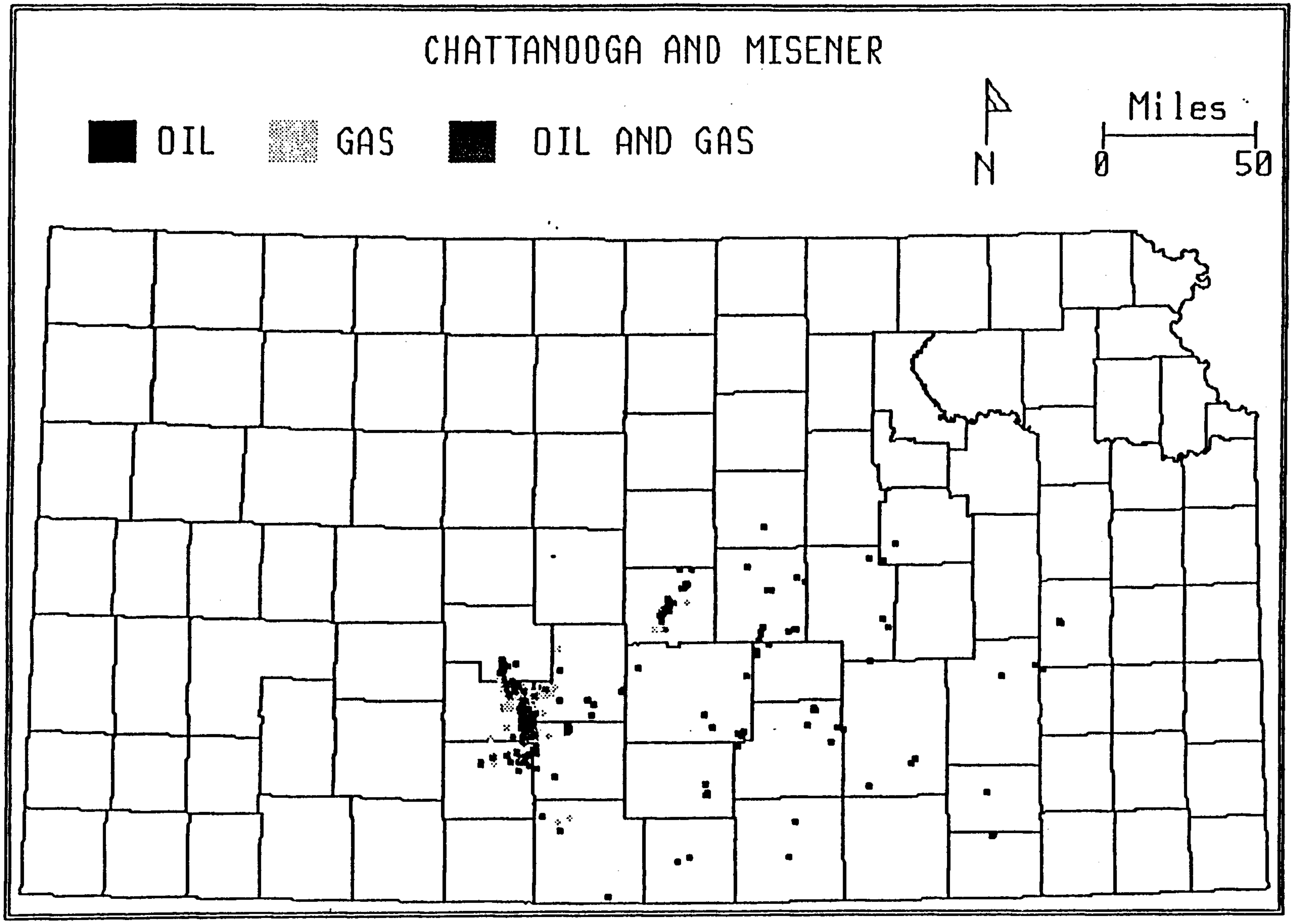
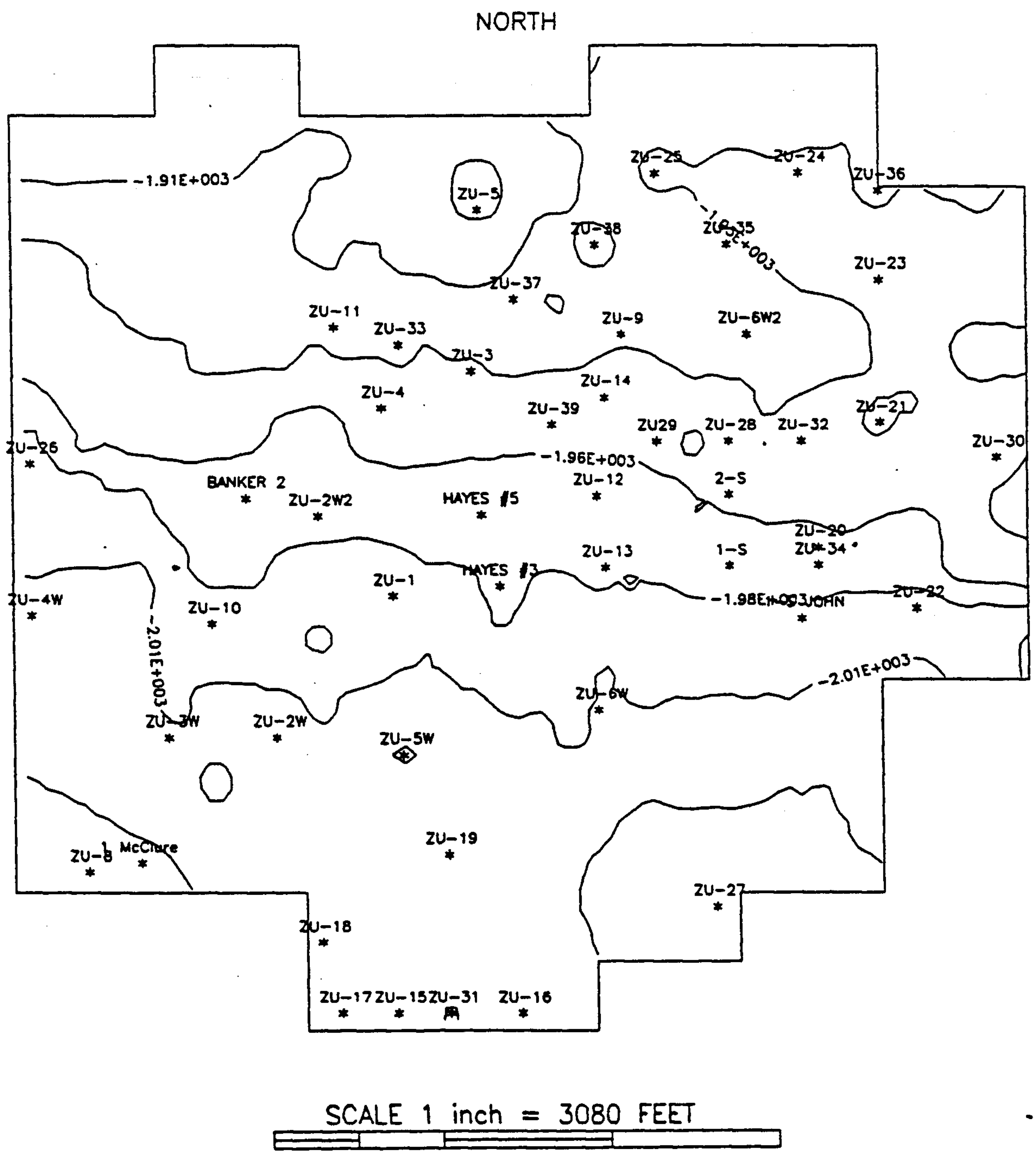
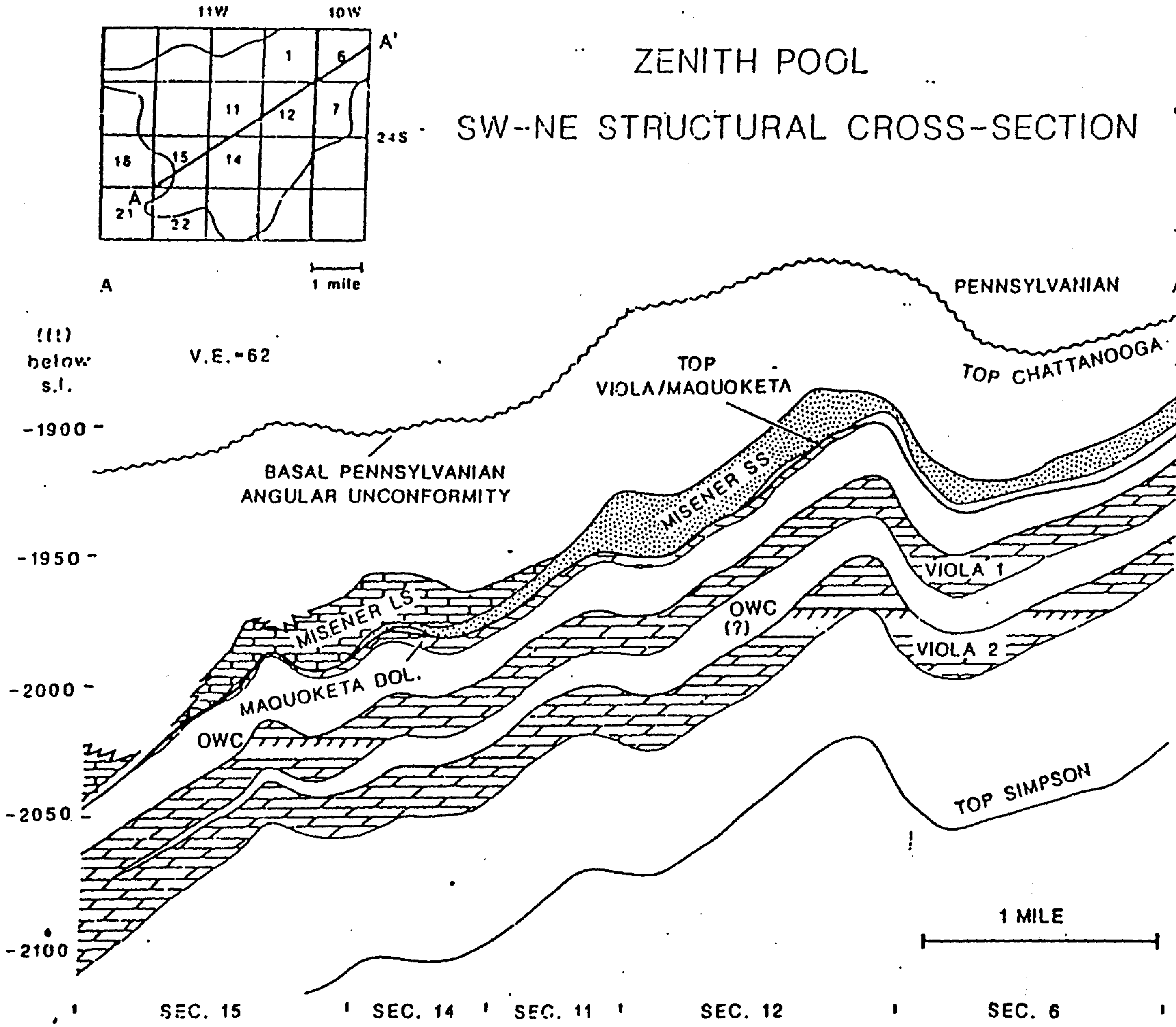


Figure 3

STRUCTURE MAP OF THE TOP OF THE VIOLA PAY 1

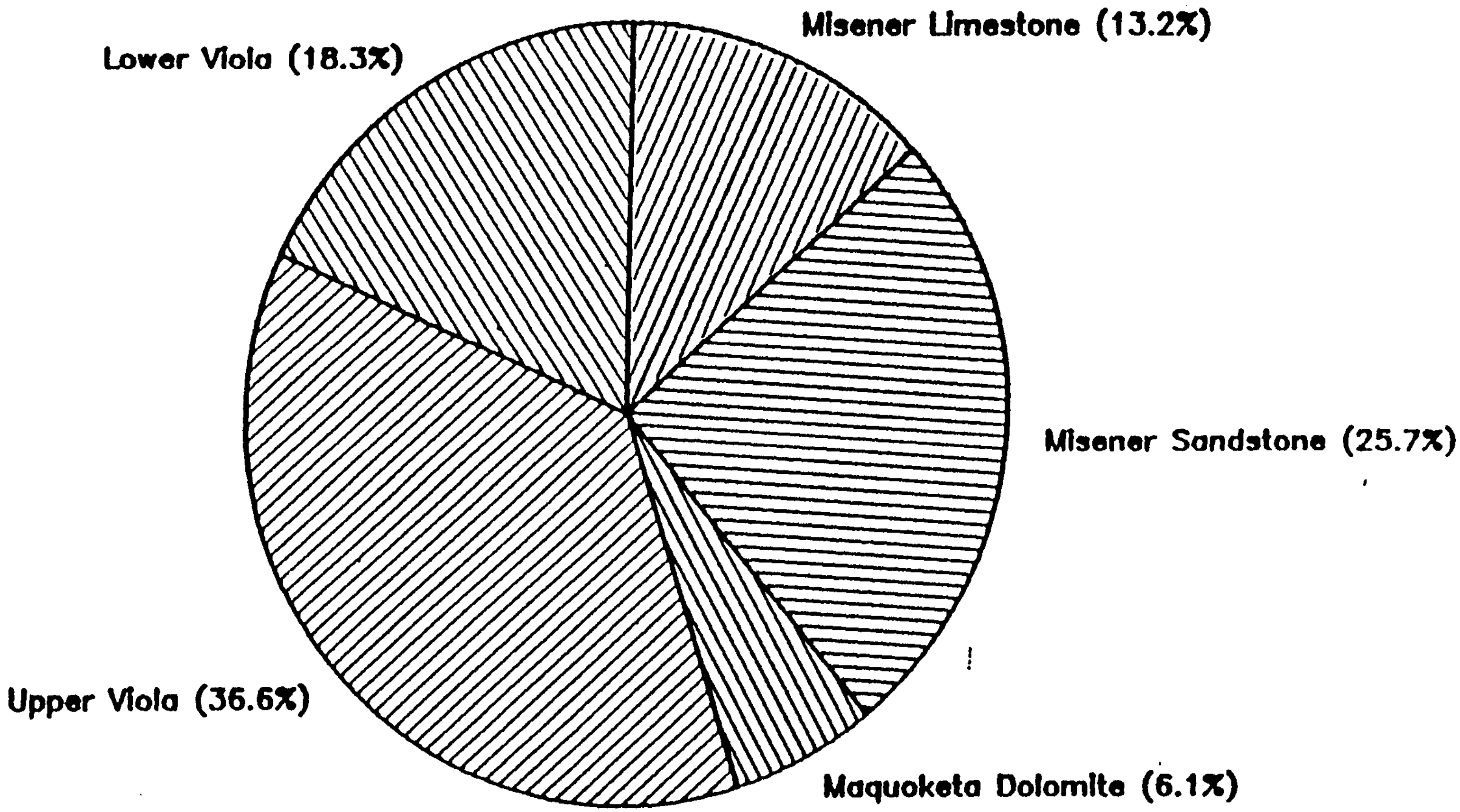


SCALE 1 inch = 3080 FEET


ZENITH POOL
SW-NE STRUCTURAL CROSS-SECTION
11W
10W
24S
A
A'
1 mile
PENNSYLVANIAN
(ft)
below
s.l.
V.E.=62
TOP
VIOLA/MAQUOKETA
TOP CHATTANOOGA
-1900
-1950
-2000
-2050
-2100
BASAL PENNSYLVANIAN
ANGULAR UNCONFORMITY
MISENER SS
MISENER LS
MAQUOKETA DOL.
OWC
OWC
(?)
VIOLA 1
VIOLA 2
TOP SIMPSON
1 MILE
SEC. 15
SEC. 14
SEC. 11
SEC. 12
SEC. 6

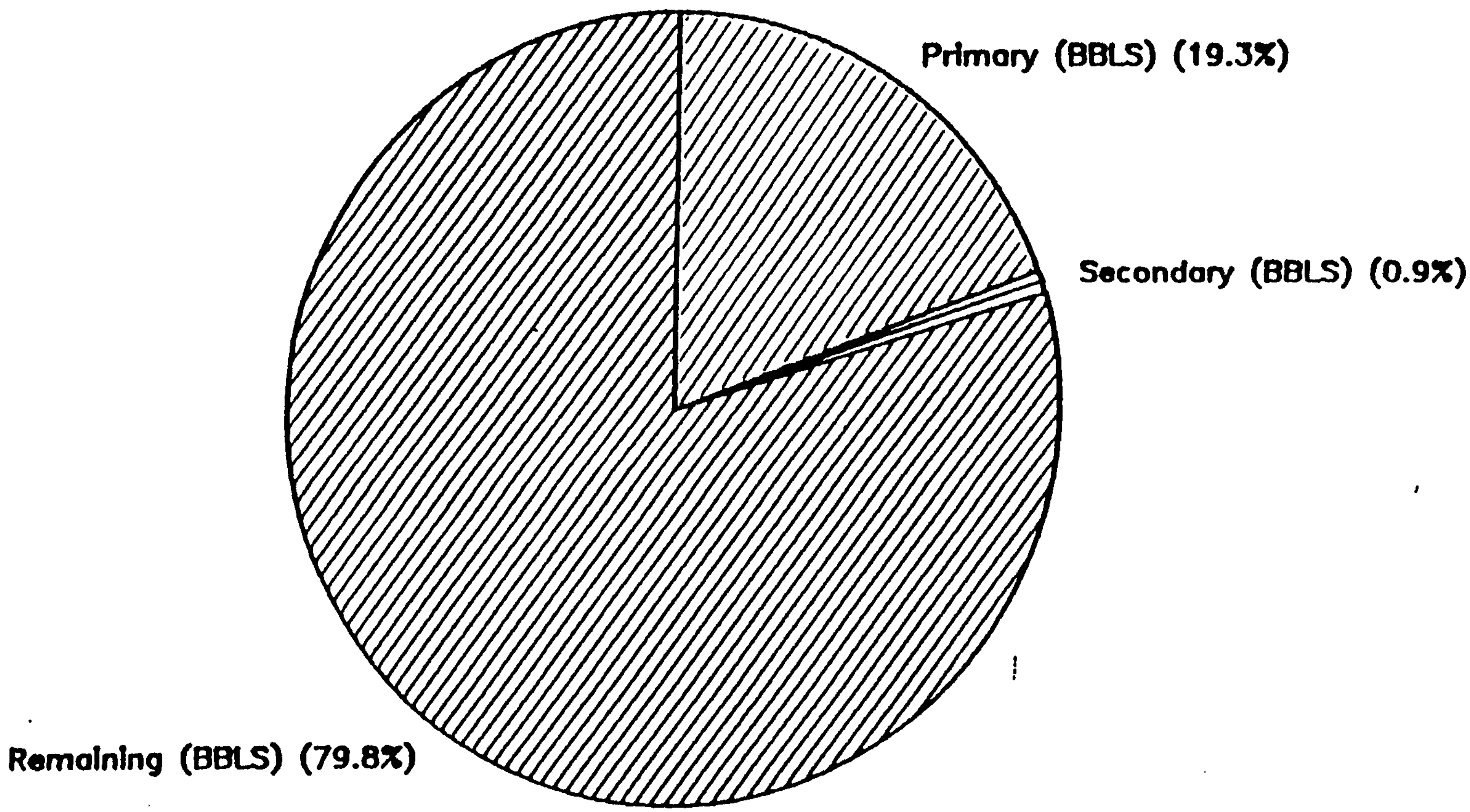
FORMATIONS IN THE ZENITH FIELD

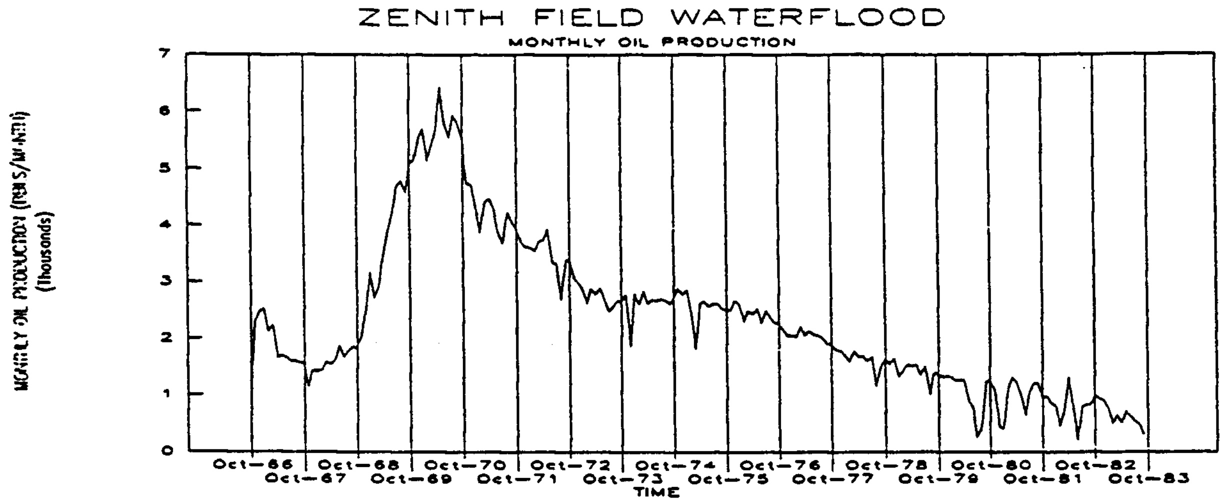
OOIP – 116,600,000 BBLS

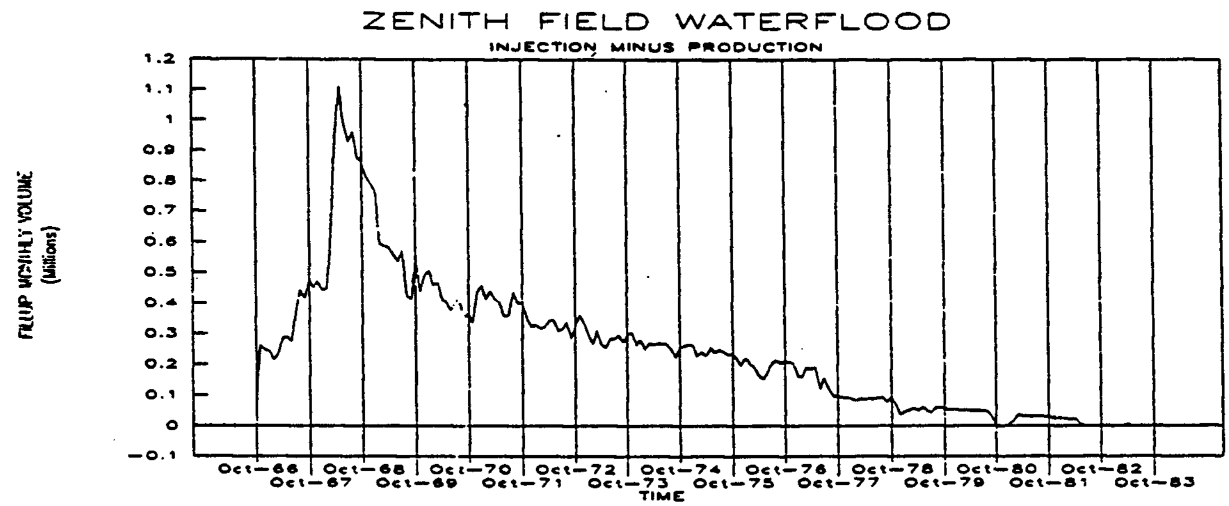


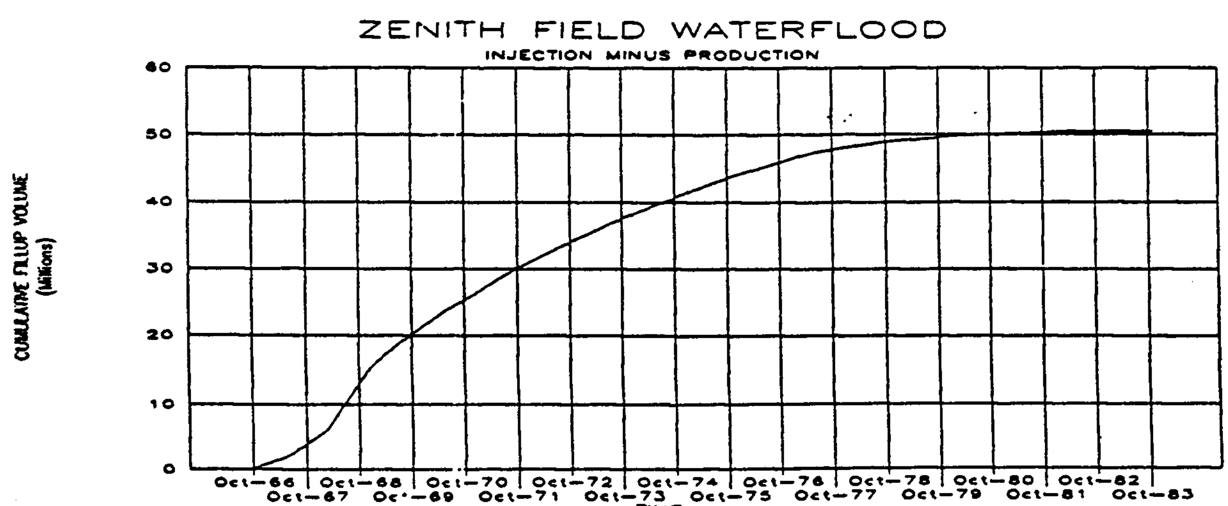
ZENITH FIELD OIL PRODUCTION

OOIP – 116,600,000 BBLS




ZENITH FIELD WATERFLOOD
MONTHLY OIL PRODUCTION
(Thousands)
TIME
Oct-66 Oct-67 Oct-68 Oct-69 Oct-70 Oct-71 Oct-72 Oct-73 Oct-74 Oct-75 Oct-76 Oct-77 Oct-78 Oct-79 Oct-80 Oct-81 Oct-82 Oct-83


ZENITH FIELD WATERFLOOD
INJECTION MINUS PRODUCTION
FILLUP MONTHLY VOLUME
(Millions)
TIME
Oct-66 Oct-67 Oct-68 Oct-69 Oct-70 Oct-71 Oct-72 Oct-73 Oct-74 Oct-75 Oct-76 Oct-77 Oct-78 Oct-79 Oct-80 Oct-81 Oct-82 Oct-83


ZENITH FIELD WATERFLOOD
INJECTION MINUS PRODUCTION
CUMULATIVE FILLUP VOLUME
(Millions)
TIME
Oct-66 Oct-67 Oct-68 Oct-69 Oct-70 Oct-71 Oct-72 Oct-73 Oct-74 Oct-75 Oct-76 Oct-77 Oct-78 Oct-79 Oct-80 Oct-81 Oct-82 Oct-83

"Zenith Field – A field demonstration project for improved efficiency for oil and gas recovery in Kansas"

Kansas Geological Survey and the Tertiary Oil Recovery Project University of Kansas Lawrence, Kansas in cooperation with Hallwood Petroleum

A. One year reservoir study of Zenith field funded by the Kansas Corporation Commission in December 1889 utilizing overcharge penalty funds available through the U.S. Department of Energy

B. Project designed to fund first year of a two-year study to characterize reservoir and recommend steps in remedial action to improve oil recovery (year one) and implement remedial actions, if deemed necessary (year two).

C. Focus -- Work toward recommending actions that will minimize water production and make what water that is injected go where it will accomplish most toward increasing oil recovery. Utilize methods developed by TORP, if feasible.

   1. Zenith has had poor waterflood performance with attendant operating problems.

   2. Preliminary studies indicate that a large potential exists for additional oil recovery and improved efficiency.

D. Rationale for project leading to funding and current activities

   1. Develop a demonstration project that would focus on a low volume field nearing abandonment

      a. results from Zenith field study, potentially applicable to 300 geologically similar fields in central Kansas that have produced over 750 million bbls.

      b. demonstration: paper at SPE meeting in Denver in June; preprint; news clips; visit with DOE in Washington; planned paper for Journal of Petroleum Technology; workshops including Midcontinent AAPG in Wichita in Sept. '91

2. Timely interdisciplinary application of new concepts and methodology in geology and engineering

   a. implementation of team: geologists, computer engineer, petroleum engineers (completion and reservoir), chemist, field personnel, company staff

   b. application of new concepts

      – refined geological model of reservoir heterogeneity and relationships to fluid flow using combined geological and engineering data

   c. introduction of new methodology: computer mapping techniques and analysis to facilitate interpretation and visualization of reservoir rock and performance (PC, mainframe, color, 3-D graphic workstation and analytical modeling software)

3. Evaluate petroleum recovery to date

   a. assessing problems with well completions (testing and analysis of mechanics);

      – establish well files of completion history

      – determine well bores that exhibit problems of communication of fluid behind casing during completion or other exhibited downhole problems

   b. defining paths of fluid movement and flow properties of reservoir rock using chemical tracers, pressure testing, and fluid travel surveys on injection wells;

      – determine injected water movement near well bore region to evaluate cement bonding to production casing and formation (cross formational flow in channels)

      – evaluate cross flow between wells, and presence of natural fractures

   c. introduction of workstation technology to modify parameters and re-analyze reservoir in real-time and for use in demonstration

d. computer simulation of fluid flow in reservoir to match previous production performance (history matching); use in modeling the effects of waterflood designs using the computer to optimize field operations

e. develop reservoir management program for field operations

4. Provide research on a timely basis that independents are not in position to conduct themselves (cooperative effort performed in a timely manner with a resourceful company)
   a. major strides in improving field operations by Hallwood

      -- company has been able to again operate this field at a profit

      -- most of the injection system has been rebuilt to better control and monitor injected water volumes to input wells

      -- Arbuckle disposal well was drilled and completed to handle excess produced water

      -- improved overall unit maintenance and cleanup resulting in improved economics

5. Reservoir management – in Zenith, namely improved waterflood performance

   a. possible remedial actions

      – workovers of existing wells to isolate intervals of injection and production

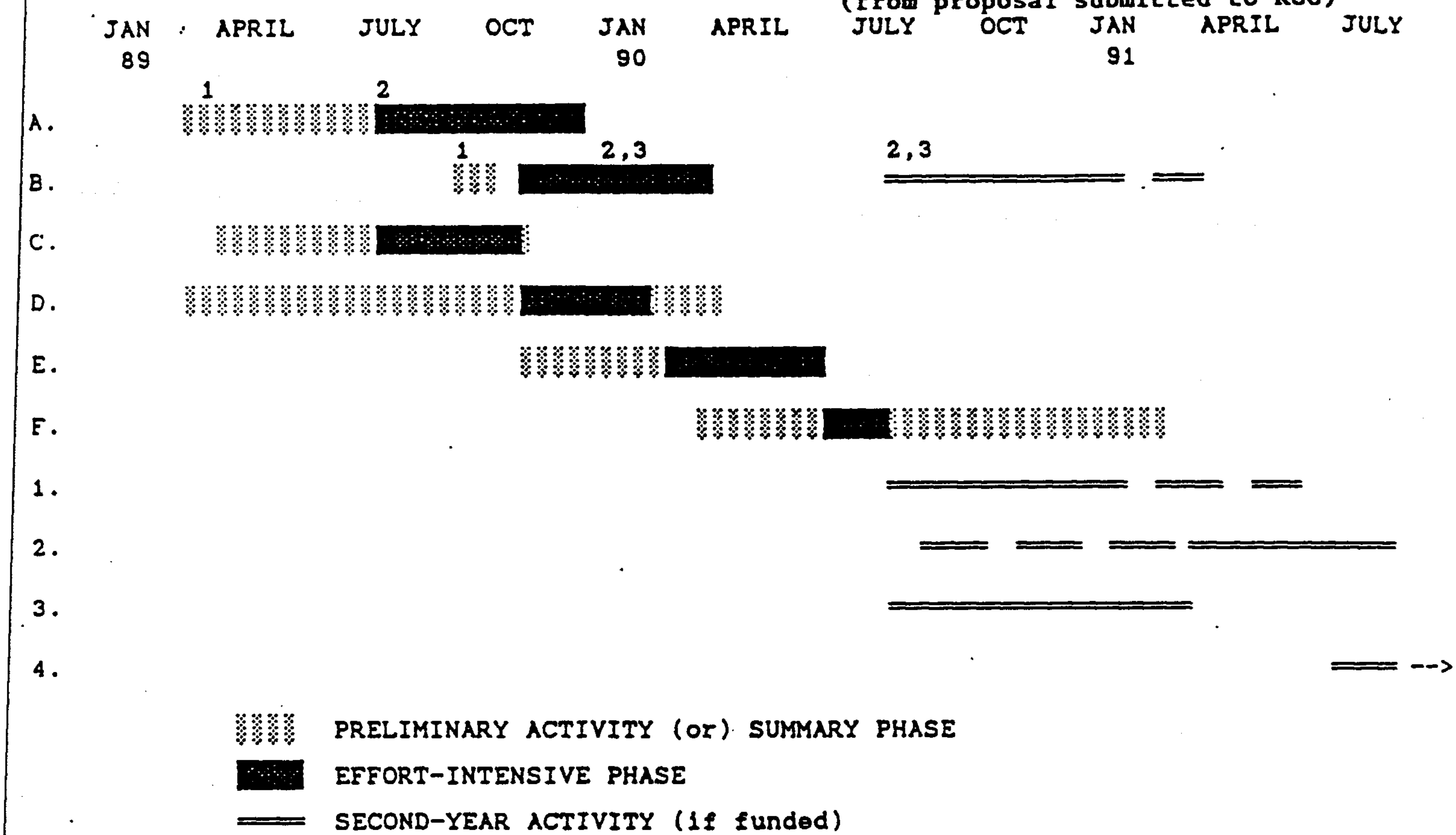
      – utilization of different cementing techniques on production casing to ensure good bond of pipe-cement-formation

      – use of gelled polymers to reduce water/oil ratios

DIVISION OF RESPONSIBILITY

- Operator
  - Collect Field Data
  - Equipment and Supplies
  - Lease Operations
  - Supervision of Well Drilling or workovers
- TORP/KGS
  - Analysis of Reservoir Data
  - Geologic Mapping
  - Reservoir Simulation
  - Advise on Field Testing

TIMETABLE OF ACTIVITIES AND METHODOLOGY
(from proposal submitted to KCC)



FIRST-YEAR ACTIVITIES

A. Characterization of interwell porosity system and identification of potential areas of bypassed oil: 1) thickness, subcrop, porosity maps; 2) cross sections.

B. Petrographic core analysis and correlation to wireline logs and maps; evaluation of porosity types (vugs and inter-crystalline porosity, fractures, heterogeneity due to texture and depositional variations): 1) thin sections of rock from cores; 2) stable isotopes (C/O) of carbonate cements; 3) fluid inclusions of carbonate cements.

C. Production and fluid history of wells in field and establishment of reservoir parameters; review of completion and plugging procedures.

D. Tracer studies and transient pressure testing.

E. Modeling (computer simulation of primary production and waterflood).

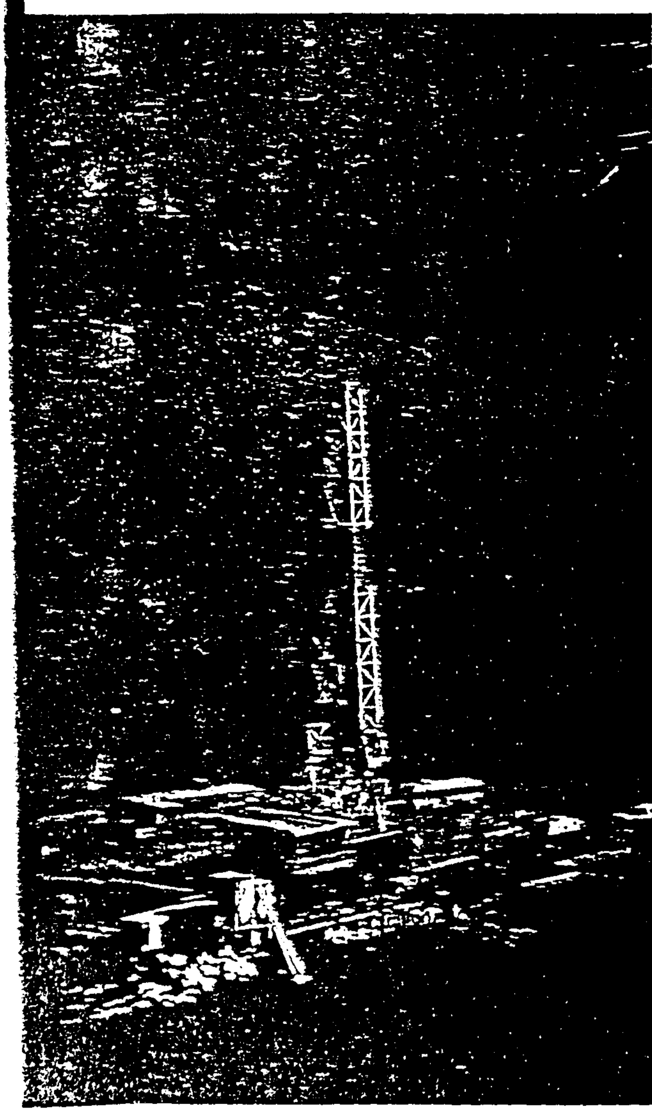
F. Evaluation of research results and recommendations for application of enhanced oil recovery techniques to field; communication of results to industry and public through publications or workshops.

SECOND-YEAR ACTIVITIES (if funded)

1. Application of enhanced oil recovery techniques (if recommended).
2. Monitoring of fluid production in field for evaluation of above.
3. Analogue verification using screening criteria to establish fields in which methodology is potentially applicable.
4. Final report; continued monitoring of results; dissemination of results in appropriate journals and publications.

THE AMERICAN OIL & GAS
REPORTER®
APRIL 1990
The business publication for the domestic exploration / drilling / production industry

1990 Spring Drilling Rig Directory
Plus Focus On Drill Bits
Special Report...65



David Willard
President PPROA

"The gas market has not gotten to the point yet that it has spawned much activity in the Panhandle, but I think it will over time."

Page 19

James C. "Chris" Hall
President CIPA

"They ought to be looking at what is happening to the California oil and gas industry, in light of what it might foretell about what could happen in the national arena."

Page 24

Greg W. Hartsough
President KOGA

"In the shallow areas, plugging bonds actually go down under Kentucky's new regulations."

Page 33

J. Paul Jennings
President KIOGA

"The two main issues facing us are compliance with increasingly costly environmental rules, and ever increasing ad valorem taxes."

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Field Provides Demonstration Project

By Lanny Schoeling,
Don W. Green
and Rodney R. Reynolds

LAWRENCE, KS.—The Zenith Field project, 25 miles west of Hutchinson in Stafford County, Ks., was brought to the attention of the Tertiary Oil Recovery Project in fall 1988 by Striker Oil Company, which was the operator at that time. On June 1, 1989, Quinoco Petroleum Inc. took over field operations of the Zenith unit. The Zenith field (near its economic limit under operating conditions in fall 1988) is large, with more than 100 million barrels of original oil in place.

The field was discovered in 1938, and most of the primary production occurred before 1946. Primary production was relatively good, with more than 23 million barrels produced. Primary drive mechanisms have been characterized as solution gas drive with some water drive in the southern portion of the field.

The field produces from five separate producing horizons: two Viola limestones, Maquoketa dolomite, Misener sandstone, and Misener limestone. A waterflood was initiated in 1966 and has performed poorly. High water/oil ratios have existed since early in the waterflood, causing operating problems and poor economics. The reason for the poor waterflood performance has not been thoroughly investigated. However, preliminary studies indicate that a large potential exists for additional oil recovery.

Because of the large remaining resource in the field, Striker Oil Company, TORP, and the Kansas Geological Survey formed a cooperative project involving engineers and geologists to study the field. A proposal was written, "A Field Demonstration Project for Improved Efficiency for Oil and Gas Recovery in Kansas," and was funded in December 1989 by the Kansas Corporation Commission, utilizing overcharge penalty funds available through the U.S. Department of Energy.

The objective of the project is to develop a method for assessing the oil recovery potential in mature reservoirs operated by independent oil operators, using collaborative engineering and geological techniques. The Zenith Project will serve as a demonstration project in the state of Kansas.

Specific objectives are to:

- Characterize the reservoir from a geologic and engineering standpoint;
- Conduct reservoir computer simulation runs in an attempt to match previous production performance;
- Design potential production scenarios by predicting oil production performance based on the reservoir model developed; and
- Develop a reservoir management program for field operations.

Well History

Like other mature fields throughout Kansas, the Zenith Field has produced oil for more than 50 years. Changes in technology and regulations have resulted in different types of completion, production and abandonment techniques being used within these fields over the years.

As was common practice during the late 1930s, typical completions were open hole. Early development in the Zenith Field occurred as single open hole completions in the Misener formation. Rotary rigs drilled to the top of the pay, production casing was set, and cable tools were used to drill into the pay.

By the early 1940s, Viola production had been discovered. Wells were deepened using cable tools, resulting in commingled open-hole completions.

Little or no stimulation was necessary during initial completions in either pay. Small acid jobs or natural completions resulted in initial well potentials as high as 26,000 barrels of oil a day.

Development occurred rapidly on 10-20 acre spacing, and some 300 oil wells were initially completed in the field. Peak production occurred during 1942 when more than 3 million barrels of oil were sold.

Depletion and abandonment also occurred rapidly, because of a rapid decline in reservoir pressure. By 1946, most wells were approaching marginal

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status, and by 1953 there were only 36 producing wells left in the field. Abandonment of uneconomical producing wells continued until 1966, when the Zenith Unit was created to initiate waterflood operations.

The plug and abandonment techniques used on the majority of the primary producers in the field consisted of filling the open-hole section with sand or gravel topped with a cement plug. A portion of the production casing was then recovered, and cement plugs were set in the surface pipe and at the surface.

This plugging method is of primary concern as it relates to enhanced oil recovery. The old well bores may tend to provide crossflow and/or communication between reservoirs, which would affect the movement of injected and produced fluids.

Most of the wells drilled in this field after the creation of the Zenith Unit in 1966 used conventional drilling and completion practices: rotary drilling to total depth and production casing set through and perforated adjacent to pay intervals.

Demonstration Project

TORP and KGS began the Zenith Field study in spring 1989 by conducting an extensive data search in the offices of Striker Oil Company, KGS, and the KCC; preparing a computer data base, and mapping and characterizing each reservoir.

The data search, which became more complicated than anticipated, has, however, been conducted with some degree of success. Not all the data gathered throughout the life of the field are available because of two reasons: The data were not passed on to the new operator following an acquisition; and companies misplaced data after they sold the property.

Initially, cores were taken in more than 50 wells by a major oil company. The project has not been able to locate any of these original core analyses. However, several core analyses from more recent wells are available. It is hoped that additional data will be available in the KCC files. The KCC held a series of hearings in 1941 dealing with gas/oil ratio problems and correlative rights, and the KCC is attempting to locate all of the data exhibits from those hearings.

Each of the five reservoir horizons has been mapped utilizing Surface III, a commercially-available software package for a mainframe computer, with output directed to an electrostatic color plotter. An additional analysis using a less expensive personal computer-based contour-mapping software package has provided complementary mapping capabilities, and has served as an independent check for each mapping step.

Since the PC is still the most accessible computer available to small independent oil operators, it was felt that the study should be tested on the personal computer as part of the demonstration. Isopach maps of two of the horizons in the Zenith Unit from this PC-based contour-mapping software package are provided in Figures 1-2.

In the mapping process, a Lotus 1-2-3 spreadsheet was first developed to tabulate well locations, completion dates, well datums, tops, bases, and porosities of each of the horizons. The locations were identified by section-township-range, which were changed to longitude and latitude coordinates.

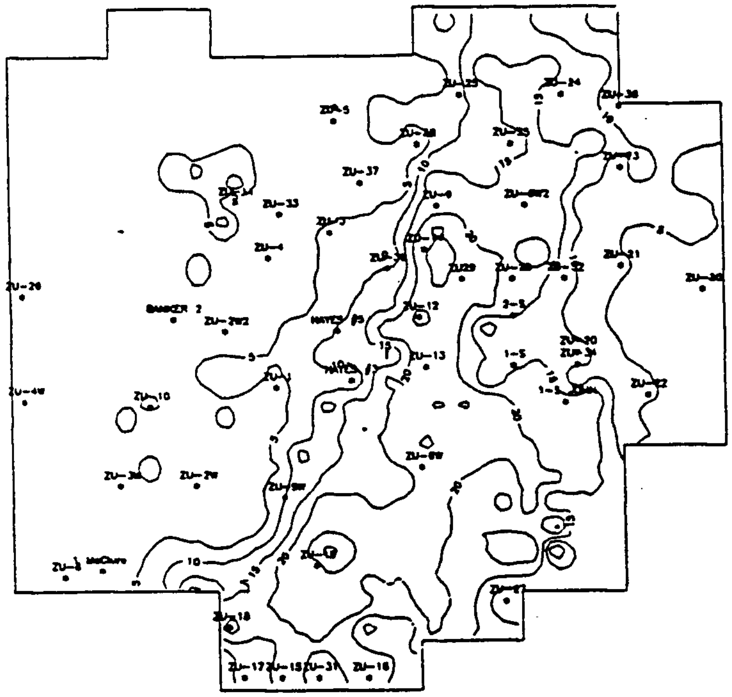
The next task was to map elevations of each structure, from which isopach maps could be developed. This involved gridding the elevations on the top and base of each structure, and computing the difference to develop a gross isopach. Once the gross isopach map was constructed, the water/oil contact was included by subtracting the water interval. The water/oil contact had the largest effect in the Viola formations of lower structure.

Porosities were calculated utilizing neutron and density well logs. A spreadsheet was developed to calculate densities, utilizing the neutron-density crossplot method when the well logs were available. Shale content was accounted for in all calculations.

Observation of the few core analyses available revealed that not all of the

FIGURE 1

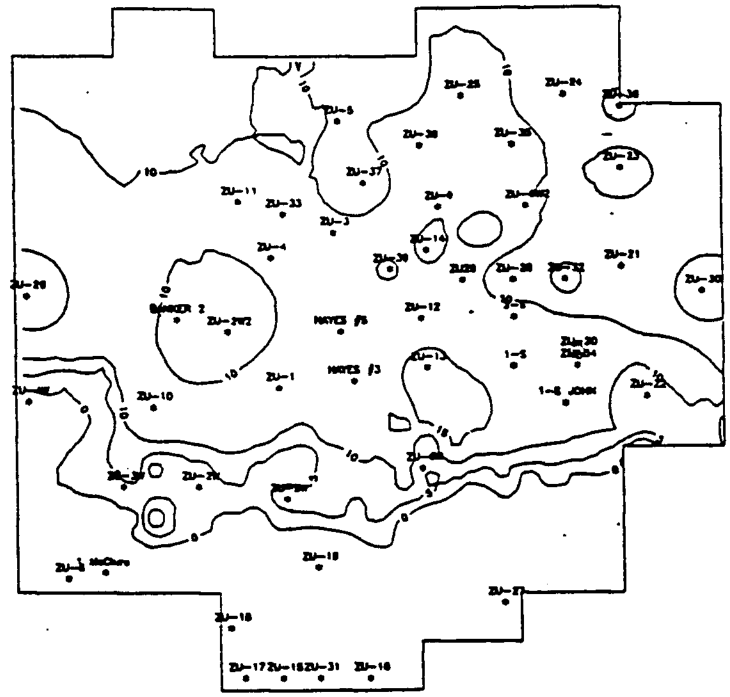
MISENER SANDSTONE NET ISOPACH MAP



ABOVE WATER-OIL CONTACT 5% POROSITY

FIGURE 2

VIOLA PAY 1 ISOPACH MAP



8% POROSITY CUTOFF & INCLUDING W-O CONTACT

porous media had adequate permeability to be considered as a part of the reservoir. It was necessary to re-calculate volumes using a range of porosity cut-offs throughout the field. The range of porosity cut-offs was determined from a semi-log porosity-permeability plot from the limited core data available for each formation.

The total pore volume of each formation was determined by integrating porosity-foot grid maps on each of the formations. The porosity-foot grid maps were developed by multiplying porosity grids by corresponding isoeach grids. Details on this graphical mapping procedure will be published in the proceedings of the Fifth Society of Petroleum Engineers (SPE) Petroleum Computer Conference, to be held June 25-28.

Computer Simulation

Computer simulations are necessary to predict an optimum design scenario for a given reservoir. The first task is to characterize the geometry and properties of a given reservoir, and place those parameters in a data base that a reservoir simulator can communicate with. The second task involves running the computer simulation on the primary drive stages to determine if predicted oil recoveries match actual field recoveries. This step is called history matching. Various properties are changed in the reservoir data base to match predicted and actual recoveries.

Once the history is matched in the reservoir, various design scenarios can be tested in the computer simulator to determine the optimum process. These design scenarios might include addition of injection or production wells in optimum locations, horizontal drilling, or a tertiary oil recovery process.

It was decided to utilize PC Boast II, a reservoir simulator developed by the Department of Energy which is publicly available to independent oil operators. Small-to-medium size reservoirs can be simulated utilizing a personal computer. It simulates flow of oil, water and gas in three space dimensions. It assumes that the reservoir fluids can be described by three fluid phases (oil, gas and water) of constant composition with physical properties that depend on pressure only.

These reservoir fluid approximations are acceptable for a large percentage of the world's oil and gas reservoirs. Consequently, PC BOAST II should have a wide range of applicability.

Since the Zenith Field is large and has five distinct reservoirs, a large simulation grid is needed, which requires the use of a mainframe computer. The plan is to initially determine computer needs by only simulating the Misener Limestone in the western portion of the field. This can be done since the western portion of the Zenith Field produced only from the Misener limestone formation for the first two years on production.

Once this is accomplished, the plan is to add the remaining reservoirs to the computer data base, and to simulate recoveries on the entire field by matching primary and secondary production.

Current Field Operations

After Quinoco Petroleum took over field operations of the Zenith Unit, several visits to the field were made by TORP personnel. These visits were cooperative efforts between our personnel and the new operators. The major objectives were to determine the condition of the surface equipment, to plan field tests, and to consider areas needed to improve reservoir and operational management.

The new operator has made major strides in improving field operations. Most of the injection system has been re-built, and an Arbuckle disposal well has been completed and put into operation. The improved injection system allows the control and monitoring of injected water volumes to input wells. The disposal well handles excess produced water, and eliminates down time of producing wells if problems occur within the injection system. The improvement of overall unit maintenance and clean-up has also occurred. These accomplishments have resulted in improved unit economics.

In addition to the computer work being performed, field work has begun to assist in acquiring data which will aid in defining the problems causing the poor waterflood performance.

Inter-well tracer surveys are being run to help define fluid-flow patterns within the reservoirs. The method used has been to mix ammonium nitrate with injected water over a 24-hour period. Samples were taken from surrounding producing wells to check for tracer material. Plans are being made to perform additional tests. This type of testing may also assist in defining communication between reservoirs by way of cross flow in old abandoned well bores, and locating natural fractures. Data from these tests will be available at a later date.

Fluid travel surveys are being run on major injection wells to determine injected water movement in the near-well bore region. Poor primary cement jobs on most new wells drilled in the field are a problem. Surveys run to date indicated that high percentages of injected water are going into the lower Viola interval and behind pipe channeling. Similar situations are expected to be present in producing wells. Additional tests of this type are also being proposed.

In addition to these field operations,

efforts have begun to study individual well files. The study of individual well data is being done to determine well bores that exhibited communication problems during initial completion, or exhibited other down-hole production problems. This information is vital to field personnel conducting and monitoring the described tests. It is also providing information necessary for improved drilling and completion procedures for future wells.

Workovers of existing well bores appear necessary to isolate intervals of injection and production. Different cementing techniques on production casing will have to be used in the future to ensure primary cement bonding sufficient to achieve isolation of the pay intervals. Cross flow by way of old well bores may be a problem, even if isolation of existing and future well bores can be accomplished.

The analyses of the data, geological mapping, computer simulation, and cooperative work with the operator will be the basis for development of a plan for improving reservoir management. In particular, we want to improve waterflooding performance. This may involve the use of enhanced oil recovery technology, such as gelled polymers to reduce water/oil ratios.

It is hoped that the general approach used here, which involves cooperation between TORP, KGS and industry, will be applicable to other Kansas fields. □

DOE Shifts R&D To Prevent Abandonment Of Existing Fields

WASHINGTON (The Energy Wire)— The Energy Department, sounding an alarm to rescue abandoned oil fields, has announced a major change in its oil and gas research program to focus on improving oil and gas recovery techniques within one-to-five years.

DOE's previous longer-term research effort—studying methods to improve recovery within 10-20 years—also will continue, although federal officials have concluded that the United States no longer has the luxury of looking farther in the future to staunch the rapid decline in U.S production.

A report on DOE's new research program points out that oil companies have discovered 500 billion barrels of reserves in the United States since the last century. Of that total, 145 billion barrels had been produced by 1987, while 27 billion barrels of proved reserves—about a 9-year supply—are capable of production with existing technology and oil prices.

Left in the ground is an additional 340 billion barrels of supply, almost two-thirds of the total discovered U.S. reserves. "Of this massive 340 billion barrel resource, as much as 76 billion barrels could be made economically producible using technologies that could be developed within the next decade," the DOE report says.

Economic recovery of the 76 billion barrels will require the use of existing wells, "but the accelerating rate of well plugging could eliminate economic access to as much as two-thirds of the remaining oil by 1995," the report says.

Of the states with currently unrecoverable reserves, Texas holds the lion's share that could be moved into the producible category with technological advancements, according to the report. Out of 100 billion barrels of so-called

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Volumetric Evaluation of a Mature Oil Field Utilizing PC and Mainframe Computer Graphics Techniques

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ABSTRACT

Mapping and volumetric analysis of large reservoirs is an important step in evaluating mature oil fields for secondary and tertiary development. This paper describes how a research group has mapped and conducted an extensive volumetric analysis on the Zenith pool, a large mature oil field in central Kansas, utilizing 1) a Data General MV20000 minicomputer with *Surface III* mapping software and 2) a personal computer with *Surfer* and spreadsheet software.

A step-by-step procedure was developed to generate structure, isopachs, and porosity maps for the five main reservoirs in the field. Lotus 123 spreadsheets were developed to compile locations, formation tops, and other critical data for over 500 wells. This data was sent to the minicomputer to generate contour maps depicting structure, isopachs, and porosities with output directed to a electrostatic color plotter. Grid-to-grid manipulation and cross-multiplication of these contour maps allowed construction of porosity-foot maps for each reservoir. The final contour maps incorporated the effects of oil/water contact with a porosity cut-off determined from porosity-permeability crossplots. Integration of the porosity-foot maps then facilitated volumetric and spatial comparison to historic production data.

PC-derived crossplots were utilized in determining distribution and ranges of data that were in turn depicted as color-coded ranges on maps. Attributes mapped using this technique include oil production and oil recovery per quarter-section, initial production potential and completion dates for each well.

The main advantage of the mainframe computer was computational speed and high-quality graphics. However, complementary analysis using PC-based contour-mapping software provided similar results and served as an independent check for each mapping step.

INTRODUCTION

Enhanced oil recovery (EOR) is increasingly important in mature petroleum provinces where older fields provide the bulk of production. EOR procedures, however, are expensive and must be justified by either incremental oil production or decreased lifting costs.

In order to prudently apply EOR techniques it is important to understand the geologic characteristics of the oil field, properly design the EOR process with the geology in mind, and determine the economics of that process. One of the first assessments necessary for an oil field is a volumetric calculation of original oil in place (OOIP). Comparison of the volumetric estimates with historic production data yield valuable baseline information on location and the potential of a particular process.

A volumetric assessment is a task suited to computers in that it is a numerically intensive operation in which detailed results can be obtained in a relatively short time. A study of this type using a combination of mainframe and personal computers (PC) was focused on the Zenith pool in central Kansas. Goals of this study were to: a) evaluate the efficiency of primary and secondary recovery in the field with respect to OOIP, b) target areas within the field that may have significant remaining reserves, and c) provide individual reservoir geometries and rock properties in any grid dimension for use in reservoir simulation studies.

SUBJECT FIELD FOR THE STUDY

Geology

The Zenith pool is located at the southwestern end of the Zenith-Peace Creek field in central Kansas (Figure 1). It is a stratigraphic trap developed on a broad south-southwestward plunging anticlinal fold off the Central Kansas Uplift. At this locality lower Paleozoic sandstone and carbonate reservoirs pinch out northward unconformably beneath impermeable shales and conglomerates at the base of the Pennsylvanian System.[1,2] To the east, these reservoirs terminate against the downthrown side of a normal fault along the north-northeast/south-southwest Peace Creek fault system.[3] Westward limits of the oil accumulation is either by stratigraphic pinchout or decrease in porosity of the reservoir units.

Five major pay zones are present in the field (Figure 2). Two zones of cherty porous dolomite in the Middle Ordovician Viola Limestone (upper and lower Viola reservoirs) are the most laterally extensive reservoirs in the pool.[4] A minor pay zone, the

Upper Ordovician Maquoketa dolomite, locally overlies the Viola limestone. The Devonian-Mississippian Misener sandstone and a suprajacent carbonate reservoir, the Misener limestone, overlie the Ordovician carbonate reservoirs and are in direct contact with the Maquoketa dolomite in some places. Although the upper Viola reservoir is apparently sealed by impermeable limestone beds at the top of the Viola, it has an oil/water contact (OWC) common to the Maquoketa and Misener reservoirs (-2019 feet subsea), thereby indicating it is in hydraulic continuity with them in parts of the pool.

The lower Viola reservoir in the pool has probably not produced much oil in the Zenith pool because it has relatively low porosity and in parts of the field its OWC is about 50 feet higher than the other reservoirs. Spatial comparison of potentially productive areas of the lower Viola reservoir with that of the upper Viola reservoir indicates that the lower Viola reservoir may contain from one-fourth to one-half the OOIP of the upper Viola reservoir. However, it is not included in our volumetric calculations because of lack of adequate well and production data.

Development History

The Zenith pool was discovered in 1937 and has produced over 23.1 million barrels of 41° API-gravity oil. Primary drive mechanisms have been characterized as solution-gas-drive with some water-drive in the southern portion of the field. Initial development was on 10- to 20-acre spacings and approximately 350 wells have had some production history. A peak daily production of 10,000 barrels per day was achieved in the Zenith pool in 1942. This was also the year of the highest annual production, which was over 3 million barrels.

In 1966, the majority of the Zenith pool was unitized to form the Zenith Unit. The current Zenith Unit comprises the area shown on our field maps but excludes sections 4, 9, 16, 21, 22, parts of section 23, and 24 in T.24S.-R.11W., and parts of sections 6, 7, and 18 in T.24S-R.10W. The waterflood initiated in 1966 has never fulfilled expectations and a geologic and volumetric re-evaluation of the field should now be instigated. Approximately 20 wells are currently producing in the Zenith pool and daily production is about 150 barrels. Seventy-three wells have been drilled since 1966 and many have modern logging suites that aid in recorrelating, mapping, and volumetrically reevaluating the field for possible initiation of new EOR procedures.

PROCEDURE FOR VOLUMETRIC ANALYSIS

Although sophisticated three-dimensional field models can be constructed in Unix-based workstation environments with powerful graphics processing, it was decided that preliminary studies could be done conveniently and quickly utilizing PCs and mainframe computers. This hardware, particularly the PC, is still the type of computer most available to small independent oil operators. Both types of machines also have relatively inexpensive commercial contour-mapping software packages that can be utilized for two-dimensional (planimetric) volumetric determinations.

In our volumetric evaluation, we used *Surface III* by Interactive Concepts, Inc., a surface-contouring software package operating on a Data General MV20000 minicomputer.[5] As a check to mainframe procedures, volumetric analysis was also carried out using an IBM-compatible PC and *Surfer*, a contouring-software package by Golden Software, Inc. Both software packages offer surface contouring, gridding capabilities, and several different types of search algorithms. Inasmuch as wells are nearly uniformly distributed in our study area, a nearest-neighbor search method was used with at least eight neighboring points to be found and scaled with a $1/D^2$ weighting function.[4] The mainframe software automatically sets the maximum allowed distance for its search radius. In the PC version, these parameters were approximated to emulate the mainframe package. Results from the PC and mainframe were similar (Table 1), indicating the procedures developed can be used by independent oil operators in the convenient and relatively inexpensive PC environment.

Procedures for the volumetric evaluation were divided into four stages (Figure 3): 1) establish master and plotting databases; 2) generate mapping grids; 3) generate porosity-foot mapping grids; and 4) conduct volumetric calculations and volumetric mapping.

Stage #1: Establish Master and Plotting Databases

A spreadsheet program was utilized to construct a database for subsequent computer mapping. This spreadsheet contained approximately 28,500 entries based on geophysical logs, lithologic logs, and scout cards from 500 wells. Data entered for each well included operator and well name, spot location, latitude-longitude, surface datum, key formation tops and bases, average porosity and net pay information for major reservoirs, well status, completion and plugging dates, total depth, casing points, perforated or open-hole intervals, producing zones tested, and initial production potentials.

Net-to-gross pay ratios and average porosities for each reservoir at given well localities were calculated using numerous smaller spreadsheets. These smaller spreadsheets were utilized for well-log analysis where gamma ray, neutron porosity, and density-porosity measurements were visually read from geophysical logs at two-foot thickness intervals and entered in the spreadsheet. Neutron-density crossplot porosities with shaliness corrections were computed using porosity and shale-volume equations.[7] A total of 166 separate average porosity determinations were made for the five reservoirs in the field. The smaller spreadsheets were also utilized to compute net-to-gross pay ratios and average porosities of net pay intervals taking into account porosity cutoffs. These data were then entered into the master spreadsheet.

The latitude-longitude coordinates of each well in the master database were used as a source for X-Y mapping coordinates for both the PC and mainframe computer. For mainframe operations, X-Y coordinates were translated to Modified Polyconic Projection. In the PC case, the latitude-longitude coordinates were converted to X-Y feet in the spreadsheet and directly exported to the PC mapping program. Data for mainframe analysis were sent to and from the PC by communication software with ASCII and binary file transfer capabilities such as *Kermit* (in public domain) or *Smarterm 400* (from Persoft, Inc).

Stage #2: Generate Mapping Grids

Several separate and essentially independent mapping grids were generated in this step. These include structure, isopach, porosity, and net-to-gross pay ratio (NPG) grids. Maps derived from some of these grids for the Misener sandstone are presented in Figures 4 - 6. It is essential at this step that errors be detected and corrected in the mapping grids and the database. Errors were detected by visual inspection of preliminary contour maps and by error-analysis routines within the software that compare calculated grid values to original well data.

Isopachs of each reservoir and interlayered nonreservoir strata are some of the first steps necessary in this stage (Figure 4). Although this task is relatively simple, three reservoirs considered (i.e., Misener sandstone, Misener limestone, and Maquoketa dolomite) were not universally present over the study area and procedures to define the location of their stratigraphic pinchouts were necessary (i.e., 0-line).

Several methods are available for defining 0-lines.[8] In our case, well density and spacing were sufficiently close to obtain a program-defined pinchout with the mainframe computer. In this procedure, a mapping grid was constructed and a data value of 1 was assigned to each well where the reservoir is known or inferred to be present, and a value of 0 was assigned to all wells where it was known or inferred to be absent. These data were then gridded and contoured by the mapping program. The 0.5 contour, which tends to locate the 0-line about halfway between points where the unit is present and where it is absent, was selected as a reasonable 0-line. Although this 0-line can be digitized, it can also be expressed by the contouring grid by assigning a value of 1 to any grid node that was greater than or equal to 0.5, and 0 to any node that was less than 0.5. The resultant grid expresses the presence or absence of the unit by 1's and 0's. This grid was then multiplied by the isopach grid, thereby imparting the program-defined 0-line to the isopach. The procedures for defining a new 0-line can noticeably change the mapped pinchout of a unit but it has an insignificant effect on volumes calculated for a reservoir (usually less than 1% decrease). This procedure was not utilized in the PC case.

The porosity grid expressed a contour of the average porosity of a given reservoir (Figure 5). The NGP ratio (Figure 6) varies between 0 and 1, and expressed the fractional thickness of a reservoir interval that has porosity greater than the cutoff porosity (the minimum porosity at which the reservoir is no longer a viable pay zone). Cutoff porosities for each reservoir mapped were determined by semilogarithmic permeability versus porosity crossplots that were conveniently constructed by the graphing and regression-line fitting options on the PC spreadsheet program. Considerable scatter in the sparse core data available indicated that both optimistic and pessimistic cutoff porosities should be considered for volumetric calculations for each reservoir.

Stage #3: Generate Porosity-Foot Mapping Grids

This stage takes the mapping grids developed in Stage 2 and performs several grid-to-grid mathematical operations to produce a grid that expresses the porosity-feet of a reservoir above its OWC. This latter grid was the basis for all volumetric calculations.

The first step was to produce a grid of the structure of the base of a reservoir. In our study, the geologic surface having the most formation picks by which the most detailed geologic structure could be determined was the top of the Viola/Maquoketa. Structure grids for the bases of all the reservoir units were determined by adding or subtracting isopachs of intervening units from this key structural horizon.

The grid of the structure of the base of the reservoir was then subtracted from the subsea depth of the OWC (-2019'). The resultant grid gives the footage that the base of the reservoir was above or below the OWC. If the base is shallower than the OWC, the difference is a negative value and a positive value if the base is below the OWC. At this point, all grid nodes that were negative were assigned a value of 0.

The next step was to subtract this grid from the thickness grid of the reservoir. Negative values at grid nodes from the preceding operation indicated that the top of the reservoir was below the OWC, hence no footage of the reservoir at that locality was considered oil-bearing, and all negative values were again assigned an 0. The resultant grid expressed the oil-saturated thickness of the reservoir (i.e., the isopach of the reservoir that was above the OWC). This grid was then multiplied times the porosity and NGP ratio grids to obtain a grid that expressed the net porosity-feet of a reservoir above its OWC.

The porosity-foot map for the Misener sandstone (Figure 7) was an expression of the grid-to-grid operations presented in Stage 3. The recess apparent in SW Section 2 and NW Section 11 (as compared to the original isopach in Figure 4), represented the locus of grid nodes that were below the 5% cutoff porosity assumed for this reservoir (Figure 5). The 0 porosity-foot contour in the southeast part of the map area (e.g., Section 24) represented the effect of the OWC in the downdip areas of the field. The NGP ratio had minimal effect on the porosity-foot map except at one small area in the SE of Section 10 and the SW of Section 11.

Stage #4: Volumetric Calculations and Volumetric Mapping

Volumetric data in terms of barrels of pore volume (above the OWC) were obtained by numerical integration of the final porosity-foot grid obtained in Stage 3. For mainframe and PC operations, each section of the field (nominally a 1 X 1 mile) was divided into 400 smaller areas over which this integration was performed. These individual volumes were then summed for each reservoir for every quarter-section of the pool. Expressing the pore volume of each reservoir per quarter-section facilitated easy comparison to historical production data that was also tabulated by quarter-sections.

The volumetric integration for each reservoir in the mainframe computer was done using options in the contouring software package. The results were then downloaded to the PC to be incorporated and summarized as a spreadsheet. Calculation of OOIP from the quarter-section pore volume data sent back from the mainframe was done by multiplying the pore volume by the assumed hydrocarbon saturation for each reservoir (65% for Misener reservoirs; 70% for others) and then dividing by a formation volume factor (1.197) to convert reservoir barrels into stock-tank barrels. Simple spreadsheet manipulations were convenient for calculating production-per-acre and recovery factors for each quarter-section in the field.

Maps expressing the production-per-acre, recovery percentage, and remaining oil per acre for each quarter-section were generated with the mainframe contouring software using a supporting program which posts symbols having different colors and sizes. Inasmuch as each quarter-section is almost equidimensional, a color-coded square can express various size classifications of data for that quarter-section. Figure 8 is a map of this type that illustrates recovery percentages (i.e., the ratio of oil produced versus OOIP) for each quarter-section. Similarly, circles of various sizes were used to express attributes intrinsic to wells such as completion date and initial production potential.

COMPARISON OF MAINFRAME AND PC FOR VOLUMETRIC EVALUATION

A complementary analysis utilizing the PC was conducted on all reservoirs except the lower Viola. Results were compared to the results from the mainframe for the Zenith Unit in Table 1. Minor differences in OOIP calculated for each reservoir were attributed to: 1) variations in the areas searched, and 2) the methods utilized to calculate grid nodes. Notwithstanding these differences, the PC performed its tasks satisfactorily but did not have as much detail as the mainframe.

The major advantages of the mainframe version were superior graphics, increased speed, and a larger available memory. The speed and memory particularly aided in calculation of volumes for every quarter-section of the field. The software also could easily be utilized for various mapping methods. Mainframe operations are most applicable for large reservoirs like the Zenith Pool where large grid sizes are needed.

The major advantages of the PC were cost, convenience, and accessibility. The PC version is most applicable to small reservoirs utilizing small grid sizes.

DISCUSSION OF RESULTS

Volumetric calculations utilizing computers yielded detailed results for calculated OOIP for four of the five major reservoirs in the Zenith pool. Although uncertainty exists regarding the porosity cutoff for each reservoir, computer analysis allows for relatively quick turnaround in calculations for both optimistic and pessimistic scenarios. Table 1 summarizes the calculated barrels of OOIP for all the reservoirs except the lower Viola. If OOIP estimates for the lower Viola are included (estimated to be one-fourth to one-half that of the upper Viola), the recovery for the field may be on the order of 20 to 30%.

Some quarter-sections have extraordinary recovery factors in excess of 60% of OOIP (Figure 8). Many of these quarter-sections are in downdip positions in the pool well below the OWC inferred for the lower Viola reservoir. The recoveries also cannot be accounted for by any reasonable variations in porosities or isopachs of the reservoirs. The high recovery factors probably indicate that significant lateral movement of large volumes of oil may have occurred in the field during its production history. This movement may have occurred in response to pressure gradients formed early in the primary recovery stages by wells extracting large amounts of oil.

Some quarter-sections in the field, such as Section 1, have rather low recoveries. These areas may have been inefficiently produced and therefore could be potential targets for EOR operations. Future reservoir simulation models based on structural, isopach, and porosity information compiled for this volumetric evaluation could help verify the potential in these areas and indicate where oil may have moved in the field. Results of the volumetric evaluation can also serve as part of the criteria by which the results of the simulation models can be evaluated.

CONCLUSIONS

Volumetric calculations utilizing computer graphic techniques produced detailed results for calculating OOIP. Computer analysis allowed for relatively quick turnaround in calculations for different porosity cutoff scenarios.

Volumetric results from the mainframe and personal computer had minimal differences. The major advantages of the mainframe version were the superior graphics, increased speed, and large memory available. The major advantages of the PC version were cost, convenience, and accessibility.

Oil recovery maps for quarter-sections which show fraction of OOIP produced can be useful in targeting potential areas for EOR processes. These maps should be used with discretion, however. Development history must be considered to determine if lateral movement of oil between sections has occurred.

ACKNOWLEDGEMENTS

The authors thank Kevin Cunningham, Lea Ann Davidson, and Renate Hensiek for their help in preparing figures and tables. Appreciation is extended to Ruth Sleeper for her assistance in readying the text.

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TABLE 1.

Summary of Mainframe and PC Volumetric Calculations
for Zenith Unit (res. bbls. original oil in place)

MAINFRAME	Misener limestone	Misener sandstone	Maquoketa dolomite	Upper Viola	TOTAL[2]	RECOVERY %[2,3]	RECOVERY %[4] including lower Viola
no porosity cutoffs	14,796,000	28,207,000	6,966,000	38,919,000	88,888,000	26.7	21.9 - 24.1%
with porosity cutoffs[1]	9,816,000	27,564,000	5,714,000	29,890,000	72,984,000	32.6	27.0 - 29.5%
PC							
no porosity cutoffs	15,390,000	30,000,000	7,131,000	42,726,000	95,247,000	25.0	20.4 - 22.4%
with porosity cutoffs[1]	9,777,000	29,887,000	5,400,000	33,594,000	78,658,000	30.2	24.9 - 27.3%

[1]Misener Limestone = 11%
Misener Sandstone = 5%
Maquoketa dolomite = 8%
Upper Viola = 8%

[2]excludes lower Viola reservoir

[3]23,768,000 res. bbls cumulative recovery through 1983 in Zenith Unit

[4]lower Viola reservoir estimated to have 1/4 to 1/2 reservoir volume of upper Viola reservoir

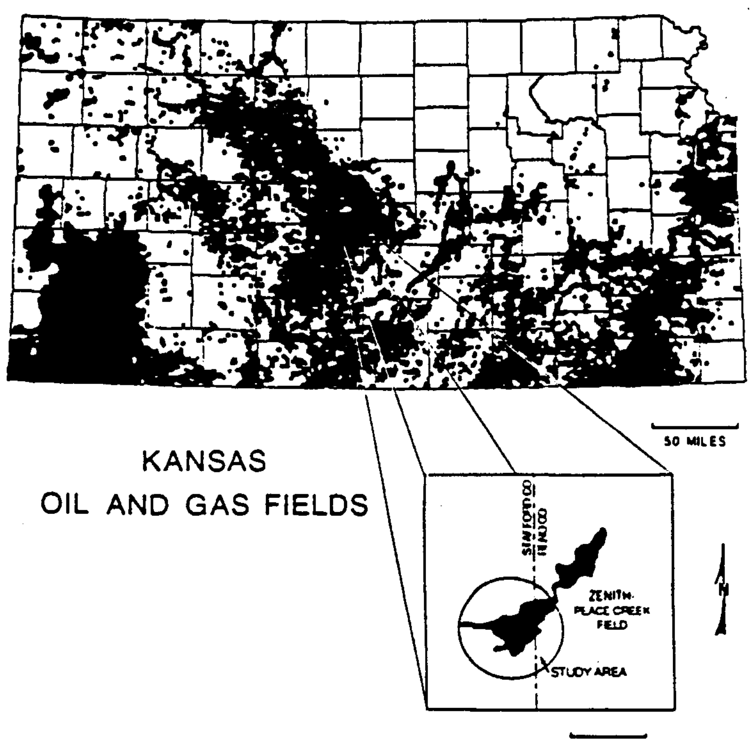


FIGURE 1. Location map for Zenith Pool.

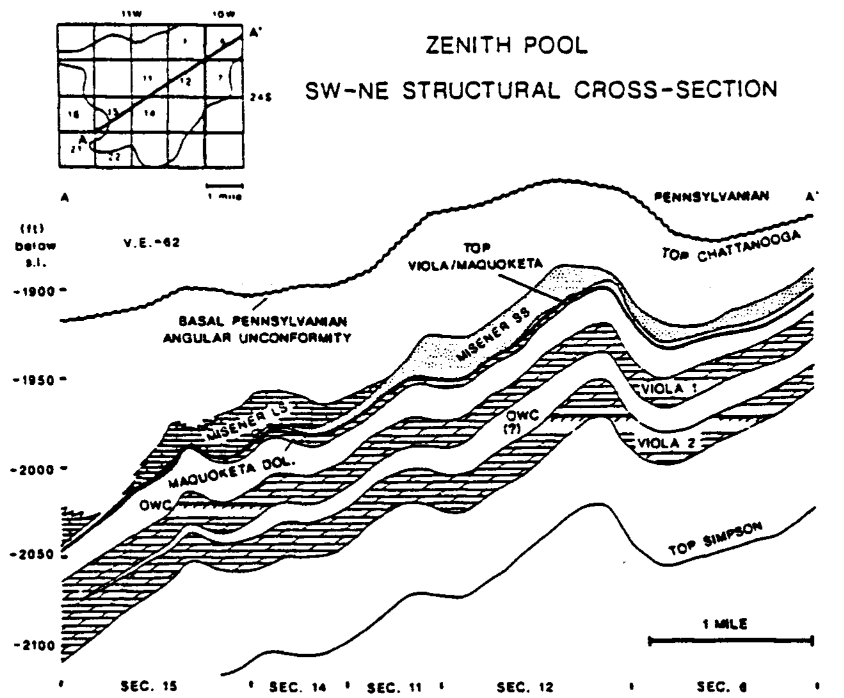


FIGURE 2. Southwest-northeast structural cross-section across Zenith Pool.

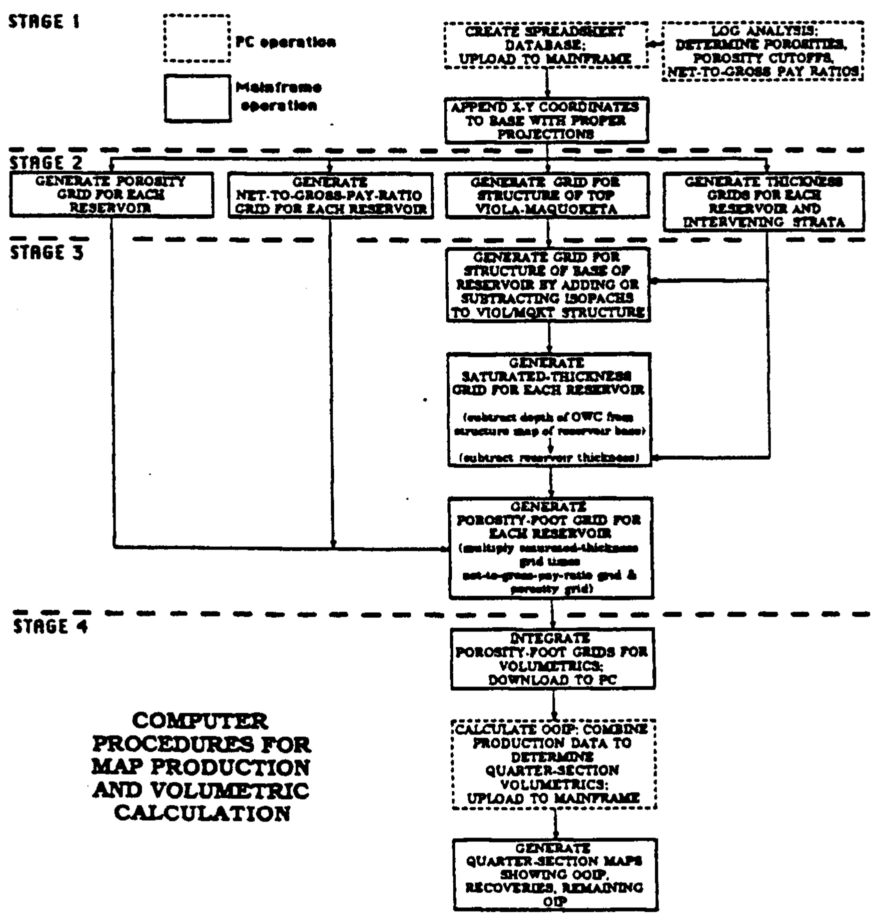


FIGURE 3. Flowchart of procedures.

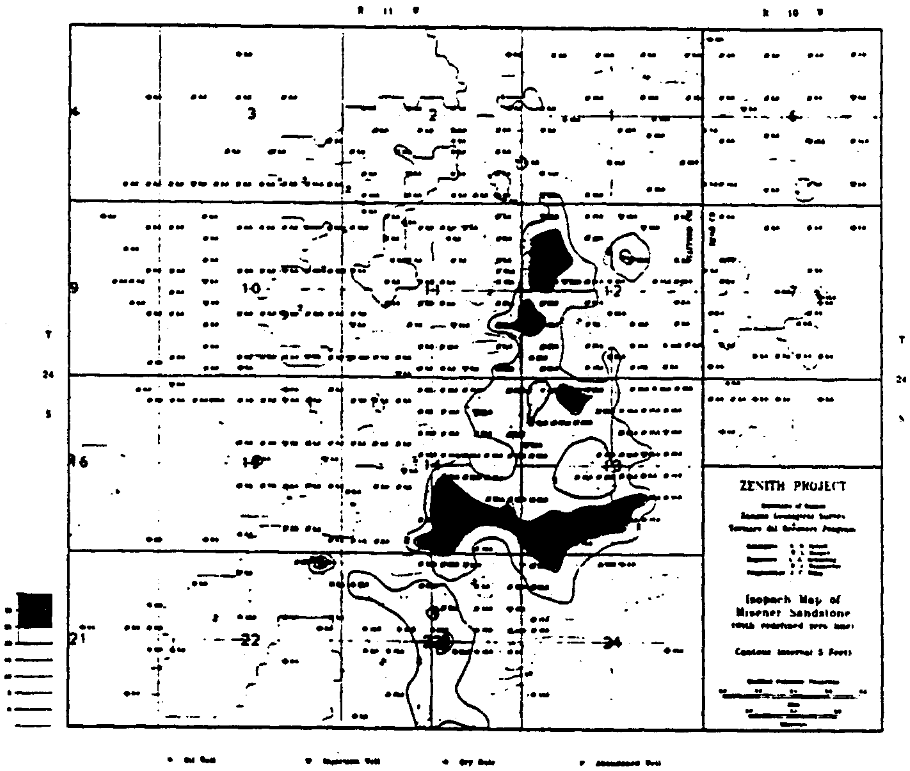


FIGURE 4. Isopach of Misener sandstone, with well data.

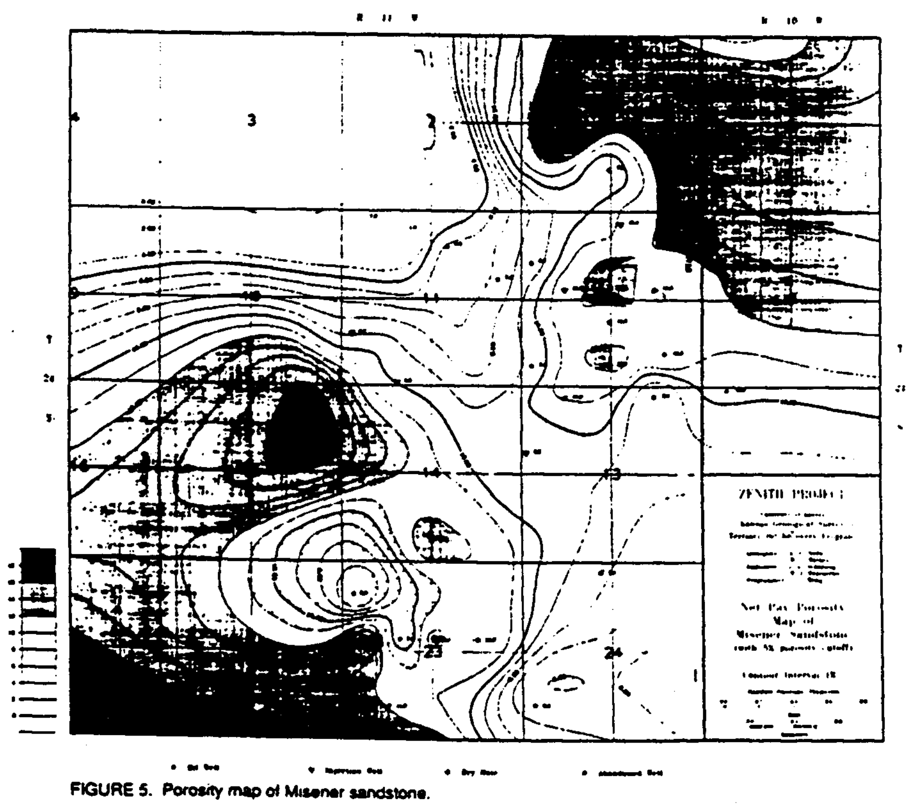


FIGURE 5. Porosity map of Misener sandstone.

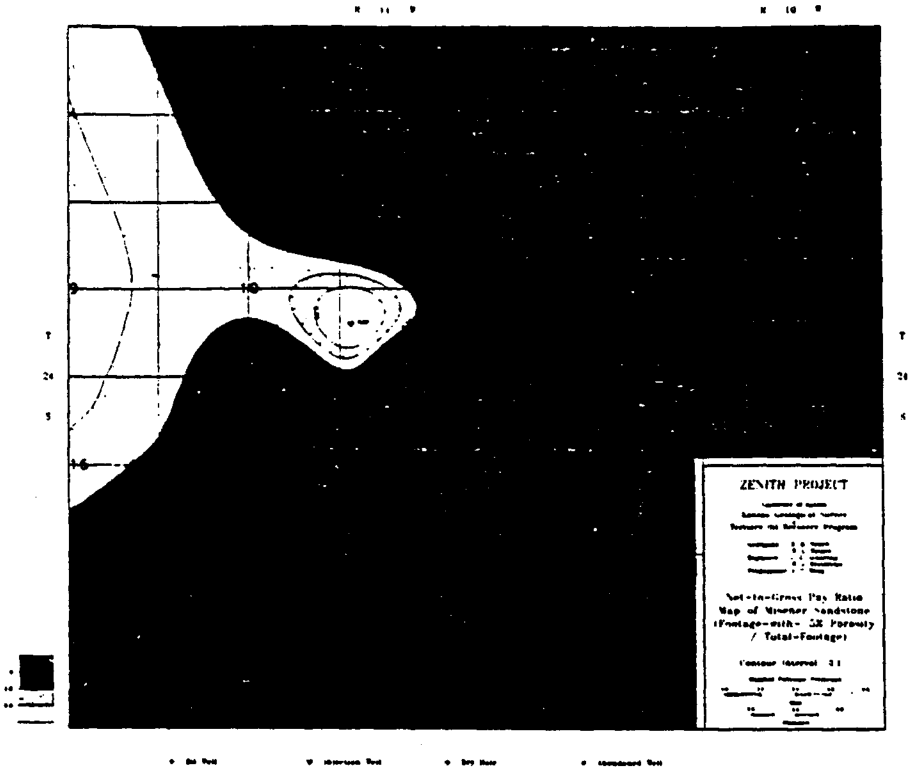


FIGURE 6. Net-to-gross-pay ratio for Misener sandstone.

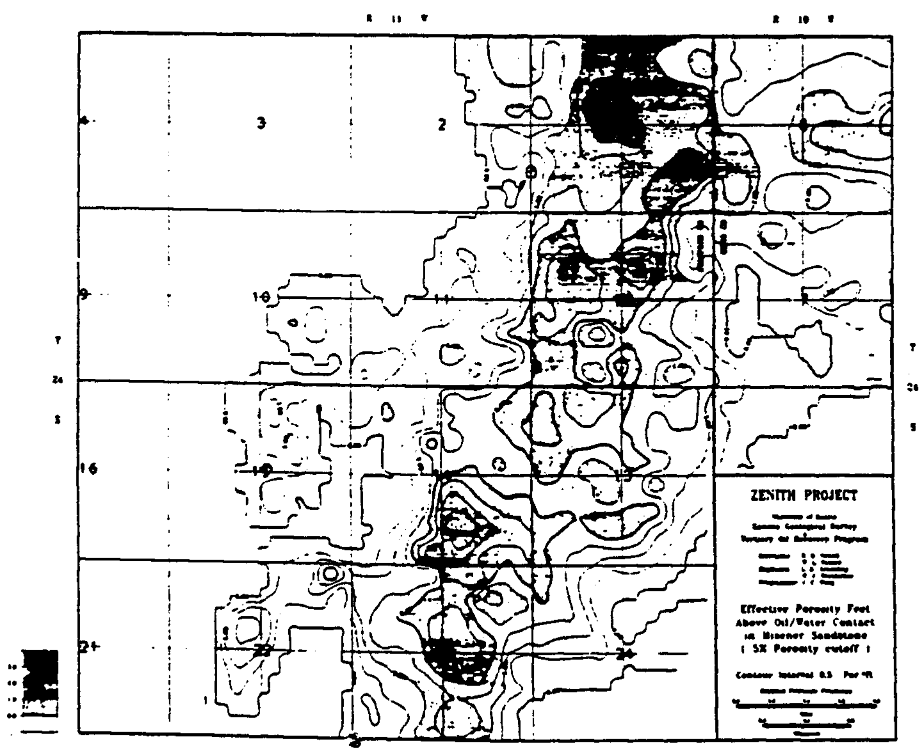


FIGURE 7. Net porosity-feet above OWC in Misener sandstone.

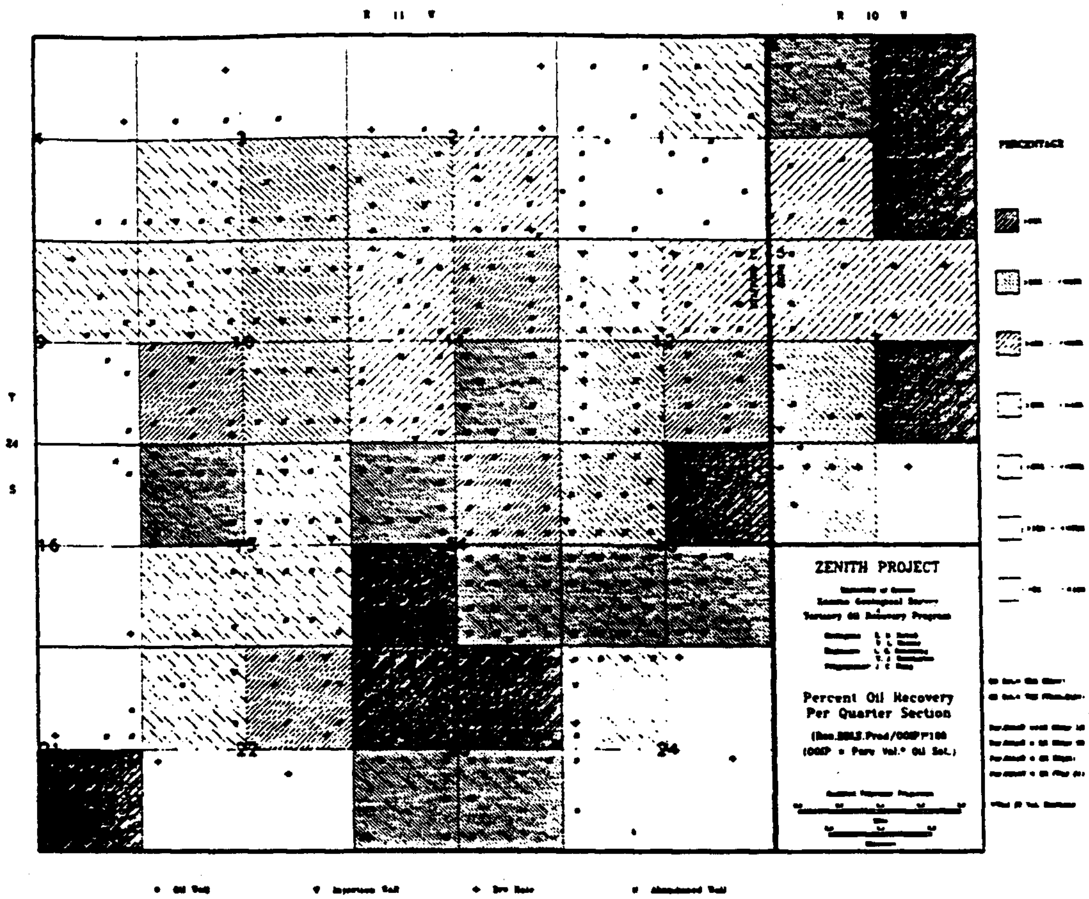


FIGURE 8. Percent oil recovery for quarter-sections.

ZENITH UNIT
Stafford and Reno Counties, Kansas

PROCEDURE FOR ECHOMETER TESTING

1. Shut injection off to ZU-25, perform fall-off test by obtaining fluid levels at regular time intervals until static fluid level is reached.

2. Obtain static pumping fluid levels on ZU-3, ZU-12, ZU-28, and Stewart 2S. Obtain static shut-in fluid levels on TA'd ZU-32, ZU-33, ZU-39, and Stewart 1S. Increase injection rate into Hayes #5 and ZU-29 (approx. 600 BPD) and monitor fluid levels on the above wells. Note any changes and the time interval at which the changes occur.

3. Steps 1 and 2 should be performed simultaneously. After results are obtained, proceed to step 4.

4. Repeat step 1 for Hayes #5 and ZU-5W.

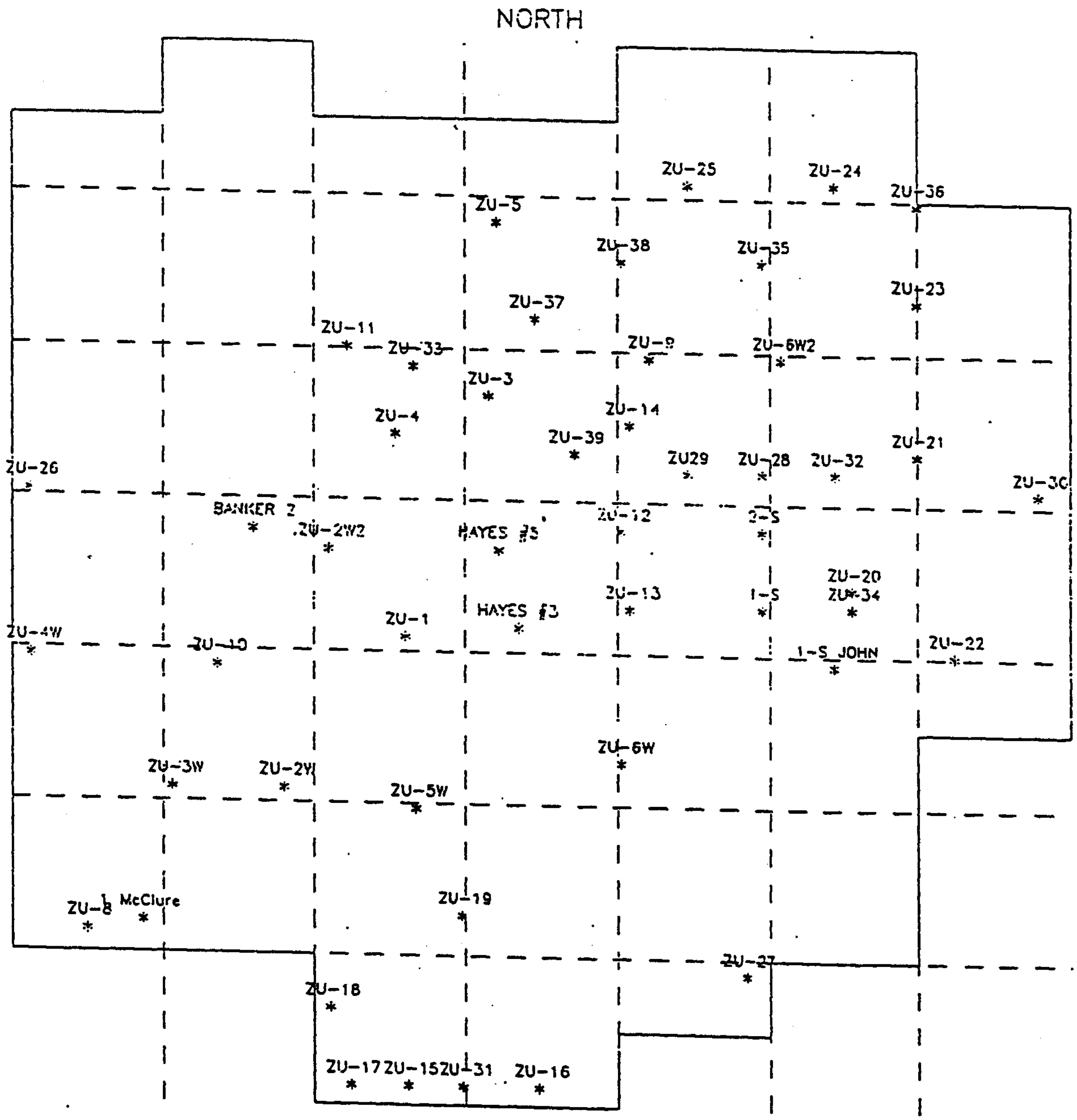
5. Shut down producing well ZU-28. Monitor static pumping fluid levels in ZU- 12 and Stewart 2S. Monitor static-shut in fluid levels in ZU-32, ZU-39, and Stewart 1S. Note any changes and corresponding time intervals.

6. Steps 4 and 5 should be performed simultaneously. After results are obtained, proceed to step 7.

7. Return wells to normal operating conditions.

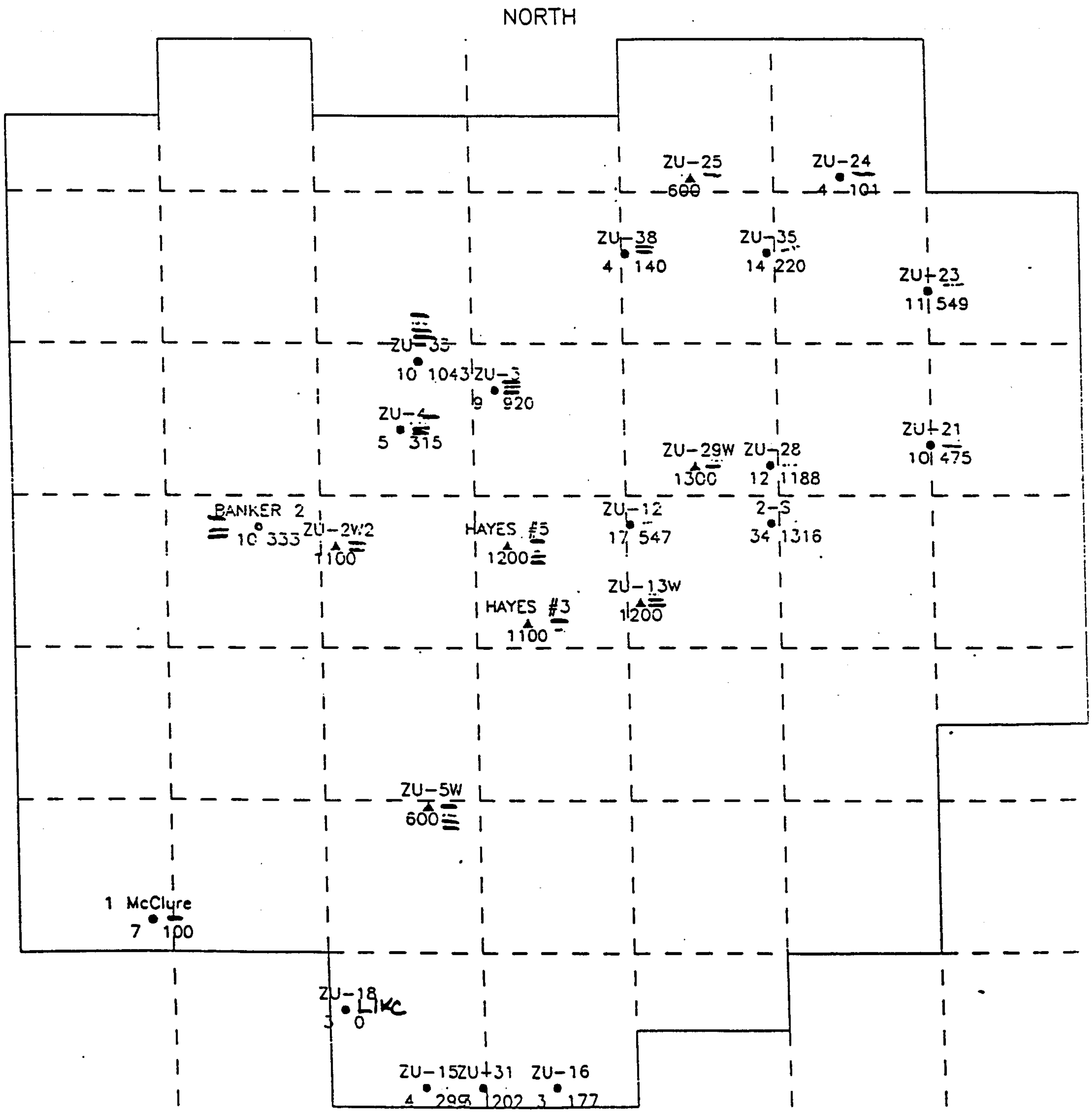
8. Analyze results from tests.

WORKING MAP FOR FIELD USE



SCALE 1 inch = 3080 FEET

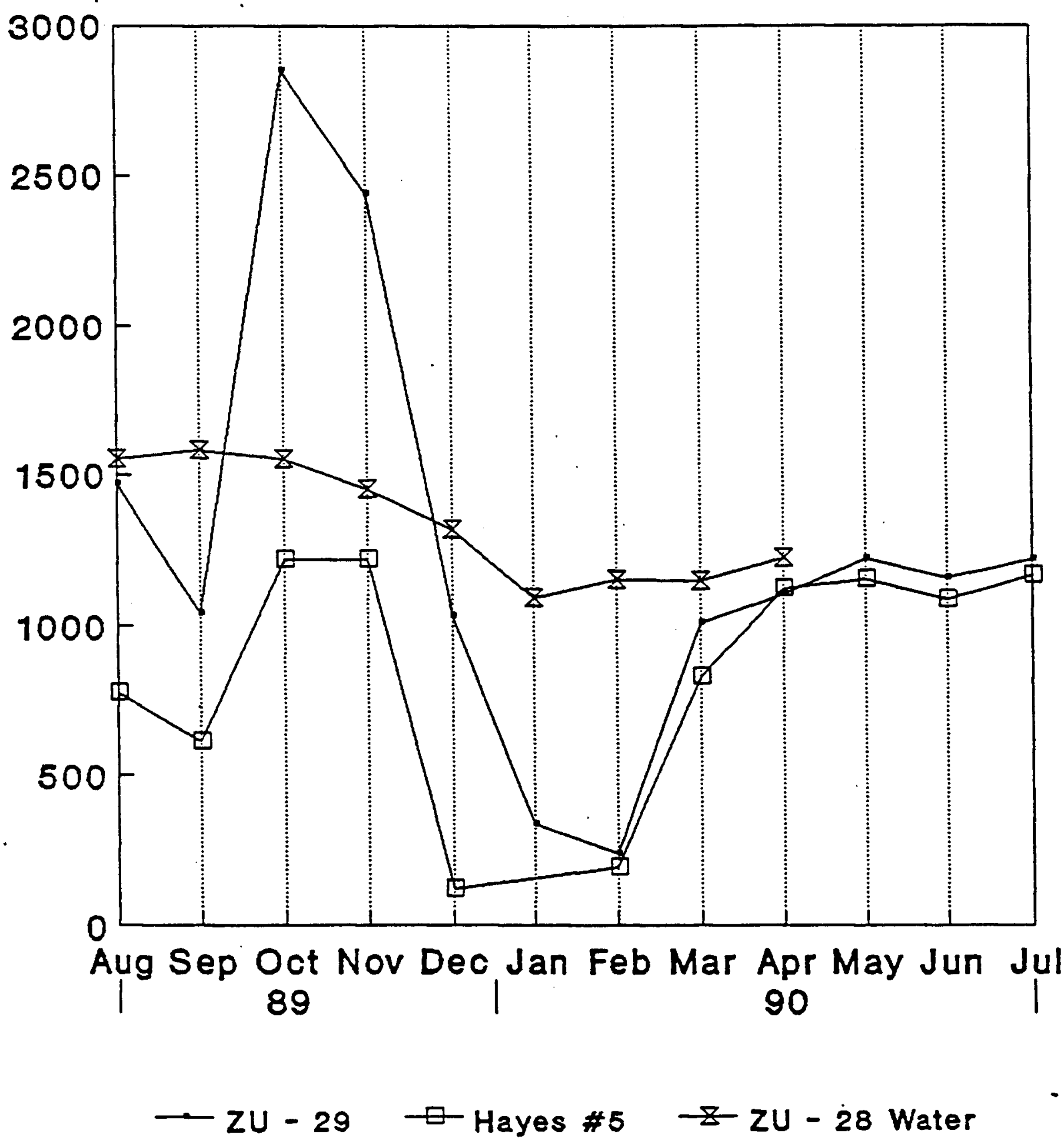
CURRENT INJECTION AND PRODUCING WELLS



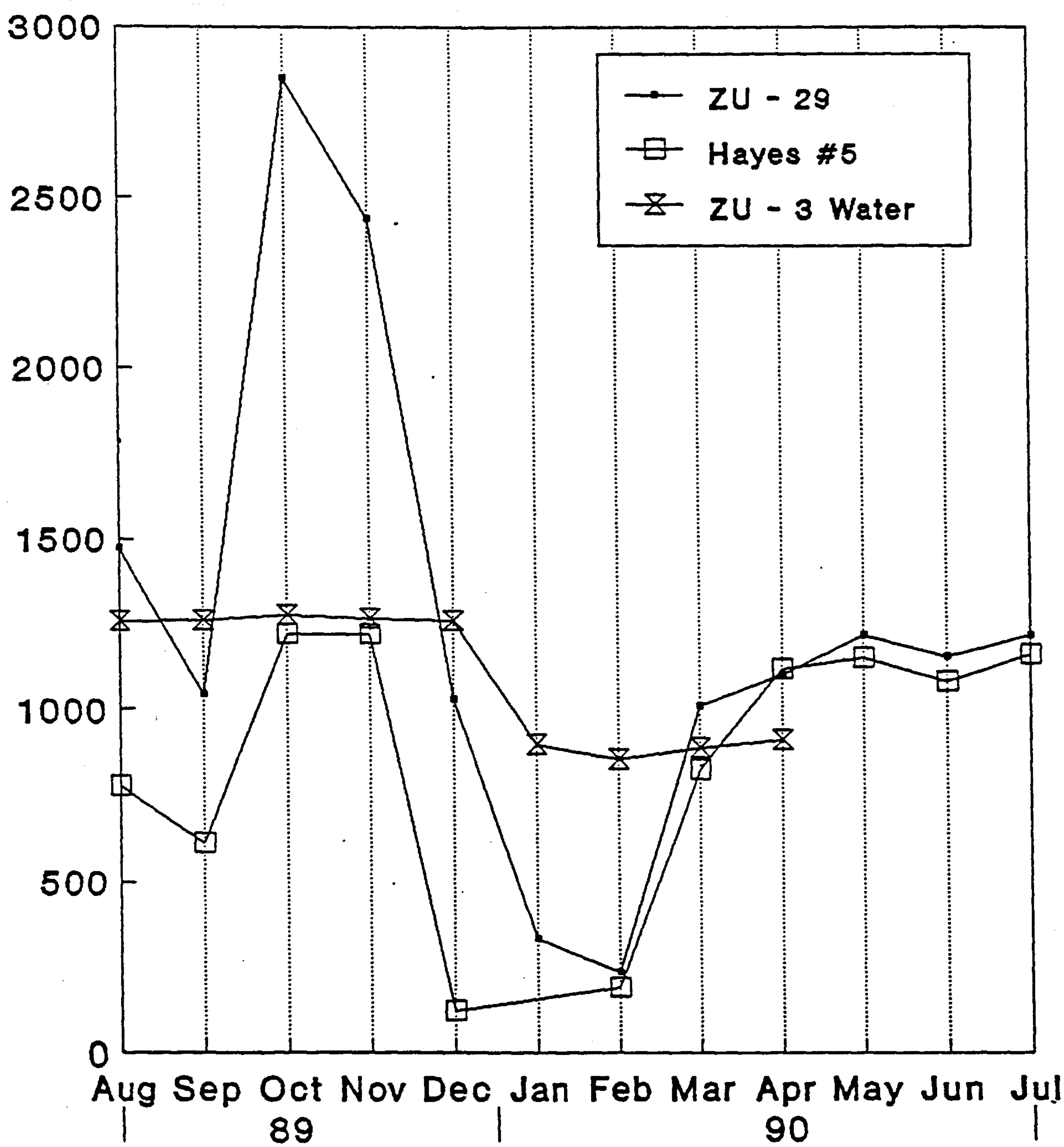
SCALE 1 inch = 2640 FEET

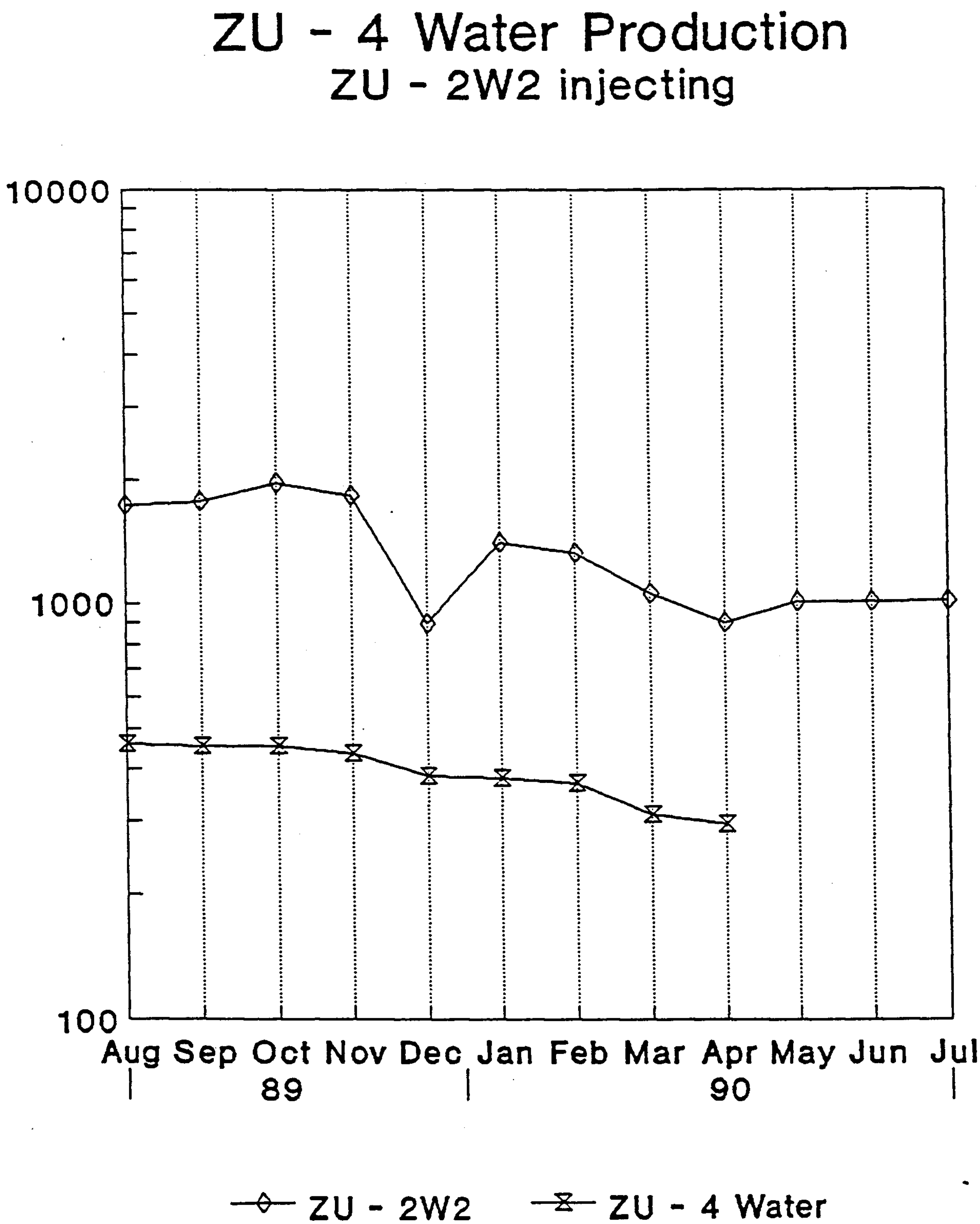
— Misner Lime
Misner SAND
— Maquoketa

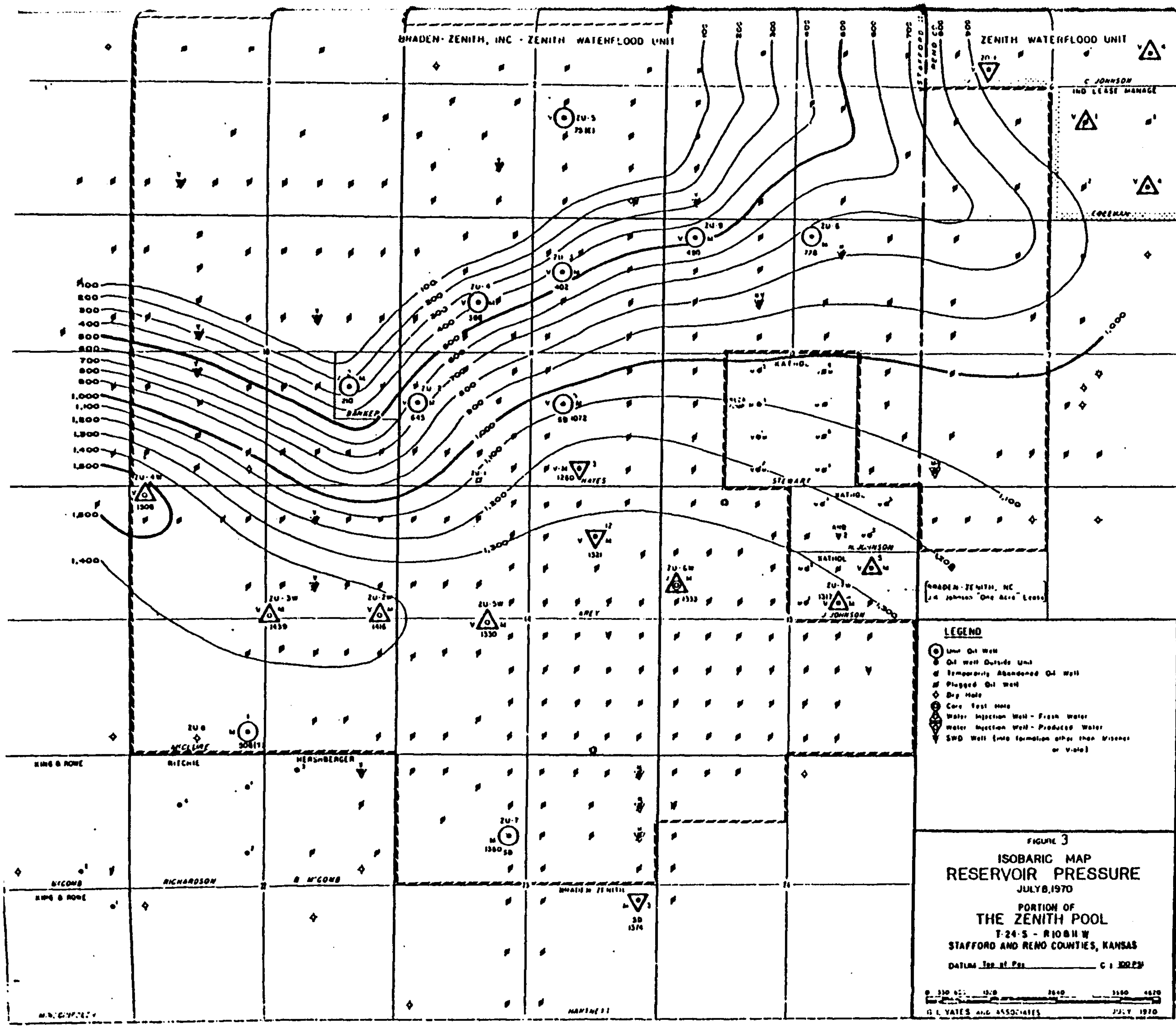
ZU - 28 Water Production
Hayes 5 and ZU - 29 injecting



ZU - 3 Water Production
Hayes 5 and ZU-29 injection

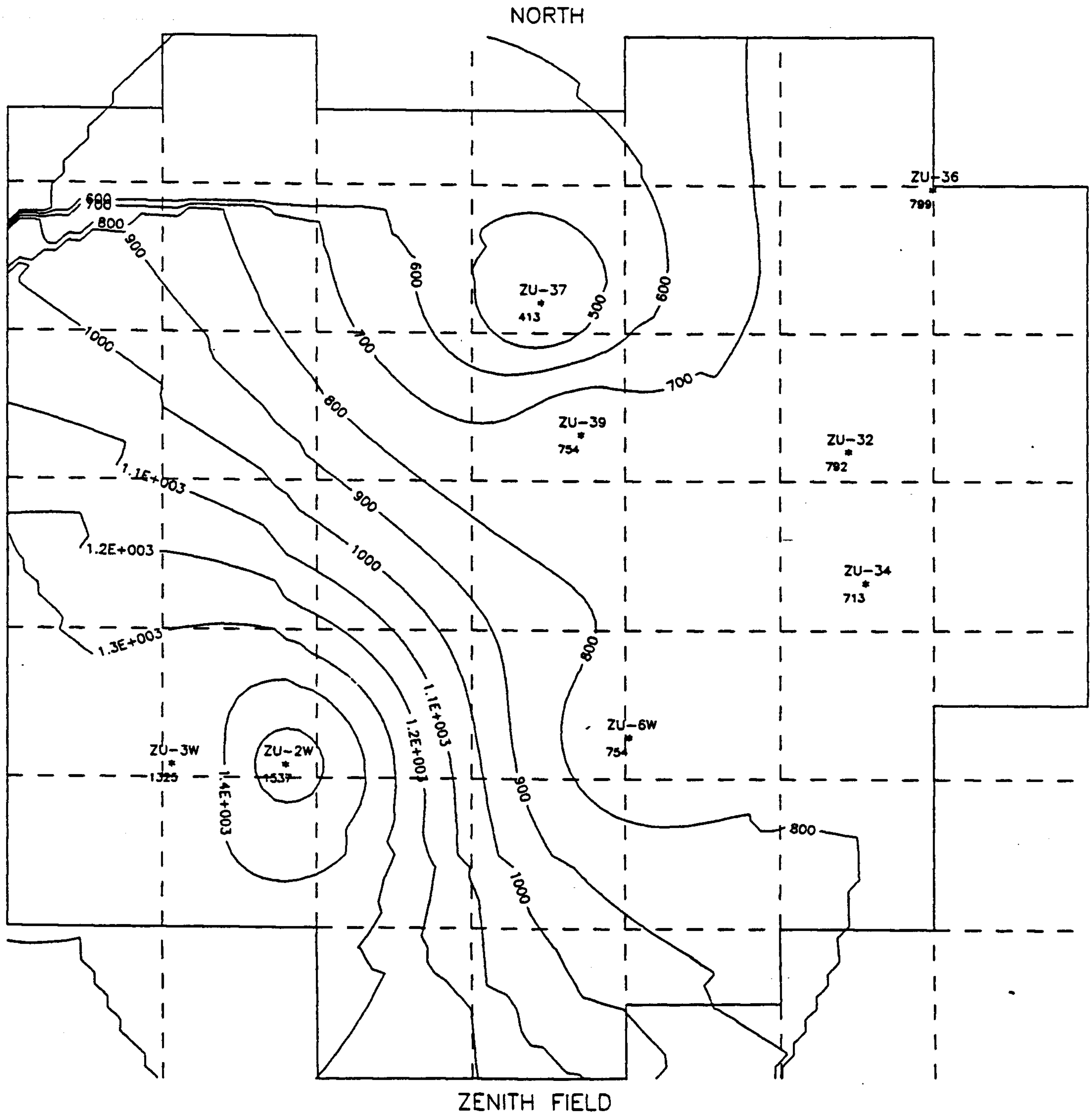



ZU - 4 Water Production
ZU - 2W2 injecting
10000
1000
100
Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul
89
90
ZU - 2W2
ZU - 4 Water



BRADEN-ZENITH, INC - ZENITH WATERFLOOD UNIT
ZENITH WATERFLOOD UNIT
T
24
S
LEGEND
Unit Oil Well
Oil Well Outside Unit
Temporarily Abandoned Oil Well
Plugged Oil Well
Dry Hole
Core Test Hole
Water Injection Well - Fresh Water
Water Injection Well - Produced Water
SWD Well (into formation other than Vissener or Viola)
FIGURE 3
ISOBARIC MAP
RESERVOIR PRESSURE
JULY 8, 1970
PORTION OF
THE ZENITH POOL
T-24-S - R10 & 11 W
STAFFORD AND RENO COUNTIES, KANSAS
G. L. YATES AND ASSOCIATES
JULY 1970

PRESSURE PROFILE FROM FLUID LEVELS (JULY 1990)



SCALE 1 inch = 2640 FEET

T9

WELL DATA SHEET

Lease ZU Well No. 36 Pool Zenith Date 5/90

Location SW/4 Sec. 6-24S-10W County Reno State Kansas

Dist. "H"
5 'From
KB to GL

Date Completed
Well Elevation 1802 GL, 1807 KB
Producing Formation
From ' To ' From ' To
From ' To ' From ' To

Initial Production bopd bwpd
mcfd GOR

Initial Treatment
2-17-86 Perf sqz holes 3746-48, sqz dn csg w/150 sx, found wiper plug @ 3750, no improvement in cmt, re-sqz thru same holes w/150 sx plus celloflakes as LCM, drill out to 3750, TOC 3709, set CIBP 3740

3-3-86 Perf sqz holes @ 3707-09, sqz 25 sx, TOC 3630

8 5/8 "OD Surface
Pipe set @ 210 '
w/ 175 sx.

Top of Cement
@

Subsequent Workover or Reconditioning:

3-10-86 Perf Misner 3703-05, stress frac, ON fill up 275' with 175' oil, dump 500 gal acid and frac w/ N_2 & 5000# sd, ON FL 2000', swab 35 BPH 20% oil, put on pmp

3-16-86 Pmp tst 454 BPD, 5% oil

Present Production bopd b
Gas m
From ' To
Static F. L. @ ' Date
Pumping F. L. @ ' Date

3703
3705 L. Misner Sd

CIBP @ 3740

Remarks: No cmt raised behind pipe on primary cmt job above 3750

5 1/2 "OD # Thd
Gr. , Casing
Set @ 3818 w/ 165 sx

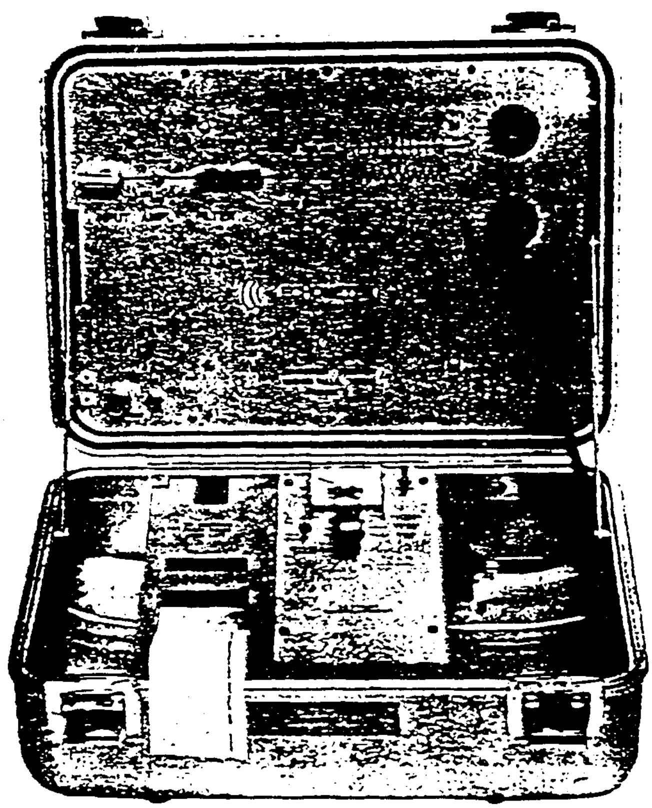
ECHOMETER
LIQUID LEVEL INSTRUMENT

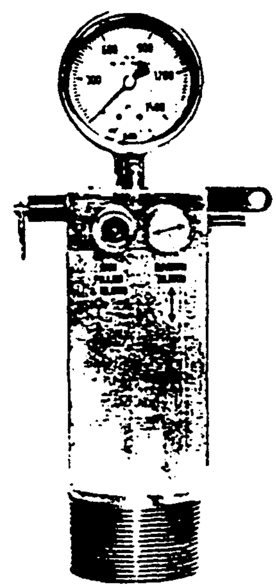
MODEL D

✓ COMPACT GAS GUN · SAFER & BETTER PERFORMANCE

✓ NEW TIMER · FOR MORE ACCURATE BOTTOMHOLE PRESSURES

✓ NUMBER ONE IN SALES





WORLD'S MOST POPULAR LIQUID LEVEL INSTRUMENT

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Patent Nos.3316997
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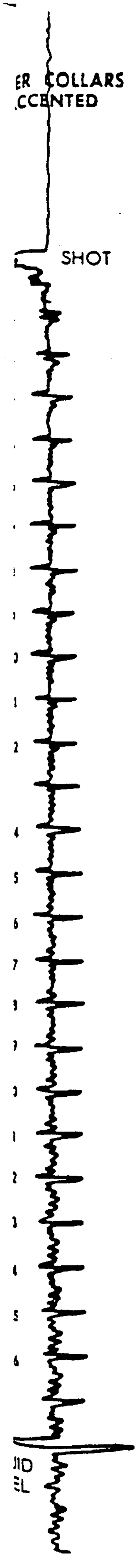
Schcols are held throughout the
U. S. & Canada in major producing areas.

TELEX 361053
ANSWERBACK. ECHOMETER



PRINCIPLE OF OPERATION

A pressure pulse is generated from a sealed well head attachment which is connected to the surface casing annulus valve. The pressure pulse travels down the casing annulus gas and is reflected by collars, the liquid level and other obstructions. A microphone in the wellhead attachment converts the pressure pulses into electrical pulses which are amplified, filtered and recorded on a strip of paper. The record shows the number of tubing collars to the liquid level and hence the depth of the liquid level can be determined.

"THE ECHOMETER LIQUID LEVEL INSTRUMENT"

The Echometer liquid level instrument consists of an amplifier-recorder and a gun-microphone wellhead.

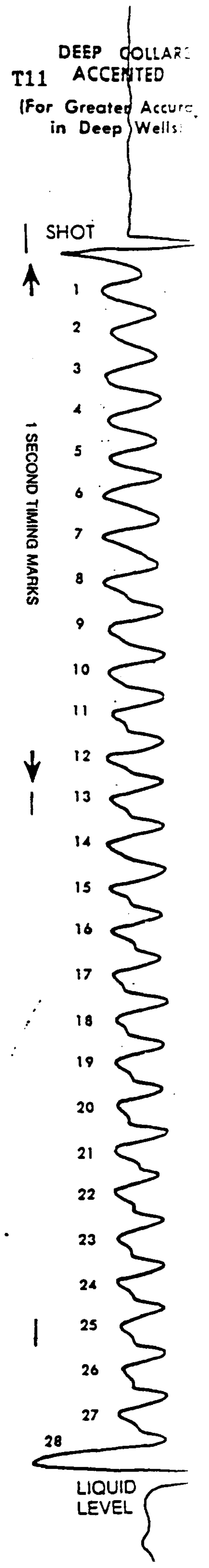
The amplifier-recorder features a stable, high gain amplifier with two sensitivity controls. An automatic gain control is utilized to limit pen movement on strong signals returned from collars near the top of the well. The signals are filtered to accent the information desired and eliminate the information not desired. The filter has 3 positions - UPPER COLLARS, DEEP COLLARS and LIQUID LEVEL. UPPER COLLARS accents the collars near the top of the well and is shown as sharp kicks. UPPER COLLARS responds rapidly to any downhole signal and is useful in dirty wells, high pressure wells, dual tubing wells, and other wells in which the collars are difficult to distinguish. DEEP COLLARS position accents the deep collars in a deep, low pressure well. The recording of deep collars results in greater accuracy. THE LIQUID LEVEL position accents the signal received from the liquid level in a deep, low pressure well. During normal operation, the collar filter position is selected and the collar sensitivity control is set until the pen movement is approximately ⅛". No other adjustments are necessary unless the liquid level is difficult to obtain. The signals are recorded on heat sensitive paper powered by a constant speed chart drive. A self-contained 12 volt rechargeable battery powers the system. Operation from a 12 volt automobile cigar lighter is possible with recharging of the self-contained battery performed automatically simultaneously. A new one-second timer places a timing mark on the chart at the instant of "firing" and each second thereafter. See discussion which follows on back page and request additional information if desired.

The compact gas gun offers superior performance, greater safety, and less expense of operation. The gas gun consists of a small volume chamber and a quick opening valve. The chamber can be charged as needed to obtain the desired record. On shallow wells, a small charge is utilized. On deep, low pressure wells, a large charge is utilized. The gun can be operated as an explosive device or an implosion device. On wells having less than 100 PSI casing pressure, the gas gun is charged to a pressure in excess of the casing pressure which will result in the desired results. Either carbon dioxide or nitrogen gas is normally used. Carbon dioxide gas is commonly available, inexpensive, and large volumes of the gas can be contained in small containers with less pressure. A 7.5 oz. container or a 5# bottle is used for transporting the carbon dioxide gas. The 7.5 oz. container is 2 inches O.D. by 12 inches long and will charge the gun an equivalent of 50 45 caliber blanks. The 5# bottle is 6 inches O.D. by 18 inches long and will supply approximately 500 shots. CO_2 cost approximately 15¢/pound. The portable 7.5 oz. containers and the 5# bottle can be easily refilled from a commonly available 50# syphon type large CO_2 bottle stored at a warehouse or convenient location. CO_2 cost is less than 1¢ per shot. If the well has over 100 PSI casing pressure, the gas gun is evacuated. Then, the gas valve is opened to permit gas from the casing annulus to expand into the gas gun chamber. This implosion of the casing gas into the gas gun results in a pressure pulse. A gas supply bottle is not necessary on these wells with casing pressure.

The output of the microphone to desired downhole pressure signals has been increased, while surface vibration response has been reduced. This new microphone is the best microphone ever developed for use with liquid level instruments because of its sensitivity, signal to noise ratio, and ruggedness.

SCHOOLS

Echometer Company holds schools regularly in the United States and Canada on the use and operation of liquid level instruments and the efficient production of oil wells. Customers may attend without a fee.



Thesis Project Report
Kent Adams
July 5, 1990

COMPUTER SIMULATION OF THE ZENITH FIELD

Current Status

1. Boast II is up and running. All of the bugs have been worked out of the input file.

2. A run was made using the permeabilities obtained from porosity/permeability crossplots. These perms were very low. The simulator calculated negative bottom hole pressures in order to get the production assigned to each well.

3. Pressure drawdown data was analyzed in hopes of backing out a permeability. The data was very limited and the full results of the drawdown test was not reported. The data we had was:

   a) The initial pressure of the reservoir before the test.
   b) The average pressure the last four hours of the twenty-four hour flow test.
   c) The oil production for the last four hours.

   I applied standard drawdown analysis techniques to the data and backed out perms of several hundred millidarcies.

4. I input the perms backed out from the drawdown tests into the simulator and obtained a better output. There was still some convergence problems and parts of the field had negative reservoir pressure calculated.

5. The negative pressures calculated were at the edge of the limestone. I attributed these to too much oil production from such a small pay zone. There is a section of the field were the Misener Limestone overlays the Misener Sandstone. I was assigning all of the production in this section to the limestone. I made an eyeball estimation of how much net pay from each zone was contributing to production for this section. I then reduced the production in the limestone by a corresponding amount. The simulator now calculates reasonable field pressures.

Current Work

Several indications in the model indicate a fractured reservoir. First, core permeability is too small to enable the required production to be simulated in the limestone. Second, pressure drawdown analysis indicates that the actual permeability needs to be several hundred millidarcies in order to obtain the reported production. Based on this evidence, I believe we are going to have to take the fractures into account. From the literature there are two ways to approach a fractured reservoir:

1. If the fracture system is dense, widespread, well interconnected, and has no barrier to flow between the matrix and the fracture, the fracture and the matrix can be treated as an equivalent porous medium. The permeability of this medium is a sum of the matrix and the fracture permeability.

2. The other method used to model fractured reservoirs is dual porosity/dual permeability models. This approach assumes a high storative, low permeability system for the matrix and a low storative, high permeability system for the fractures. There has been substantial research done on this method with numerous simulators written to model this behavior.

We currently have a dual porosity/dual permeability simulator available in the VIP simulator. I recommend switching from Boast II to VIP. Boast doesn't have the complexity to model fractured reservoirs with the accuracy and realism of VIP. In addition, I think it would be more beneficial for me to learn to use a more "up to date" commercial simulator.

I came across a paper that has a technique to estimate fracture porosity, permeability and spacing for a fractured reservoir. The author indicates that it was used to history match a field with approximately the same type and amount of data as the Zenith Field. This technique may be useful in estimating fracture data for the VIP simulator.

Future Work

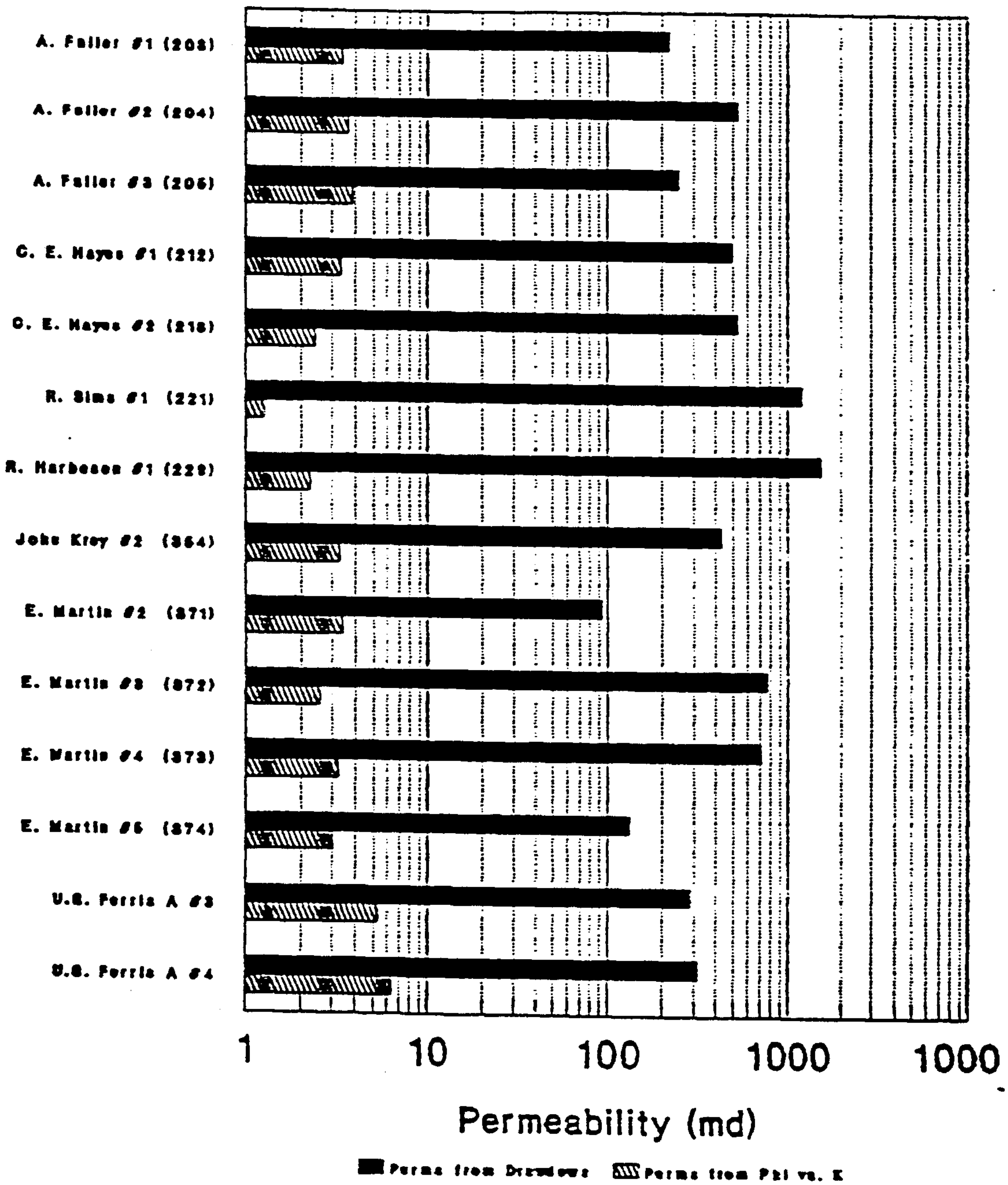
1. Get the newer version of the VIP simulator up on the TORP VAX.

2. Become familiar with the simulator by reading the users manuals and going over McCarthy's work.

3. Put together an input file for the simulator and start history matching.

I believe once I become familiar with VIP, the history matching will move along faster because I will not be stuck trying to figure out how to get a simulator that is not made to model fractured rock to model fractured rock.

Permeability Estimation for Simulation Input



MISENER LIMESTONE