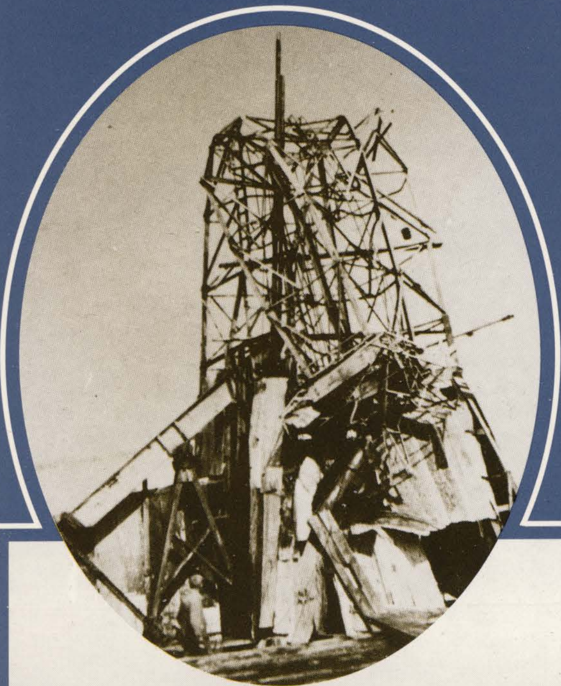
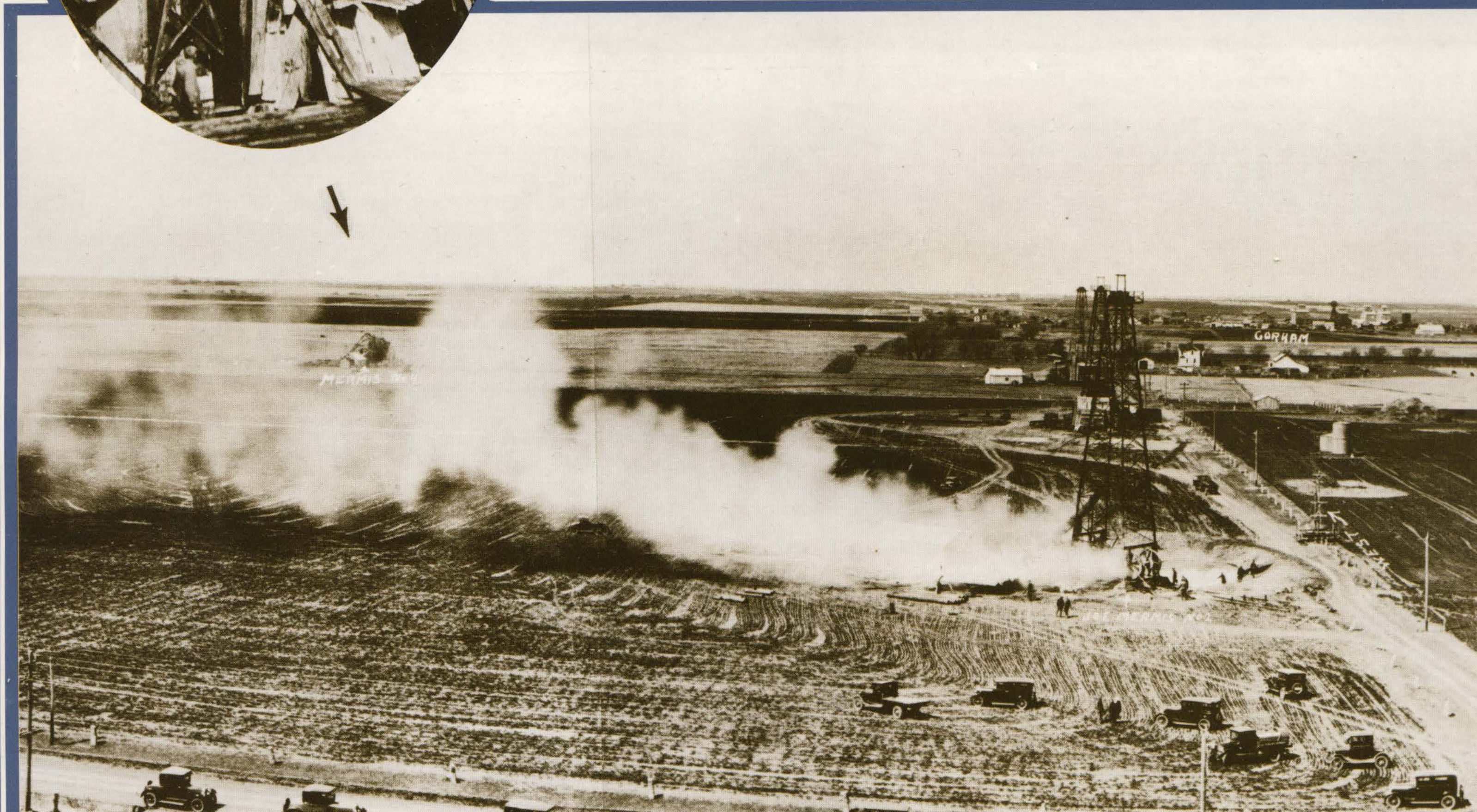


GORHAM OIL FIELD,

RUSSELL COUNTY, KANSAS

Robert F. Walters



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Lawrence, Kansas
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COVER—(FRONT) GORHAM OIL FIELD, APRIL 14, 1928; view west toward the Gorham town site. Steam is rising from Day Petroleum Company's Joe Mermis No. 2, where rigging-up operations are underway. Photographed by E. J. Banks from the derrick of Johnson and Vickers Gorham #1 in sec. 33, T. 13 S., R. 15 W.; courtesy of Russell County Historical Society. Arrow points to the Joe Mermis No. 4 with collapsed derrick (inset). See pages 56–57. (BACK) Gorham oil field, April 14, 1928, continued from the front cover. View is to the southwest.

Printed on recycled paper with soy-based ink

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Foreword

In conversations and correspondence during 1982, Robert F. Walters and I agreed that the Kansas Geological Survey would publish his monograph on the Gorham oil field of Russell County, Kansas. Additionally, the Survey would provide necessary clerical, graphical, and editorial assistance. Several reasons motivated this decision to publish the work of a professional industry geologist having no occupational ties with the Kansas Geological Survey. The first relates to his unsurpassed knowledge of the Gorham field and its prominent position in the petroleum development of central Kansas, knowledge gained through experience and long, intense, and enthusiastic study. A second reason relates to his rare historical sensitivity that sets this work apart from the usual case study of the development of a significant oil field. Lastly, I much admired his personal qualities, such as professional integrity, scholarly breadth of interest, and willingness to share his skills and insights with others.

In elaboration of the first reason, one might say that this volume on the geology and historical development of the Gorham oil field by Robert F. Walters reflects a love affair with central Kansas and the Central Kansas uplift of some 40 years duration. As Barbara W. Tuchman has observed in *Practicing History*, ". . . it is this quality of being in love with your subject that is indispensable for writing good history—or good anything, for that matter." It would seem, in a way, that his entire career has been pointed toward this volume. Dr. Walters gained his Ph.D. degree in geology from Johns Hopkins University in 1946, based partly on his dissertation on "Buried Precambrian hills in northeastern Barton County, central Kansas," a pioneering effort begun while he was a research geologist with Gulf Oil Corporation in Tulsa, Oklahoma. He discovered a thread of continuity, the movement of fluid through soluble rocks, that guided much of his later effort, and through his insoluble residue work documented a buried karst or paleokarst between buried Precambrian hills. Subsequent work and publication had to do with migration of oil and gas, production from fractured Precambrian basement rocks, subdivision into mappable units and differential entrapment in the Arbuckle dolomite, and salt dissolution and land subsidence. The Gorham oil field exhibits aspects of all these important subjects and is representative of the exciting development of the giant oil fields of central Kansas. Furthermore, with diligence, its record and history were recoverable by someone who cared.

As to the second reason, the work gives historical perspective to the methods used to develop the field by discussing exploration, drilling, and production techniques, and even the behavior of field geologists. It draws upon personal experience, anecdotes and records of friends and colleagues, and museum and library records. It helps to explain the evolution of institutions and practices that survive in Kansas to the present. In like manner, it examines the environmental impact of the field's development. This integration of geology, history, and environment causes this volume to be unique as a synthesis of the geologic conditions that led to the field's development, and the environmental conditions that development engendered.

Finally, Bob Walters has a long record of exemplary service to his profession and consulting in the public interest. This was recognized by his election in 1987 as an Honorary Member of the American Association of Petroleum Geologists. With respect to the Kansas Geological Survey, review of correspondence shows his first appointment to the Geological Survey Advisory Council (then called the Mineral Industries Advisory Council) by Chancellor W. Clarke Wescoe in 1963. He continued in this role for 10 years, serving five years as Council chair. In this capacity, he provided leadership in recommending new programs and stimulating staff discussions about old ones, securing funding for the construction of Moore Hall, and in recommending to the Chancellor appropriate personnel policies for the staff of the Geological Survey.

During the early 1970's, the Kansas Geological Survey was much involved in the problems of storing high-level nuclear waste at Lyons, Kansas. An independent consultant on drilling, coring, logging salt beds, borehole plugging, subsidence, and field operations in the midcontinent was badly needed by Union Carbide Corporation–Nuclear Division, the contractor for the Atomic Energy Commission. I could think of no better qualified person than Bob Walters, who had owned and operated oil wells, saltwater-disposal wells, and rotary-drilling tools for more than 20 years. I recommended him for the assignment. Somewhat reluctantly, he accepted the challenge, but only after his term on the Advisory Council had ended. He continued to provide valuable guidance on these matters until 1982 to successor agencies and their contractors, including the Energy Research and Development Agency, Department of Energy, and Battelle Memorial Institute.

The report by Walters in 1976 to the Solution Mining Research Institute on subsidence in Kansas caused by salt dissolution was a model of clarity on cause and effect. Because of its limited distribution, we suggested release for publication. Release having been granted, the report emerged as "Land subsidence in central Kansas related to salt dissolution," Kansas Geological Survey Bulletin 214, published in 1978, and Bob Walters had become a Geological Survey author. This volume was reprinted in 1984, an indication of its impact and popularity. Having influenced this oil finder in a new direction of public service, when the matter of publication of the Gorham oil field seemed certain I could do no less than recommend to the Chancellor in 1987 that Dr. Walters be appointed Adjunct Senior Scientist. This title conveys certain responsibilities and perquisites, but not included are salary or other compensation. It is satisfying to be associated again with Robert F. Walters in a unique publication venture, especially one that will help to preserve an important part of exploration and environmental history in Kansas.

William W. Hambleton
Emeritus Director
1990

Abstract

The 1,397 oil wells in the Gorham oil field have produced nearly 100 million barrels of oil (BO) from 1926 to 1986. Wells were drilled on 10-acre (4-hectare) spacing 660 ft (198 m) apart, within the 50 mi^2 (130 km^2) oil field. The Arbuckle dolomite (Cambrian–Ordovician) and Reagan Sandstone (Cambrian), a unit reservoir with a strong water drive (original oil-water contact near subsea −1,440 ft), has produced 66% of the oil from porosity under the Pennsylvanian unconformity surface near 3,300 ft (990 m). The Lansing–Kansas City (Pennsylvanian) limestone reservoirs have produced 25% of the oil from structural and porosity traps by primary dissolved gas drive and secondary water flooding. A fracture zone in the Topeka limestones (Pennsylvanian) provided the reservoir(s) for spectacular oil recovery of 200,000 BO per well from 30 oil wells. A fourth pay zone yielded gassy, stratigraphically trapped oil from the Tarkio (Pennsylvanian) after fracturing. Precambrian granite and quartzite yield small amounts of oil in 15 wells.

The Gorham oil field is localized by a 10-mi (16-km)-long northwest-trending anticline with 400 ft (120 m) of faulting in the Precambrian granite on the southwest flank. Fault relief diminishes upward with 30 ft (9 m) of closure present in the near-surface Fence-post limestone (Cretaceous). The anticline was defined by the then-unique method of core drilling which provided the location for the discovery well in 1926.

In the 1920's, 1930's, and early 1940's, holes were drilled by the now-obsolete method of cable-tool drilling, providing excellent samples of well cuttings used by the author for acid insoluble residue studies, permitting subdivision of the Arbuckle dolomites into six mapped units. The drilling and development history and the changing role of the petroleum geologist are reviewed with illustrations of cable-tool rigs, derricks, and historic maps.

The adverse environmental effects of this 60-year-old oil field (444 remaining active oil wells, December 31, 1986) include saline contamination of formerly useful freshwater aquifers and of limited agricultural areas plus slow, long-continued, costly subsidence affecting Interstate Highway 70 (I–70) in three areas. Subsidence rates are diminishing to only one-half foot per year, maximum, in 1986. Subsidence is caused by inadvertent dissolution of the Wellington salt (Permian) at depths of 1,300–1,550 ft (390–465 m) by improperly disposed waste oil-field brines that were unsaturated with regard to salt (halite, NaCl). Stringent regulation by the Kansas Corporation Commission of brine disposal and plugging of abandoned wells is minimizing additional adverse environmental impact.

Introduction

General

Nearly 100 million barrels of oil have been produced from the Gorham oil field, the second oldest oil field in the west ranges of Kansas. The geology, oil production, oil-field history, and the impact on the environment of this major 50 mi^2 (130 km^2) oil field are reviewed for the 60-year period from 1926 through 1986.

The Gorham oil field is representative of the giant oil fields of central Kansas including Bemis–Shutts in Ellis County, Hall–Gurney and Trapp in Russell County (fig. 1), Kraft–Prusa (Walters and Price, 1948) in Barton County, and Chase–Silica in Rice County, Kansas. All are characterized by prolific oil production averaging 50,000 to 100,000 barrels of oil (BO) per well from carbonate rocks, the Arbuckle dolomite, and the Lansing–Kansas City limestones, at relatively shallow depths of 3,000–3,300 ft (900–990 m) from hundreds of oil wells on regular 10-acre (4-hectare) spacing, 660 ft (198 m) apart.

Location

The town of Gorham, from which the Gorham oil field is named, is 9 mi (14.4 km) west of Russell, Kansas, the county seat. United States Interstate Highway 70 (I–70) is located about 1 mi (1.6 km) south of both with exits at each, plus an exit in between at the Balta road within the Gorham oil field.

Fig. 1 shows the central Kansas location of Russell County and the official Gorham oil field boundaries as determined by the Kansas Corporation Commission (KCC), the State agency that regulates well spacing, oil production, drilling permits, and saltwater disposal.

Much of the area of the Gorham oil field consists of flat-lying farmland principally devoted to wheat growing. In the northeastern portion of the oil field, in T. 13 S., R. 14 W., the land is cut by canyons approximately 150 ft (45 m) deep which provide excellent outcrops of Cretaceous rocks. Structural mapping of these rocks led to the 1923 discovery of the Fairport oil field 10 mi (16 km) north of the town

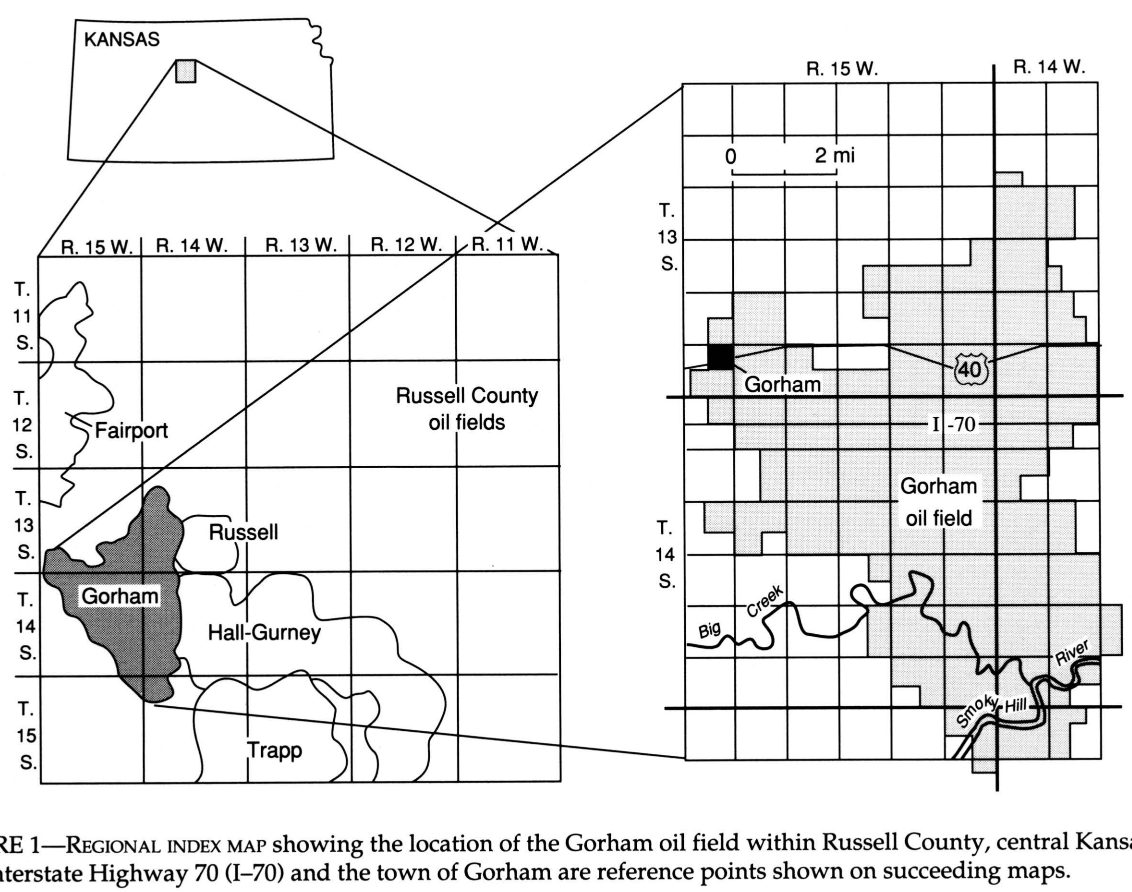


FIGURE 1—Regional index map showing the location of the Gorham oil field within Russell County, central Kansas. Interstate Highway 70 (I–70) and the town of Gorham are reference points shown on succeeding maps.

of Gorham. In the southern portion of the Gorham oil field, the valley of a west-to-east-flowing stream, Big Creek, provides outcrops of Cretaceous rocks, including "Fence-post limestone," a bed 8 inches (20 cm) thick, that was quarried by the pioneer settlers a little over a century ago to provide stone fence posts. Big Creek joins the east-flowing Smoky Hill River near the southeast corner of the Gorham oil field. The area is surveyed in land sections 1 mi^2 (2.6 km^2) with access roads on all section lines except in the rugged canyon areas where most roads follow valley floors and near Big Creek and the Smoky Hill River.

Area

Fig. 2 shows 2,168 oil and gas test holes drilled within the 95.75 mi^2 (248.95 km^2) area mapped to December 31, 1986. Dry holes (wells that produced no oil in commercial amounts) are shown by open circles. Oil wells are shown by solid dots without regard to whether the well was still producing oil on December 31, 1986, or whether it had been previously plugged and abandoned. Included within the 50.5 mi^2 (131.3 km^2) official boundary of the Gorham oil field are 1,397 oil wells, 345 dry holes, and 85 service wells (used for disposal of oil-field brine) or 1,827 holes. These figures do not include the numerous additional holes drilled for water-supply wells, stratigraphic test holes, seismic shot holes, or the 162 known shallow saltwater-disposal wells.

Reservoirs

Five principal reservoir formations produce oil.

Name used in oil field	Depth in feet	Number of oil wells*	Percent of field's production
Tarkio	2,400-2,500		
fracture zone	2,700-2,800	130	8
Topeka	2,800-2,900		
Lansing–Kansas City	3,000-3,300	477	25
Arbuckle–Gorham sand	3,300-3,400	1,044	67

*Many oil wells produce from two formations, most commonly the Lansing–Kansas City and the Arbuckle–Gorham sand.

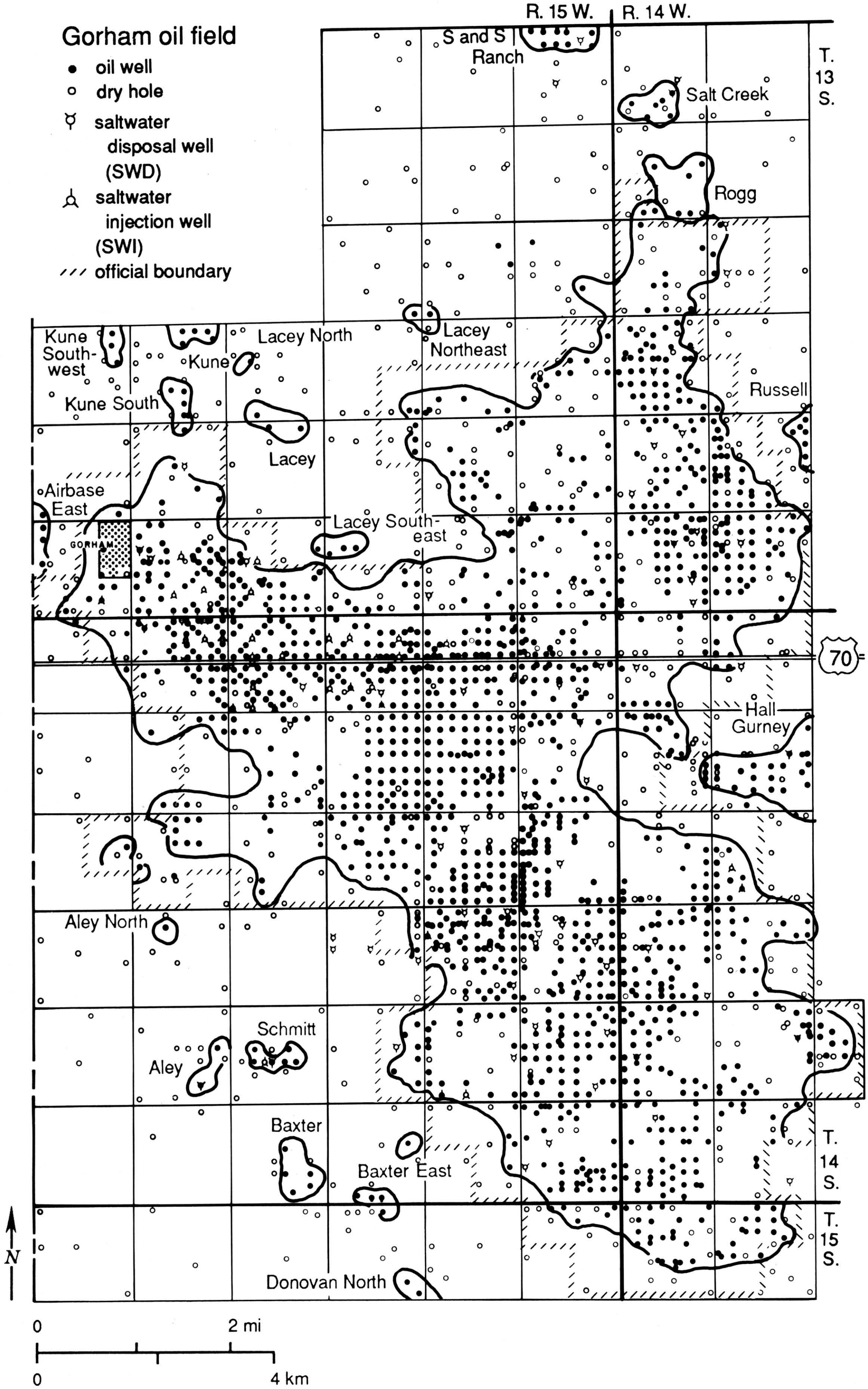
The entire 50 mi^2 (130 km^2) area of the Gorham oil field is a single oil field as defined by limits of production from its principal oil reservoir, the rocks associated with the basal Pennsylvanian unconformity including the Arbuckle dolomite, Reagan Sandstone, and parts of the "Gorham sand." This common oil reservoir has a strong water drive and an oil-water contact originally near 1,440 ft (432 m) below mean sea-level. It is now much distorted due to the withdrawal of millions of barrels of oil and perhaps ten times as much saltwater.

Within the official area of the Gorham oil field local, individual anticlinal areas are reservoirs for oil in the Pennsylvanian Lansing–Kansas City limestones. Limited oil reservoirs are present in the Shawnee Group, and Toronto and Plattsmouth limestones (called "Topeka"). Open fractures provided spectacular oil production from 30 "Topeka fracture zone" wells. Oil production called "Tarkio" occurs in Pennsylvanian Wabaunsee-age, silty sandstone lenses that are stratigraphic-trap reservoirs. In addition, minor production was obtained from fractures in Precambrian granite or quartzite on the summits of buried Precambrian hills, depths near 3,300 ft (990 m).

Literature, Gorham oil field

No study of the entire Gorham oil field has been published since Folger's (1933) four-page report for the period from discovery on October 16, 1926, to December 31, 1929, when there were 27 oil wells from which 1,108,004 BO had been produced, 70% from the Cambrian Reagan Sandstone (then called Pennsylvanian basal conglomerate) and 30% from the Pennsylvanian Lansing–Kansas City limestones (then called Oswald). Frye and Brazil (1943) reported timely important, but incomplete, groundwater studies in the Gorham oil field and elsewhere in Russell and Ellis counties. Walters (1953) discussed oil production from fractured Precambrian granite in the Gorham oil field, illustrated by a 9-mi (23.4-km)-long cross section. An abstract by Burgat and Taylor (1972) called attention to their investigation of two subsidence areas in the Gorham oil field affecting I–70 during its construction in 1965–67. Fader (1975) described and analyzed these subsidence areas. Walters (1978) investigated salt dissolution causing surface subsidence in the two areas along I–70 described by Burgat and Taylor and published a 1.25-mi (2-km) natural-scale cross section through them from the ground surface to the Precambrian basement. Macfarlane et al. (1988) reported on the hydrology of the Dakota, Kiowa, Cheyenne,

FIGURE 2—Gorham oil field and vicinity, showing 2,168 oil and gas holes drilled within the 100 mi^2 (260 km^2) study area to January 1, 1987. Within the official boundary of the 50.5-mi^2 (131-km^2) Gorham oil field (//// pattern) there were 1,397 oil wells, 345 dry holes, 41 saltwater-disposal wells, depths from 3,400 to 3,700 ft (1,020–1,110 m), plus 44 water-injection wells used in secondary recovery of oil by waterflooding.


Gorham oil field
oil well
dry hole
saltwater disposal well (SWD)
saltwater injection well (SWI)
official boundary
R. 15 W.
R. 14 W.
T. 13 S.
T. 14 S.
T. 15 S.
S and S Ranch
Salt Creek
Rogg
Kune Southwest
Kune
Lacey North
Lacey Northeast
Kune South
Russell
Lacey
Airbase East
Lacey Southeast
GORHAM
70
Hall Gurney
Aley North
Schmitt
Aley
Baxter
Baxter East
Donovan North
N
0
2 mi
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4 km

and Cedar Hills aquifers. One observation well for this project is located within the Gorham oil field near the town of Gorham.

Statistical data concerning production of oil and gas in Kansas, including figures for the Gorham oil field and for the former oil fields now merged within it, have been compiled by various authors annually since 1927 for the Kansas Geological Survey. Their publications, used in preparing the production graphs (fig. 4), are listed in the appendix, table 8, under "Kansas Geological Survey" by year of contained data, not by year of publication, which was from one to five years later.

Discovery

Oil was discovered in the Gorham oil field on October 16, 1926, in the "Oswald" (Lansing–Kansas City) limestone near 3,000 ft (900 m) by Midwest Refining Company's #36 Dortland in sec. 5, T. 14 S., R. 15 W., south of the town of Gorham and near present I–70. Fig. 3 shows the location of this discovery well, location of wells discovering 30 subsequent oil fields now merged into the Gorham oil field, and the location of cross sections and photographs. The most important of the subsequent discoveries was the finding of oil in the "Gorham sand" at 3,317 ft (995 m) near the town of Gorham on January 28, 1928, by Stearns and Streeter's Mermis #1 in sec. 33, T. 13 S., R. 15 W. The cover photograph shows the intense development taking place three months later when the panoramic photo was taken on April 14, 1928. It and many following photographs are reproduced through the courtesy of the Russell County Historical Museum of Russell, Kansas. Table 1 (appendix) lists the 31 discovery wells mapped in fig. 3 with pertinent additional information.

Oil production

The Gorham oil field production history is summarized in fig. 4. The top graph shows annual oil production. The middle curve indicates the number of producing oil wells. The lowest curve graphs average daily oil production in terms of barrels of oil per day (BOPD) per oil well. The statistical information from which the graphs were prepared is summarized in the appendix, table 2.

Sources of information

The fundamental information for this study was derived from the examination of samples of well cuttings under a binocular microscope with 20× magnification. The author's early work in the 1940's made use of the then-available excellent cable-tool well cuttings that were suitable for acid insoluble residue preparation, permitting the author's subdivision of the Cambrian and Ordovician Arbuckle dolomite beds into five mappable units. In later years, samples of well cuttings were examined at, or borrowed from, the Kansas Geological Survey Well Sample Library in Wichita, Kansas, where samples are available to the public for a modest fee.

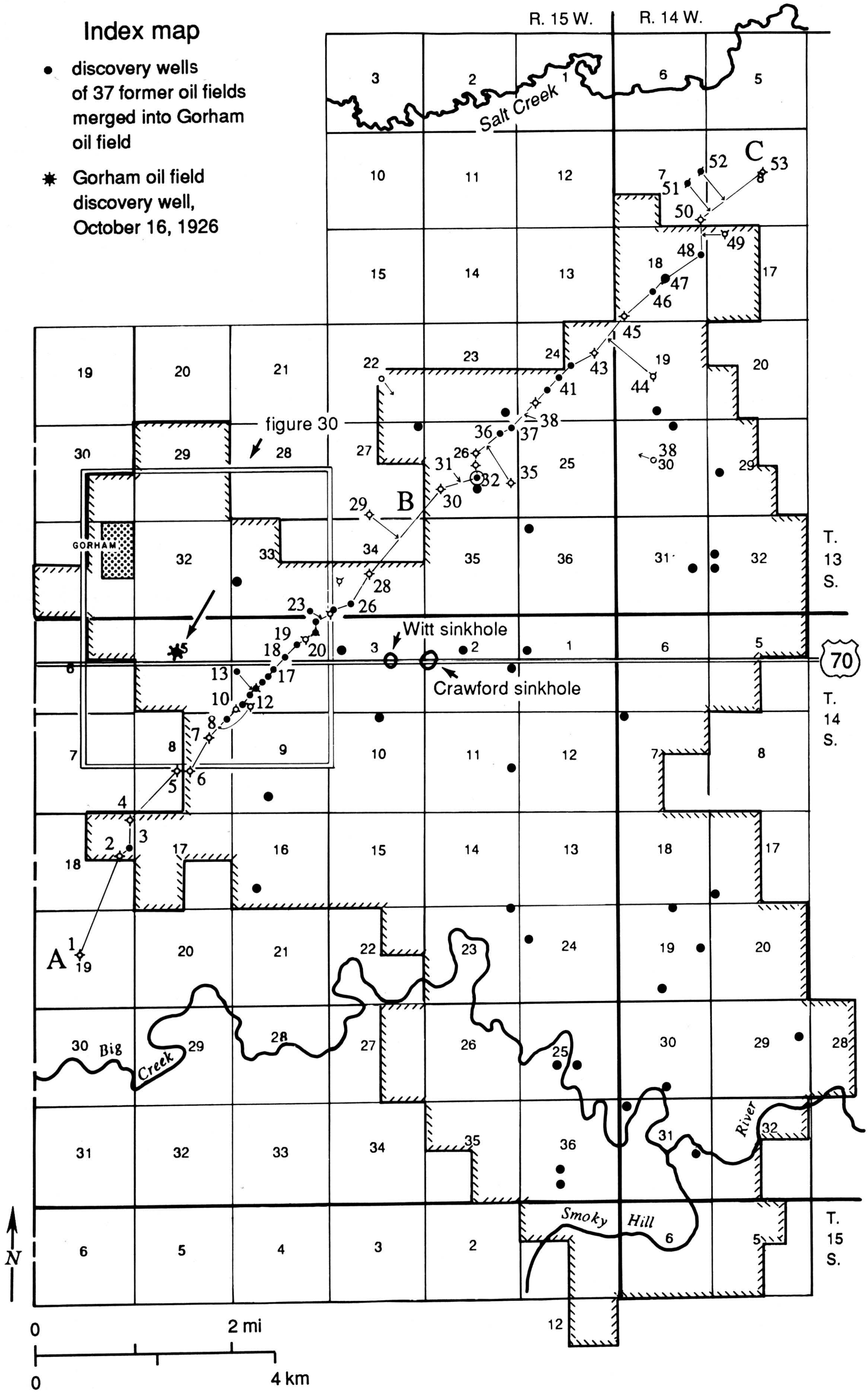
The author made extensive use of the resources of the Kansas Geological Society Library in Wichita, Kansas. Available to member geologists or to the public on a daily fee basis are extensive files of wire line geophysical logs, drilling-time logs, well-completion records, scout cards, drillstem test reports, geological reports written by the well-site geologist, and commercially prepared oil and gas production summaries on a lease by lease basis. (Publications of the Kansas Geological Survey also are available there but provide production information only by counties or oil fields, not by lease.)

The Kansas Corporation Commission (KCC) office in Wichita, Kansas, is the source of oil and gas production data, monthly, by leases. Production data are available to the public in the KCC office. The author found it much more convenient to access this information after it was abstracted by a commercial information company such as Petroleum Information, a company of the Dun and Bradstreet Corp. Well-plugging reports and saltwater disposal or injection well permits were inspected or purchased at the KCC office as they are not available elsewhere.

History

A summary of the development history of the Gorham oil field is included. In the 1970's the author

FIGURE 3—Index map of the Gorham oil field and vicinity. The squares are surveyed land sections of 1 mi^2 (640 acres [2.6 km^2; 256 hectares]), numbered from 1 to 36 in each township. All following geological maps are identical in area, but have the section numbers 1–36 omitted. The map shows the official boundaries of the Gorham oil field and the locations of 37 discovery wells of oil fields now merged into the Gorham oil field (listed in appendix, table 1). The original 1926 discovery well is shown by an arrow in sec. 5, T. 14 S., R. 15 W., near I–70 and near the town of Gorham. The map also shows locations of cross section A–B–C (figs. 5 and 6), the area included in the 1928 historical map (fig. 30), and the locations of the Witt and Crawford sink areas affecting I–70 (figs. 45 and 48). In the south portion of the map, Big Creek makes a 90° turn in its course in and near sec. 23, T. 14 S., R. 15 W., apparently controlled by underlying faulting in the Precambrian basement rocks (fig. 7).


Index map
discovery wells of 37 former oil fields merged into Gorham oil field
Gorham oil field discovery well, October 16, 1926
R. 15 W.
R. 14 W.
Salt Creek
figure 30
GORHAM
Witt sinkhole
Crawford sinkhole
70
T. 13 S.
T. 14 S.
T. 15 S.
A
B
C
Big Creek
River
Smoky Hill
N
0
2 mi
4 km

was investigating land subsidence in central Kansas related to salt dissolution caused by human activities (Walters, 1978). The geology of the Gorham oil field established that subsidence of I–70 was caused by dissolution of salt. However, to understand *why* salt was dissolved under the highway, and not under the entire oil field, required knowledge of the development and operating history of the Gorham oil field, including answers to many questions. When and how were wells drilled? How much casing was used? How was the casing cemented, if at all? How were the wells completed? How were the wells operated? How were the wells plugged after abandonment? Also required was an understanding of production problems. How were the large volumes of corrosive brine, produced along with the oil, handled? How did operators respond to severe corrosion causing casing leaks? While these questions were being investigated in the 1970's, Dr. William Hambleton, then Director of the Kansas Geological Survey (retired 1987), encouraged the author to record his knowledge of the development history of the Gorham oil field as representative of the history of the related, contemporaneous, major oil fields of central Kansas. Just as the thousands of oil derricks formerly present in the Gorham, Bemis, Hall–Gurney, Trapp, Kraft–Prusa, and Chase–Silica oil fields have entirely vanished (except in oil-field museums), so also the history of those oil fields, largely unrecorded, is rapidly vanishing. It should be preserved because the era represented a major new development in oil-field history. The oil fields of central Kansas, drilled from 1923 (Fairport) and 1926 (Gorham) through the 1940's, were characterized by prolific oil production from carbonate rocks (Arbuckle dolomite and Lansing–Kansas City limestones), at the shallow depths of 3,000–3,300 ft (900–990 m). Previously, sandstone reservoirs produced most of the oil from early oil fields as in Pennsylvania in the 1800's, in Oklahoma during the 1900's to 1920's, and in eastern Kansas, until the discovery of the El Dorado oil field in 1917. Dr. Hambleton and his successor Dr. Lee Gerhard considered it appropriate to conserve and publish this oil-field development history.

Environmental impact

Development of the Gorham oil field over 60 years is briefly reviewed in light of its impact on the environment in past years, at present, and in the future. Topics include subsidence, water supply, brine disposal, and agriculture.

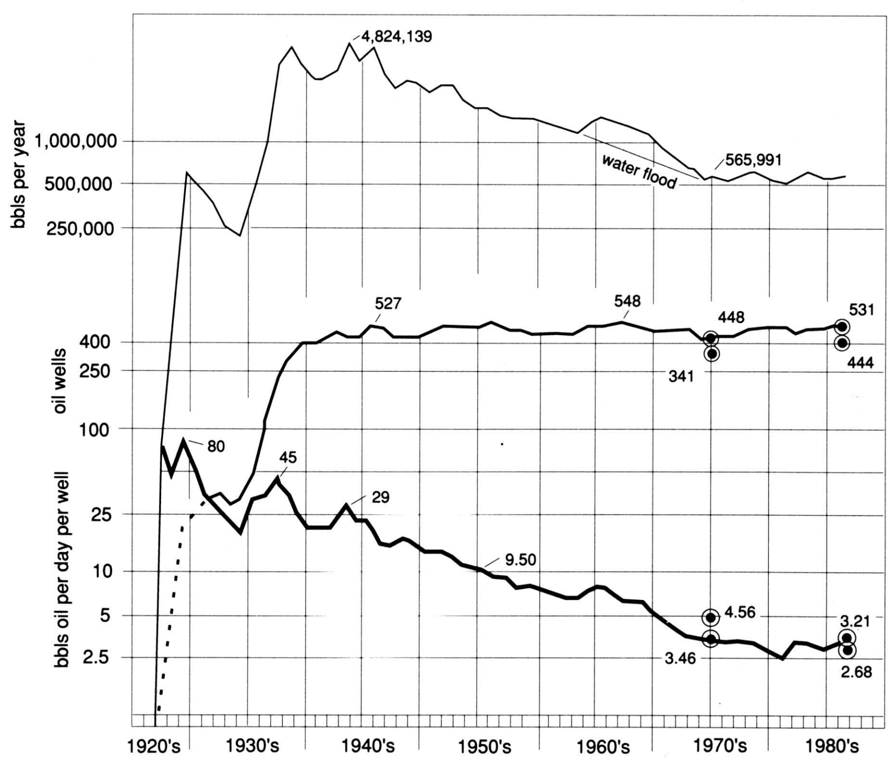


FIGURE 4—Oil production, Gorham oil field, 1926–1986. Upper graph, annual oil production in barrels of 42 U.S. gallons; middle graph, number of active producing oil wells; lower graph, average daily production in barrels of oil per day (BOPD) per oil well. In the peak year of 1942, annual production reached 4,824,139 bbls of oil from 457 oil wells or 28.90 BOPD per well. The influence of extensive waterflooding of Lansing–Kansas City zones in the 1960's is indicated by the term "waterflood." Field well counts by the author of 341 active oil wells in 1974 and 444 in November 1986 provide figures of 4.56 BOPD and 3.21 BOPD per well, modifying lower curve of BOPD per well. Statistics from which graphs were prepared are given in the appendix, table 2.

Geology

General

The Gorham oil field is localized by a 10-mi (16-km)-long northwest-trending anticline structurally controlled by block faulting in the Precambrian granite basement rocks. Cambrian Reagan Sandstone and Ordovician Arbuckle dolomite, thickness to 400 ft (120 m), are truncated to a thin edge and are absent on the upfaulted Precambrian high. Oil in the Arbuckle dolomite–Reagan Sandstone reservoir, the principal oil reservoir of the Gorham oil field, is associated with the pre-Pennsylvanian unconformity surface, depths near 3,300 ft (990 m). At the more shallow depths of 3,000–3,300 ft (900–990 m), Lansing–Kansas City limestones are draped over the major anticline and over local highs forming separate anticlinal oil reservoirs. The basement block faulting influences all the overlying sedimentary rocks of Pennsylvanian, Permian, and Cretaceous age, in diminishing amounts upward. The near-surface Fence-post limestone has 30 ft (9 m) of anticlinal closure, on which the 1926 discovery well of the Gorham oil field was located.

Cross section A–B–C

The overall relationship of the block-faulted basement rocks to the 3,300–3,700 ft (990–1,110 m) of overlying sedimentary rocks is demonstrated by cross section A–B–C, in two parts, figs. 5 (A–B) and fig. 6 (B–C). The cross section extends 14 mi (22.4 km) from southwest to northeast across the Gorham oil field as shown in fig. 3. The holes providing information used in constructing the cross section numbered consecutively from 1 to 53 are listed in the appendix, table 3, with pertinent information.

The cross section is based on many holes drilled with cable tools. These provide information on depths at which water was encountered as indicated by open circles within the body of the cross section. Where oil in commercial amounts was produced, solid dots are plotted at depths on the cross section. Arrows indicate water-flow direction. In the fresh-water supply wells 31 and 38, the arrows point toward the well bore. In shallow saltwater-disposal wells 8, 20, and 24, the arrows indicate injected waste saltwater flowing outward from the well bores into the porous formations. Lower in the cross section, wells 10, 13, and 21 are saltwater-injection (SWI) wells. In them, the outward-pointing arrows indicate where saltwater under pressure was introduced into the Lansing–Kansas City limestones in formerly oil-productive zones as part of a secondary-recovery project by waterflood. Deep saltwater-disposal wells (SWD) 44 and 49 have arrows depicting outward flows of large amounts of waste oil-field brines that were produced along with the oil and disposed of by gravity flow into porous Arbuckle dolomites, sandy dolomites, and sandstones.

The prominent fault shown between miles 3 and 4 affects all formations from the Precambrian to the outcropping Cretaceous Fence-post limestone in progressively lesser amounts upward. Although shown as a single nearly vertical fault, a zone of faulting almost certainly exists at least within the Precambrian rocks. Southwest (left) of the fault, on the downthrown side, Arbuckle beds 390 ft (117 m) thick are known from wells 2 and 3.

Another structural feature is the sub-Pennsylvanian surface, identified as an unconformity surface by the angular truncation of underlying Arbuckle beds. For an extended time period (denoted by the absence of Middle and Upper Ordovician, Silurian, Devonian, Mississippian, and Lower Pennsylvanian beds), this unconformity surface was a land surface subject to weathering, principally by dissolution of the soluble Arbuckle dolomite. The buried paleokarst features of sinkholes (wells 2, 4, and 34), the scalped sinkhole-free plain (miles 9 through 13), and the low areas with regional regolith of weathered, leached residuum of Arbuckle dolomite at

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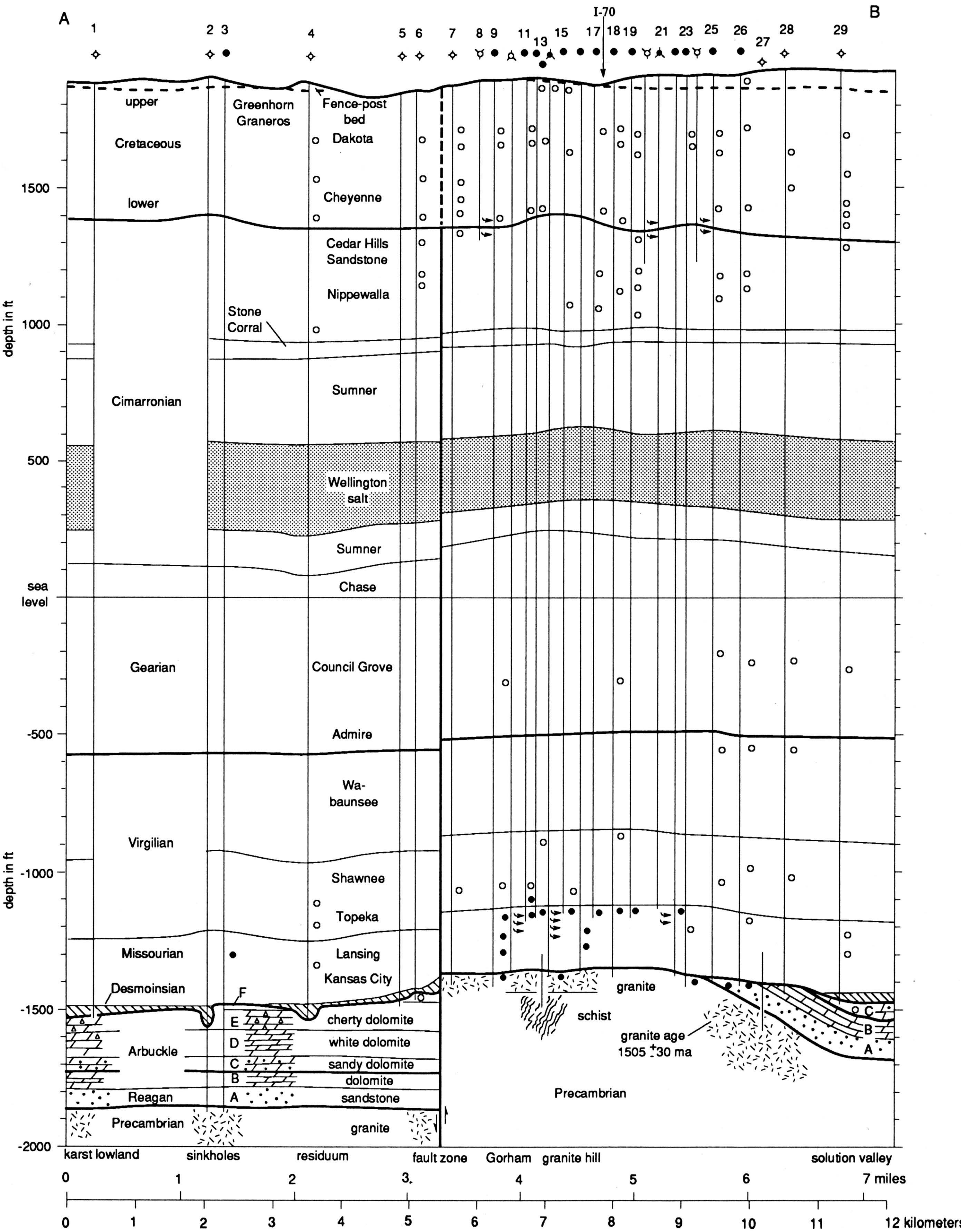
FIGURES 5 and 6 (over)—CROSS SECTION A–B–C, extending 14 mi (22 km) from southwest to northeast across the Gorham oil field; for location, see fig. 3. Control test holes numbered 1–53 are listed in the appendix, table 3. Solid dots indicate oil or oil-production zones. Open circles indicate water, usually showing the positions of aquifers from which water was recovered in test holes drilled with the now-obsolete cable tools. The vertical exaggeration ×13.2 causes dips in the Arbuckle beds to be oversteepened. Actual dips range from 1/4 of 1° to 2°. Descriptive terms below the cross section such as "karst lowland," "solution valley," etc., refer to the now-buried topography of the former pre-Pennsylvanian land surface, depths near and above sub-sea minus 1,500 ft in the cross section. The single fault between miles 3 and 4 is a zone of faulting in the granite basement rocks.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Fence-post
bed
Dakota
Cheyenne
Cedar Hills
Sandstone
Nippewalla
Stone
Corral
Sumner
Cimarronian
Wellington
salt
Sumner
Chase
sea
level
Gearian
Council Grove
Admire
Wa-
baunsee
Virgilian
Shawnee
Topeka
Missourian
Lansing
Kansas City
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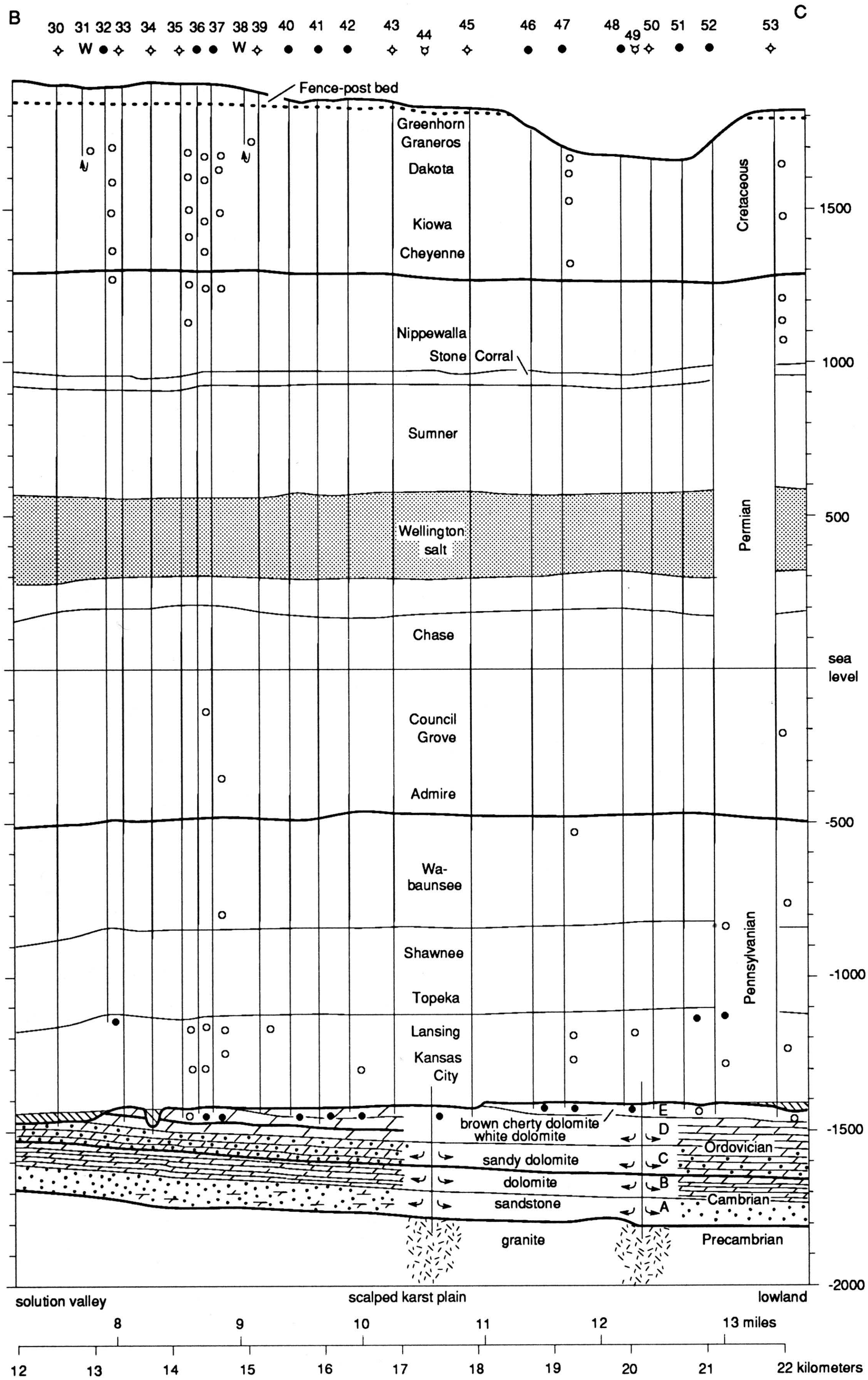
white dolomite
Arbuckle
C
sandy dolomite
B
dolomite
Reagan
A
sandstone
Precambrian
granite
granite age
1505 ±30 ma
Precambrian
C
B
A
depth in ft
1500
1000
500
-500
-1000
-1500
-2000
karst lowland
sinkholes
residuum
fault zone
Gorham
granite hill
solution valley
0
1
2
3
4
5
6
7 miles
0
1
2
3
4
5
6
7
8
9
10
11
12 kilometers


B
C
30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53
W
W
Fence-post bed
Greenhorn
Graneros
Dakota
Kiowa
Cheyenne
Cretaceous
Nippewalla
Stone Corral
Sumner
Wellington salt
Permian
Chase
sea level
Council Grove
Admire
Wa-baunsee
Shawnee
Topeka
Lansing
Kansas City
Pennsylvanian
brown cherty dolomite
white dolomite
sandy dolomite
dolomite
sandstone
granite
E
D
C
B
A
Ordovician
Cambrian
Precambrian
1500
1000
500
-500
-1000
-1500
-2000
depth in ft
solution valley
scalped karst plain
lowland
8
9
10
11
12
13 miles
12
13
14
15
16
17
18
19
20
21
22 kilometers

miles 0 to 3, wells 1 to 6, and wells 29, 30, and 53, are all evidence of a buried paleokarst topographic surface. The extensive unconformity-related oil reservoir in the Arbuckle dolomite and Reagan Sandstone is shown in figs. 5 and 6 by the numerous solid dots denoting oil production.

The Lansing–Kansas City beds over the local high, mile 1, and the regional high, miles 4 to 6, are local, anticlinal closures that form separate traps for oil in the porous Lansing–Kansas City limestones. Solid dots within the Lansing–Kansas City interval near mile 1 and miles 4, 5, 6, 8, and 13 indicate commercial oil production.

Higher in the section, the Hutchinson Salt Member of the Wellington Shale thins appreciably over both the regional high, miles 3–6, and the local high, mile 1. At still more shallow depths is the unconformity between the Permian and Cretaceous rocks. It has irregularities, only partly structural, including residual topography controlled by resistant lithology.

The cross sections indicate that the effects of the prominent basement fault are still manifest at the present land surface. Near-surface structural closure directly above the upfaulted granite was mapped at the time of the discovery of the Gorham oil-field anticline and confirmed by shallow core drilling to the Fence-post bed at depths of about 60 ft (18 m).

Cross sections A–B and B–C are drawn with a vertical exaggeration ×13.2. One effect of this is to increase the apparent dips on the cross section. For example, the slope on the Precambrian surface between miles 6 and 7 is drawn as 26° and the dip in the bedding of the Arbuckle is drawn as 22°. Actually the Precambrian surface slopes 200 ft (60 m) toward the northeast in 1 mi (1.6 km). This is a slope of a little over 2°. (A dip or slope of 91 ft in 1 mi [27 m/1 km] equals 1° angle.) The overlying Arbuckle beds dip 175 ft northeastward in 1 mi (52.5 m/1 km) or an actual dip of a little under 2°. Elsewhere, they are nearly flat, dipping only 25 ft per mile (7.5 m/1 km) or one-fourth of 1°.

Map series

Each map in the series of geological maps shows as control points only those test holes deep enough to reach the subsurface unit mapped, eliminating shallower tests. For example, the map of the Precambrian rocks, depth 3,300–3,700 ft (990–1,110 m; fig. 7), shows only those wells deep enough to penetrate into the Precambrian rocks. All more shallow test holes are eliminated. The 14 solid dots in fig. 7 indicate wells which produced oil from the Precambrian granite or quartzite.

In the series of maps, no distinction is made between oil wells active as of December 31, 1986, and oil wells abandoned prior to that date. All test holes drilled to or through the surface, zone, or unit mapped, which are not definitely known to produce oil from that interval, are shown as open circles regardless of whether they may or may not have produced oil from either shallower or deeper zones. There are no wells producing only gas.

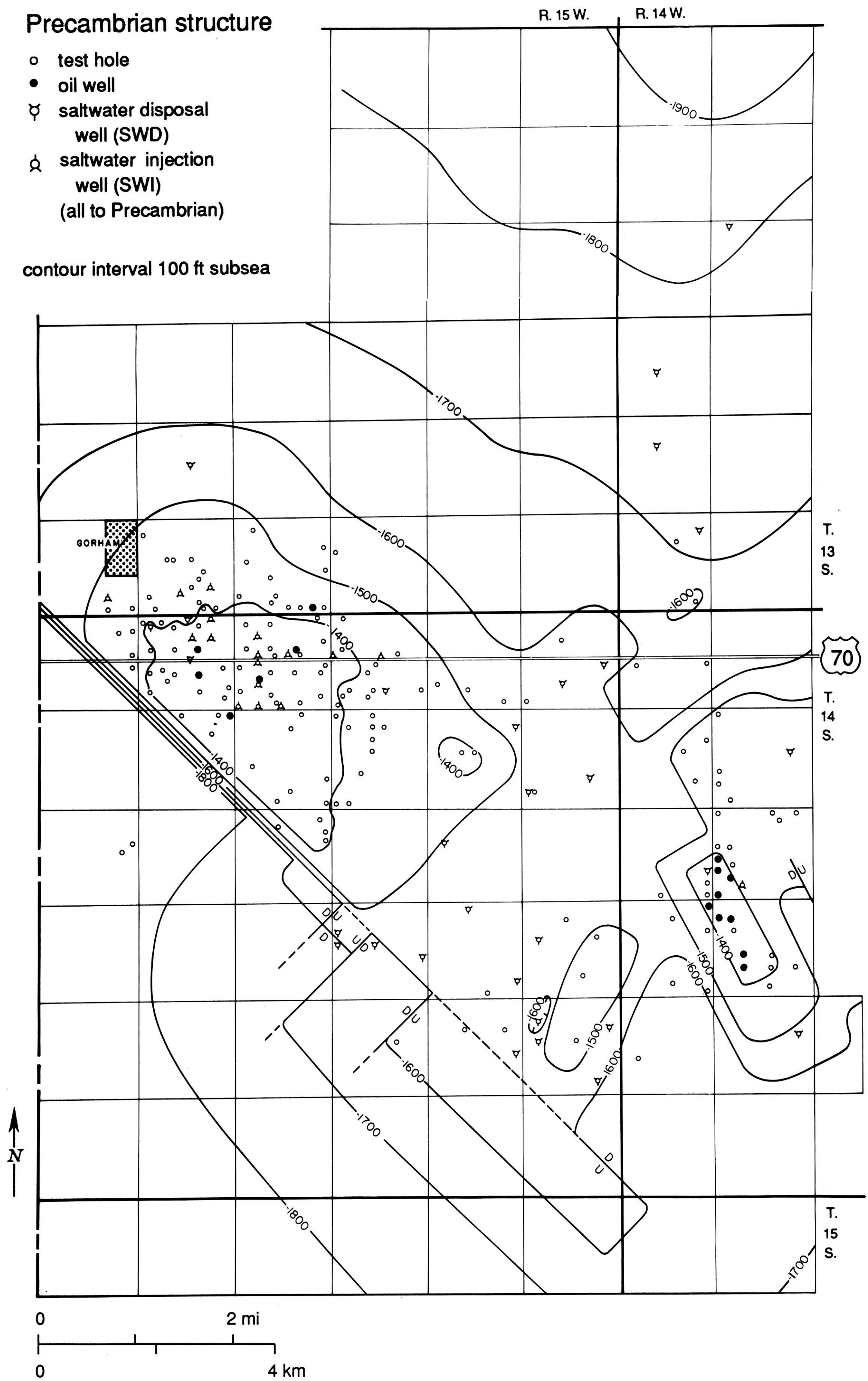
Even with this simplification, it is difficult to present the geologic maps on a single page because of the unusually large area, approximately 100 mi^2 (260 km^2) depicted on each map, and because of the close spacing of wells that were commonly drilled on 10-acre (4-hectare) locations in the older portion of the oil field. Some areas have been redrilled on 5-acre (2-hectare) spacing or as twin or even triple holes at one location. Many abandoned holes were reentered at a later date, often by a different operator. About 5% of the total reported drilling in the 1980's consisted of such reentry.

Precambrian basement rocks

Structure

The igneous and metamorphic basement rocks underlying the Gorham oil field are Precambrian in age. The basement-rock surface is mapped in fig. 7 with a contour interval of 100 ft (30 m). Only those tests actually penetrating Precambrian rocks are illustrated. Over 300 shallower wells (not shown) penetrating only part way through the Arbuckle Group were used for estimating depths to the Precambrian. The author's own identification of the stratigraphic position within the Arbuckle Group by examination of samples of well cuttings and acid

FIGURE 7—Precambrian structure; contour interval 100 ft (30 m) below sea level. Only control holes that drilled into Precambrian basement rocks are shown. Solid dots indicate the position of six wells near Gorham that produced oil from fresh Precambrian granite and nine wells that produced small amounts of oil from fractures in Precambrian quartzite on the summit of the Vaughn quartzite hill in T. 14 S., R. 14 W. The closely spaced contours south of the town of Gorham indicate a northwest-trending fault zone with more than 400 ft (120 m) of displacement down to the southwest. Cross faults with a northeast trend are mapped in secs. 21, 22, 27, and 28, near the center of T. 14 S., R. 15 W. Faulting is also established at the east edge of the map in T. 14 S., R. 14 W., and is probably also associated with the adjacent Vaughn quartzite hill.



Precambrian structure
test hole
oil well
saltwater disposal well (SWD)
saltwater injection well (SWI)
(all to Precambrian)
contour interval 100 ft subsea
R. 15 W.
R. 14 W.
T. 13 S.
T. 14 S.
T. 15 S.
GORHAM
70
-1900
-1800
-1700
-1600
-1500
-1400
D
U
N
0
2 mi
0
4 km

insoluble residues permitted him to estimate the depth to basement. This method was used almost exclusively to map the southwest flank of the Gorham anticline. Only six holes were actually drilled into the Precambrian rocks southwest of the Gorham oil field. Two are shown on cross section A–B (fig. 5), as wells 2 and 3.

The prominent northwest-trending Gorham anticline has a relief of 400 ft (120 m) on the southwest side as shown by the 100-ft contours in fig. 7. This is interpreted as a fault or fault zone. To the northwest, beyond the area mapped, the fault zone is intersected by a north-trending basement fault zone, which marks the west side of the Fairport anticline (Cole, 1962). Toward the southeast the displacement decreases and the fault zone cannot be mapped beyond sec. 36, T. 14 S., R. 15 W. In sec. 22, T. 14 S., R. 15 W., four deep saltwater-disposal wells were reportedly drilled to the Precambrian. Records are poor and samples were not saved; nevertheless, these wells suggest northeast-trending cross faults. If control were equally abundant elsewhere, it is probable that the Precambrian basement rocks would be recognized as extensively block faulted.

Granite

The Precambrian rock most commonly encountered in the 100 mi^2 (260 km^2) study area is granite. Coarse quartz grains, salmon pink orthoclase feldspar, and accessory biotite characterize this typical "tombstone granite."

Farquhar (1957), in his petrographic study *The Precambrian rocks of Kansas* recognized two types of granite: 1) "earlier" granitic gneiss or gneissic granite—metamorphic, foliated, folded, and interbanded with metasediments, quartzite, and schists; age undated, but probably about 1,500 million years (m.y.) old; and 2) "later" intrusive granite—post metamorphic, batholithic; age undated, but younger.

In both types of granite, the principal minerals are

Quartz	25–30%
Orthoclase and microcline	40–50%
Plagioclase	20–25%
Muscovite	2–3%
Biotite	1–2%
Accessory minerals (magnetite, zircon, sphene, hornblende)	0.5–1%

Farquhar states that the two granites differ greatly in origin with the "later" emplaced as an igneous rock mass of batholitic proportions, whereas the "earlier" granites were intrusive into sedimentary rock and were metamorphosed along with them into a series of quartzites, schists, and granite gneisses, banded and folded together. The principal physical distinction between the two granite types is foliation, or gneissic and/or schistose character. The small size of well cuttings, whether cable tool or rotary, usually makes distinction between the two granite types impossible, and both are here described simply as "granite."

The granite is fresh and unaltered at depth but is weathered on its upper surface due to exposure on one or more ancient land surfaces. Where weathered, the granite drills rapidly and is termed "granite wash," although it has not been transported or "washed" but is weathered in situ. This was verified in a core taken under the author's direction on Heathman Drilling Company's Polcyn #1 well, in the C SE SW SE sec. 31, T. 13 S., R. 15 W., in 1951. Farquhar (1957, p. 100 and plate 9) studied and illustrated the granite in this core, which he placed in the "earlier" granite group. He states:

> A core through the Precambrian from a well in Russell County (31–13S–15W) shows weathered granite rather than granite wash. Both of these descriptions are applied frequently, and perhaps interchangeably, to the uppermost Precambrian rocks, but this core shows conclusively the nature of the rock at one particular point. The textural characteristics are retained and weathering has merely taken place in situ. The rock is strongly foliated and contains reddish feldspars in small lenses, typical of gneiss.

The Heathman Polcyn test hole from which the described core was taken is not shown on the cross section A–B (fig. 5), but could be projected into that cross section near mile 4. Note that well 13, also projected into the cross section near mile 4, encountered comparable weathered granite in the top 6 ft (1.8 m) of penetration, then 70 ft (21 m) of fresh pink biotite granite overlying 50 ft (15 m) of schistose dark-red metamorphic rock, for a total penetration of 126 ft (37.8 m) in the Precambrian. The author examined the excellent short cable-tool samples in 1942 from this well, the Stanolind No. 6 W. E. Benso in the C NW NW SW sec. 4, T. 14 S., R. 15 W.

In the years since Farquhar's study of Kansas basement rocks, extensive investigations of the Precambrian in the midcontinent have been made. These include studies by Muehlberger et al. (1966), Bickford et al. (1981), Denison et al. (1984), Berendsen and Blair (1986), Bickford et al. (1986), Van Schmus et al. (1987), and Van Schmus and Bickford (1988). The area of the Gorham oil field is within the 1,550–1,700 m.y.-old Central Plains province (Bickford et al., 1986), the loosely defined south border of which passes through central Kansas in an east-west direction. The younger Western Granite–Rhyolite province, 1,340–1,400 m.y. old, is located in southern Kansas, most of Oklahoma, and in the Texas Panhandle. None of the regional studies cited provides lithologic descriptions or age dates for Precambrian rocks within the 100-mi^2 (260-km^2) study area. One unpublished date for granite from within the limits of the Gorham oil field was furnished by Bickford (personal communication, 1988, sample KKSRS–573). The date is for granite from the Brougher Oil, Inc. #8 Mills–B in the C NE NE SE sec. 33, T. 13 S., R. 15 W., which penetrated 143 ft (42.9 m) into the Precambrian granite. Hand-picked cuttings from that test were analyzed at the University of Kansas as part of "Project Upper Crust." The #8 Mills–B is shown as well 27, cross section A–B (fig. 5), between miles 6 and 7. The age of the granite was determined as 1,505 ± 30 m.y., by the uranium-lead-zircon method of dating.

Quartzite

Two types of Precambrian quartzite are encountered. The first, consisting of coarse quartz grains tightly cemented by silica, is difficult to drill with rotary tools; penetrations are short. Sometimes it is even considered "impenetrable." When drilled with cable tools, the cuttings of such quartzite show the grains shattered by percussion drilling and the cuttings superficially resemble broken glass. These quartzites are encountered on the highest parts of the buried quartzite hills.

The second type of quartzite has minor amounts of light-colored mica, ferromagnesian minerals, or chlorite-weathering products. Such quartzites drill easily. The twisting action of rotary bits shucks out the quartz grains, sometimes without fracturing them. The rapid drilling rate, often unsupervised, resulted in penetrations of a hundred feet or more. Because such long penetrations sometimes show little change in lithology (Walters, 1953), these metamorphic quartzites may have steep to near-vertical dips. However, Berendsen (personal communication, 1989) notes that the Mount Simon Precambrian sediments look the same for hundreds of feet. An example of the second type of granular, speckled quartzite occurs in the Ohio Oil Company's #5 J. Harbaugh, C SE SW NW sec. 25, T. 14 S., R. 15 W. Granular schistose quartzite was drilled from 3,260 to 3,400 ft (978–1,020 m), a 140-ft (42-m) penetration with cable tools. The quartz grains show sub-parallel orientation and include black specks of magnetite. A dark, shiny, black ferromagnesian mineral is a common accessory. Clear mica fragments to 3 mm in size are present in the cuttings. The speckled granular schistose quartzites characteristically drill relatively rapidly. One mile (1.6 km) west of the J. Harbaugh #5 SWD, the Waudby #3 in the C N SE NW sec. 26, was recompleted as an SWD well in 1983. It was drilled in the Precambrian from 3,432 to 3,526 ft (1,030–1,058 m) TD in schistose quartzite for a 93-ft (28-m) penetration.

Farquhar (1957, p. 68) describes the petrography of the granular quartzites, which he calls "foliated metasediment quartzites": "The chief mineral is quartz, but almost all the samples contain some white mica to 8% by volume. Feldspar, epidote, chloritized biotite, magnetite, and graphite are present in small quantities, the dark minerals giving the rock a slightly speckled appearance."

Both granular quartzite and fractured hard quartzite occasionally serve as commercial oil reservoirs located on the summits of buried Precambrian quartzite hills. There are nine such Precambrian quartzite oil wells on the summit area of the Vaughn hill indicated by solid dots on the Precambrian map (fig. 7). On the Krug quartzite hill, four holes showed oil in the Precambrian quartzite, but no commercial production resulted.

Schist

Schist is not commonly encountered under the Gorham oil field. Schist associated with granite was encountered in the Stanolind No. 6 Benso in sec. 4, T. 15 S., R. 14 W., cross section A–B (fig. 5, well number 13). Schistose dark-red metamorphic rock 40 ft (12 m) thick was encountered under 74 ft (22 m) of fresh pink biotite granite as shown by excellent short samples of cable-tool well cuttings. In the eastern portion of the Gorham oil field, quartz muscovite schist associated with quartzite (Farquhar, 1957, p. 69) was encountered in sec. 17, T. 14 S., R. 14 W. An excellent example of Precambrian schist occurs just east of the area mapped. In sec. 21, T. 14 S., R. 14 W., Hall–Gurney oil field, biotite hornblende schist with well-developed schistosity was drilled as described and illustrated by Farquhar (1957, p. 74 and plate 3–F).

Buried Precambrian hills

As shown on the Precambrian map (fig. 7), tests that penetrated granite, and no other rock type, are abundant southeast of the town of Gorham. There the highest portion of a broad, low-relief area of upfaulted granite is defined by the subsea -1,400-ft contour. When exposed in Early Pennsylvanian time on the sub-Pennsylvanian land surface, this area was a broad flat-topped hill, for convenience named "Gorham granite hill." On this high area or buried flat-top hill, the granite itself rarely serves as a reservoir for commercial amounts of oil produced from fractures in the granite subjacent to the unconformity surface beneath the Pennsylvanian beds (Walters, 1953). Six wells, the only ones known to have produced oil from granite within the Gorham oil field, are indicated on the Precambrian map by solid dots, and three of them are also shown on the cross section (fig. 5) as wells 9, 14, and 23. Ten other holes that drilled into granite on the Gorham granite hill were reported as having noncommercial oil shows in weathered "granite wash."

A second high area on the Precambrian map is also defined by the –1,400-ft contour. It occurs in secs. 17–20, T. 14 S., R. 14 W. Here the Precambrian rocks are resistant metamorphic quartzites consisting almost entirely of coarse quartz grains with accessory black magnetite and light-colored mica. This area of quartzite is a residual hill on the Precambrian surface. Oil is produced from overlying shallower beds, principally in the Lansing–Kansas City, that are draped over the quartzite hill. This is the area of the former Vaughn oil field, now merged into the Gorham oil field. For convenience, the Precambrian hill, rising 200 ft (60 m) or more above the general level of the basement rocks, is called the "Vaughn quartzite hill." It has a steep southwest flank that is probably downfaulted but is mapped as a slope because the known 240 ft (72 m) of relief in 0.75 mi (1.2 km) is a slope of only 3.5°.

A second Precambrian buried-quartzite hill, for convenience called the "Krug hill," is located 1 mi (1.6 km) north of the Vaughn hill. On Krug hill, in sec. 8, T. 14 S., R. 14 W., Pennsylvanian beds directly overlie Precambrian quartzite identified in four test holes at depths of subsea –1,410 to subsea –1,424 ft (–423 to –427 m); hence, Krug hill is not defined on the Precambrian map by the 100-ft contour interval.

Structural control

A fundamental theme of this report is that the structural framework or position of the Precambrian basement directly affected all younger rock layers. This is true of the residual quartzite hills, the upfaulted broad granite area, and the low-lying areas. These Precambrian basement rocks, encountered at drilling depths of 3,300 ft (990 m) in the high areas to 3,700 ft (1,110 m) in the low areas, exert a controlling influence on all shallower structural features. The amount of fault displacement, 400+ ft (120+ m) at the Precambrian level on the southwest flank of the Gorham anticline, diminishes upward but is still present to the extent of 30 ft (9 m) of closure in the near surface or outcropping Fence-post limestone beds.

Cambrian Reagan Sandstone and Cambro–Ordovician Arbuckle Group

Thickness

Overlying the Precambrian basement rocks in the vicinity of the Gorham oil field are basal dolomitic sandstones, thought to be of Cambrian age, with a thickness of as much as 90 ft (27 m). These porous, permeable sandstones, together with dolomites and sandy dolomites of the Arbuckle Group, have a thickness of over 400 ft (120 m) in the Gorham area. All have been gently tilted, then truncated by one or more periods of post-Ordovician erosion as shown on cross sections A–B and B–C (figs. 5 and 6).

Acid insoluble residues

Mapping of units within the Arbuckle Group is based on the author's examination of well cuttings from 261 selected tests in the area that were drilled with cable tools. Acid insoluble residues prepared from cable-tool cuttings of the carbonate rocks were logged on a scale of 10 ft/inch (1.2 m/1 cm). This detailed study permitted recognition of five units within the Arbuckle Group and provided a basis for correlating within the Arbuckle from well to well. The recognition of these units was essential to understanding the geology of the Gorham anticline. These units are difficult or impossible to recognize in cuttings from rotary-drilled wells or from wire line logs with the usual short penetrations of the Arbuckle (under 30 ft [9 m]).

Acid insoluble residues were prepared by dissolving a small, weighed amount of well cuttings in 15% HCl acid, then weighing the dry undissolved residue. Actually, nothing is present in the acid insoluble residues that was not present in the original well cuttings but the insoluble residues of sand grains, chert, loose silicified oolites, and rare shale are more readily seen. In addition, even quite small amounts of some residue are diagnostic of certain beds. For example, near the top of the white dolomite member, which is characterized by its purity and low residue content, as much as 5% by weight of diagnostic fine druzy branching quartz crystals are present in residues, yet the quartz druze cannot be distinguished in the original dolomite cuttings. The residue work was originally undertaken seeking a correlation between recognized beds in the Arbuckle and their oil-reservoir properties. The study was tedious, slow, costly, destructive of a few ounces of samples of cuttings, and was only partly successful. Samples from modern rotary-drilled holes are not suitable material unless hand picked fragment by fragment, which introduces a bias concerning how much chert and which chert should be included. Acid insoluble residue work is no longer undertaken as part of a commercial oil-exploration program.

Correlation

The lithologic terms used to describe the various mapped Cambrian and Ordovician units in the Gorham oil field and their probable correlation with the standard named outcropping units in Missouri are shown in chart form as fig. 8. Regional correlation is hampered because essentially no fossils are preserved in these dolomites and sandstones and no unique lithologic bed, such as a volcanic ash, is present. However, the local correlations shown in fig. 8 of the Gorham oil field for the Reagan and Arbuckle beds A, B, C, D, E, and F, with the Arbuckle beds in the Bemis oil field to the northwest and the Hall–Gurney, Kraft–Prusa, and Stoltenberg oil fields to the southeast, is consistent for 60 mi (96 km) based on the author's examination of well cuttings and acid insoluble residues (Walters, 1946, 1948, 1956). Fig. 8 is not to scale horizontally but is accurately scaled vertically to show the relative thickness of the named members. It also illustrates the regional disconformity between the Upper Ordovician Simpson shale and the Lower Ordovician Arbuckle Group.

The history of attempts to correlate the subsurface Arbuckle beds of central Kansas with the much-studied outcrops and shallow subsurface in Missouri began with the work of Keroher and Kirby (1948), who made a reconnaissance study of the Arbuckle rocks in Kansas, utilizing acid insoluble residues. They examined only 24 wells in the west ranges of Kansas. None was in Russell County. They recognized that Arbuckle beds of Ordovician age over-

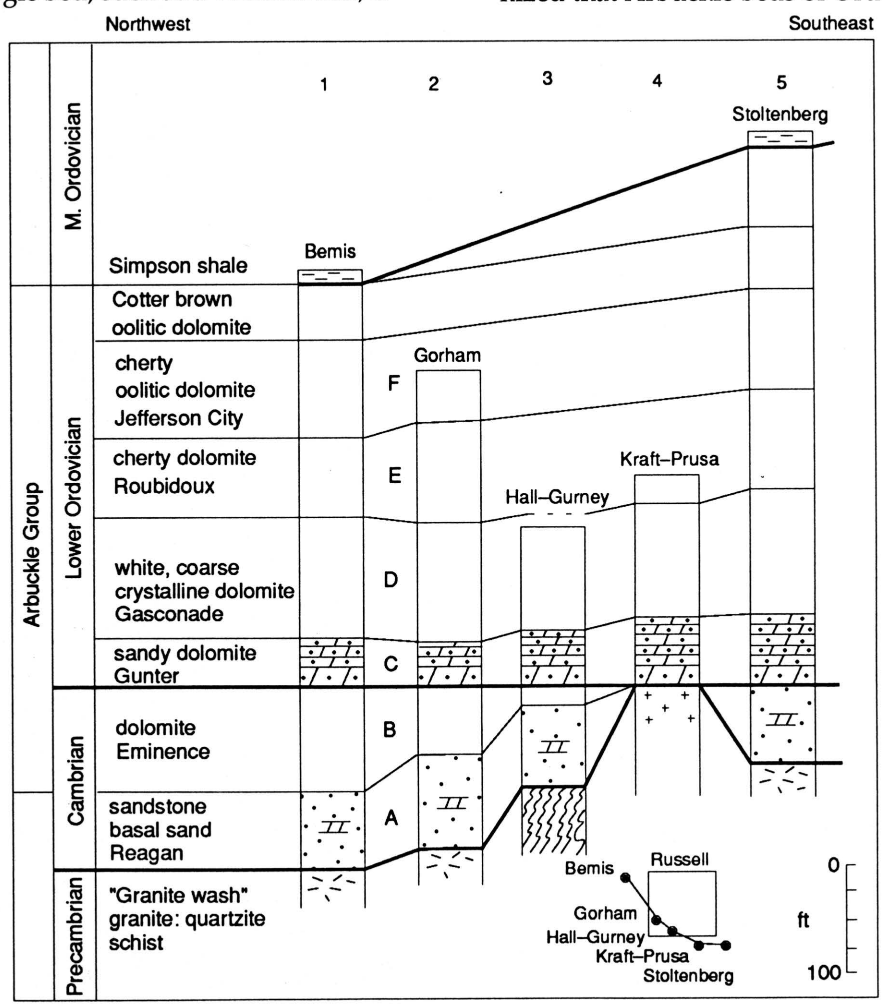


FIGURE 8—Correlation of Reagan Sandstone, unit A, and Arbuckle units B, C, D, E, and F of this report with beds in other central Kansas oil fields and with formations named from Missouri outcrops. Correlations are based on the author's acid insoluble residue and lithology studies. Vertical scale as shown, but not to scale horizontally.

lapped Precambrian rocks and that the unit termed "sandy dolomite" in this report was deposited directly on Precambrian rocks in central Kansas, but they correlated that unit with the Roubidoux, rather than with the Gunter Formation.

McCracken (1955) correlated the upper Arbuckle beds from Missouri into central Kansas using acid insoluble residue criteria. His published cross section included the Simpson and Noble No. 1 Pulliam in sec. 35, T. 19 S., R. 8 W., in the Chase–Silica oil field, Rice County, Kansas, about 20 mi (32 km) southeast of the Stoltenberg oil field (fig. 8). Beds he designated below the Simpson shale as Cotter, Jefferson City, and Roubidoux, in downward sequence, correlate in position, thickness, and lithology with beds so named in fig. 8, column 5, Stoltenberg oil field. Chenoweth (1967) reconstructed the late Cambrian and early Ordovician history of the southern midcontinent including Kansas. He correlated the lower Ordovician Arbuckle beds in Kansas as Roubidoux, Gasconade, and Gunter, in downward sequence, overlying the Cambrian dolomites which he correlated as Eminence–Potosi. It is, therefore, probable that the central Kansas Arbuckle dolomite and the Reagan Sandstone correlations with the Missouri section are correct in fig. 8, even though correlations for 200 mi (320 km) are based on lithologic similiarities and/or progressive changes in lithology unconfirmed by fossil evidence.

Information compiled in fig. 8 is derived from the following wells or composite sections:

1. Bemis field Ellis County	L. H. Wentz #2 Fred Bemis	C SE NE NW sec. 28, T. 11 S., R. 17 W.
2. Gorham field Russell County	composite section	T. 13 S., R. 14 & 15 W. T. 14 S., R. 14 & 15 W.
3. Hall–Gurney Russell County	Empire A–3 Krug	C NE NW NW sec. 24, T. 15 S., R. 14 W.
4. Kraft–Prusa Barton County	composite section	T. 16 S., R. 11 & 12 W. T. 17 S., R. 11 & 12 W.
5. Stoltenberg Ellsworth County	Magnolia #6 Schroeder	C E NW SW sec. 26, T. 16 S., R. 10 W.

The lithologic descriptive names and the letters A–B–C–D–E–F are used in the following descriptions of lithology and reservoir characteristics rather than the names of the presumed equivalent beds in Missouri and Oklahoma.

Lithology

A—Reagan Sandstone

The thickness of this unit varies from a thin edge to as much as 90 ft (27 m). The formation consists of clean quartz sandstone with some recrystallized pointed grains, sometimes doubly terminated. The terms "Reagan Sandstone," "basal sandstone," and "Gorham sandstone" are applied to this sandstone, which is an excellent, persistent, and prolific oil reservoir in its truncated updip edge within the Gorham oil field. Saltwater fills the pore space in the extensive downdip deeper areas providing a strong natural water drive as oil was removed. These sandstones become coarser downward with basal gravels, which include little feldspar or locally derived material from the underlying Precambrian basement rocks. These sandstones, where unleached, have 10–20% dolomite cement. The Reagan Sandstone unit is thought to be of Cambrian age. It is absent in the eastern portion of the area mapped where the Ordovician sandy dolomite member, bed C, overlaps directly on Precambrian quartzite. It also is absent over the considerable upfaulted area southeast of the town of Gorham from which it was removed by erosion in pre-Pennsylvanian time.

B—Dolomites

These light-colored dolomites are coarse to finely crystalline, sometimes sandy, and in part have minor chert. They have variable reservoir qualities from poor to excellent. They vary locally in thickness from 60 ft (18 m) to absent by overlap and/or by truncation. The lithology also varies, becoming sandy in some areas near the quartzite hills, which were islands during the deposition of these dolomites. The dolomites of unit B are thought to be Cambrian in age. They are difficult to distinguish from Arbuckle dolomite described as unit "D" and are impossible to distinguish when short penetrations of white, coarsely crystalline dolomites are drilled.

C—Sandy dolomite

The thickness of this unit is 40–50 ft (12–15 m). It consists of light-colored dolomite with up to 50% included sand grains. It becomes a fair to good oil reservoir where porosity is solution-enhanced. Severe and prolonged weathering on the sub-Pennsylvanian paleo-land surface caused sand grains to weather out by dissolution of the dolomite matrix leaving a residual sand called "Gorham sandstone," which is sometimes confused with the Cambrian Reagan Sandstone by local operators. Sand grains in the sandy dolomite member become finer downward rather than coarser as is the case with the Cambrian sandstones. Red grains are present in sparse amounts. A quartzitic crust of secondary silica commonly forms at the unconformity surface as part of the weathering process. This is sometimes called "quartzite" and is confused by operators who do not distinguish this residual quartzitic sandstone from Precambrian quartzite in test holes with short penetration. The sandy dolomite is basal Ordovician in age. In the eastern portion of the Gorham area on the Vaughn and Krug buried-quartzite hills, the sandy dolomite unit overlaps directly on Precambrian quartzite with beds B and A missing by overlap. In other central Kansas areas, this unit was deposited directly on Precambrian rocks as in the Kraft–Prusa oil field (Walters, 1946).

D—White dolomite

These white, coarsely crystalline dolomites, thickness to 100 ft (30 m), have a low insoluble residue content and are nearly pure dolomite. The lowest 10–15 ft (3–4.5 m) include 5% rounded sand grains. These white dolomites formed an excellent oil reservoir due to enhancement of porosity by partial dissolution due to weathering on the unconformity surfaces. In some areas as shown on the cross section (fig. 5), fractures enlarged by solution then filled with insoluble residual material (popularly called "conglomerate") interrupt the continuity of the Arbuckle oil reservoirs. These are interpreted as former sinkholes developed on the sub-Pennsylvanian land surface as part of a paleokarst terrain.

E—Cherty oolitic dolomite

These brown to white, variably crystalline dolomites have a nearly uniform thickness of 90 ft (27 m). They are characterized by distinctive brown quartzose oolitic cherts, white translucent cherts, and "floating" individual rounded frosted sand grains. This unit is considered Ordovician. It provides an erratic, commonly poor oil reservoir.

F—Cherty dolomite

The buff to brown dolomites of this unit are comparable to those described in "E" but with larger amounts of translucent to milky chert. The subcrop of this unit occurs in the northeast corner of the map in secs. 5 and 6, T. 13 S., R. 14 W. with a control hole in sec. 31, T. 12 S., R. 14 W. and in the downfaulted area south of the town of Gorham.

Sub-Pennsylvanian surface

Bedrock areal geology

The distribution of units A, B, C, D, E, and F is mapped in fig. 9. The Arbuckle beds have a concentric distribution outward from the area of subcrop of Precambrian granite. Their distribution depicts an unconformity surface developed across gently dipping rocks. The distribution pattern dramatically defines the major faulted anticline underlying the Gorham oil field. Faulting on the southwest flank is clearly post-Arbuckle with the increase in amount of fault displacement westward to the west edge of the map indicated by the presence of progressively younger Arbuckle beds in a westward direction adjacent to the fault. Also apparent from the areal geology map of the sub-Pennsylvanian surface is the onlap relationship of Arbuckle beds to the Vaughn and Krug quartzite hills in T. 14 S., R. 14 W., where the Ordovician sandy dolomite unit, bed C, overlaps on Precambrian quartzite ("Q" in fig. 9).

The discrimination of lithologic units within the Arbuckle Group permits determination of bedding planes. Dips within the Arbuckle are commonly 25 ft/mi (7.5 m/km) or 0.25 of 1°. The carbonate rocks that cropped out on the nearly flat sub-Pennsylvanian land surface were subject to erosion by dissolution in Early Pennsylvanian time in the warm, humid climate indicated by the Desmoinesian-age coal beds formed in swamps in what is now eastern Kansas. The topography of the unconformity surface or paleo-land surface developed across the truncated Arbuckle beds, the granite hill, and the two quartzite hills is the subject of the next section.

Surficial rocks

To understand the geology of the sub-Pennsylvanian unconformity-related oil reservoir, the principal reservoir of the Gorham oil field, it was necessary not only to distinguish among the Arbuckle beds mapped in fig. 9 (bedrock areal geology), but also to understand the surficial deposits derived from those beds by weathering on the pre-Pennslvanian unconformity.

"Gorham sand" in the Gorham oil field

The name "Gorham sand" is much used in oil-field communication and reporting. It is a useful practical term. "Gorham sand" is applied to any sandstone above or below the sub-Pennsylvanian unconformity, near the town of Gorham, Kansas, or in the adjacent oil fields. It is encountered at depths near 3,300 ft (990 m). Many sandstones of widely different age and origin are covered by the term. The name "Gorham sand" is particularly useful because many of the unconformity-related sandstones of Precambrian, Cambrian, Ordovician, and Pennsylvanian age cannot be distinguished in short well penetrations. All may be oil stained, oil saturated, or oil productive, adding further to the confusion and the interest. Five sandstones covered by the local general term "Gorham sand" are next discussed with criteria for distinguishing among them.

Gorham sand 1

The popular name "Gorham sand" was first used in January 1928 (Folger and Hall, 1933, p. 78), but those authors preferred to call the sandstone "Pennsylvanian basal conglomerate" as did Kesler (1928) and Koester (1934). All were describing the Cambrian Reagan Sandstone or basal sandstone, which occurs at the unconformity surface near the town of Gorham. In that vicinity the Reagan Sandstone rests directly on Precambrian basement rocks and underlies either Pennsylvanian beds or the Arbuckle dolomite. Lithology consists of quartz sand grains, quite pure, almost monomineralic. The sand grains, in part rounded and frosted, are fine in the top 20 ft (6 m), increasing in coarseness downward to a basal zone of pebbles 2 mm or more in diameter. Part of the grains are characterized by clear crystalline quartz overgrowths resulting in a pointed, angular, quartz-crystal shape. This nearly pure quartz sandstone is the result of in situ leaching of the basal dolomitic sandstone member during Early Pennsylvanian time and earlier by downward and lateral movement of fresh meteoric water. Slight vertical compaction occurred with no horizontal movement. The Reagan Sandstone forms a most important and prolific oil reservoir in the Gorham oil field. This reservoir has a strong water drive with excellent oil recoveries. With short penetrations, as is commonly the case when oil is encountered, the basal sandstone cannot be distinguished lithologically from other sandstones next described.

Gorham sand 2

This sandstone consists of pure quartz grains derived directly and locally from the Cambrian basal sandstone described as Gorham sand 1. In Early Pennsylvanian time, the sand grains were eroded, locally transported perhaps only a few hundred feet, and redeposited. If the sands were redeposited on in situ sandstone 1, then sandstone 2 is indistinguishable from 1 and may be a part of the common oil reservoir. If redeposited on Arbuckle dolomite, the sandstone is distinguished from 1 by its position. Commonly such redeposited locally transported sandstones are isolated lenses that are limited oil reservoirs yielding small quantities of oil by dissolved-gas drive. The term "Gorham sand" is appropriate for Gorham sand 2.

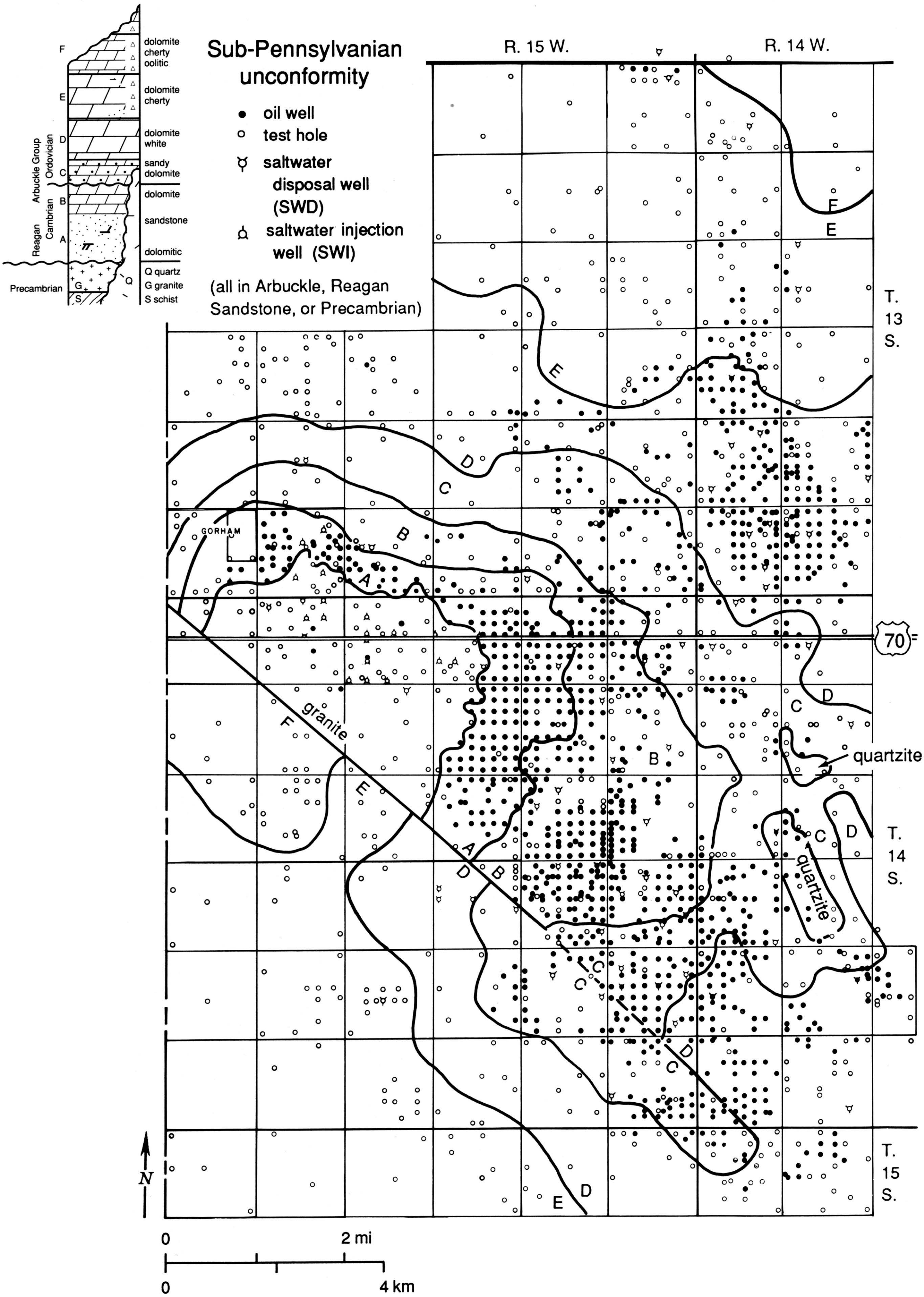
Gorham sand 3

The quartz sand grains of Gorham sand 3 are the same as in 2 but have been transported a further distance and mixed with other material, commonly red clay and oxidized bright-colored cherts, some oolitic. This is variously called "conglomerate," "sandy conglomerate," or "Gorham sand." Because of the clay content, this member is not a commercial oil reservoir. The term "Pennsylvanian basal conglomerate" or "conglomerate" is used in this report for such mixed transported material. Where untransported and weathered in situ, the term "residuum" is used.

Gorham sand 4

The quartz sand grains of Gorham sand 4 are a residual sandstone deposited on the Early Pennsylvanian land surface. They were formed by dissolving the dolomite content of the sandy dolomite unit of the Arbuckle, bed C, which is commonly 50% sand grains and 50% dolomite crystals. The sand grains have not been moved except by compaction. Weathering on the paleo-land surface not only removed the dolomite but also commonly developed a hard siliceous crust by cementation of sand grains with silica into a sedimentary quartzite. Sand grains become finer downward and include rare bright red grains. This member is variably a poor, fair, or good oil reservoir. It is variously known as "Gorham sand" or "quartzite" or even "quartzite sand." It is often confused with quartzite of Precambrian age, particularly where penetrations are short. Gorham sand 4 is termed Arbuckle "residual sandstone" or "residuum" in this and previously published reports (Walters, 1946).

FIGURE 9—SUB-PENNSYLVANIAN BEDROCK AREAL GEOLOGY. The mapped distribution of five units within the Arbuckle (Ordovician and Cambrian), the basal Reagan Sandstone (Cambrian), and the subcrops of granite and quartzite (Precambrian) defines a major faulted anticline underlying the Gorham oil field. Post-Arbuckle downfaulting on the southwest flank involves progressively younger beds westward, indicating an increase in amount of post-Arbuckle fault displacement to over 100 ft (30 m) at the west edge of the mapped area. The total present relief is 150 ft (45 m) on this unconformity surface. The overlap of Ordovician Arbuckle beds on Precambrian also is shown by the areal distribution pattern. The Vaughn and Krug quartzite hills are surrounded by the bed "C" subcrop of Ordovician age. The Arbuckle–Reagan Sandstone oil reservoir associated with this unconformity has produced 63 million bbls of oil, or 67% of the total Gorham oil-field production.


Sub-Pennsylvanian unconformity
oil well
test hole
saltwater disposal well (SWD)
saltwater injection well (SWI)
(all in Arbuckle, Reagan Sandstone, or Precambrian)
dolomite cherty oolitic
dolomite cherty
dolomite white
sandy dolomite
dolomite
sandstone
dolomitic
Q quartz
G granite
S schist
Arbuckle Group
Ordovician
Cambrian
Reagan
Precambrian
R. 15 W.
R. 14 W.
T. 13 S.
T. 14 S.
T. 15 S.
GORHAM
70
granite
quartzite
quartzite
N
0
2 mi
0
4 km

Gorham sand 5

The term "Gorham sand" is often applied to Precambrian quartzite in which the grains have not been moved or transported since Precambrian time. Precambrian quartzites form the summits of the now deeply buried Precambrian quartzite hills but were exposed on the Early Pennsylvanian land surface. In short penetrations, the granular quartzite in situ is indistinguishable from the same material locally transported short distances on the Early Pennsylvanian land surface. Both are called "Gorham sand," especially if oil stained. Quartzite in situ forms a poor oil reservoir. Production commonly is exhausted in a few weeks or months with only a few hundred barrels of oil recovery.

The author identified these various "sands," all locally termed "Gorham sand," while examining samples of well cuttings under a 20× binocular microscope. The recognition of and distinction among the various sandstones is an important part of the author's contribution to the understanding of the petroleum-related geology of the Gorham oil field. Distinguishing among these five sandstones is critical in defining the stratigraphy, structure, and geologic history. In addition, because these sandstones differ greatly as oil reservoirs, distinguishing among them is important and useful economically.

Paleotopography and oil

This understanding of the weathering products formed in Late Mississippian and Early Pennsylvanian time on what was then a land surface and is now the sub-Pennsylvanian unconformity provides background for a discussion of the topography of that buried land surface. Fig. 10 is a map of the present attitude of the nearly flat topography of this buried Early Pennsylvanian land surface, depth near 3,300 ft (990 m). The principal oil reservoir of the Gorham oil field results from the extensive porosity developed subjacent to the sub-Pennsylvanian unconformity in the Arbuckle dolomite beds and the Reagan Sandstone. The development of the oil reservoir itself was much affected by the topography and weathering of this ancient land.

Granite hill

Weathering in Late Mississippian and Early Pennsylvanian time had little effect on the Gorham granite hill other than altering part of the feldspars and ferromagnesium minerals, resulting in a thin regolith of "granite wash." Rain water running off this hill area entered the porous basal sandstone and dissolved the 10–20% carbonate cement. This process enhanced reservoir porosity in the sandstone while forming a solution valley surrounding the Gorham hill. The solution valley or moat was best developed on the east side of the Gorham hill coinciding with the updip edge of the Reagan Sandstone, forming what was to become the most prolific portion of the unconformity reservoir of the Gorham oil field.

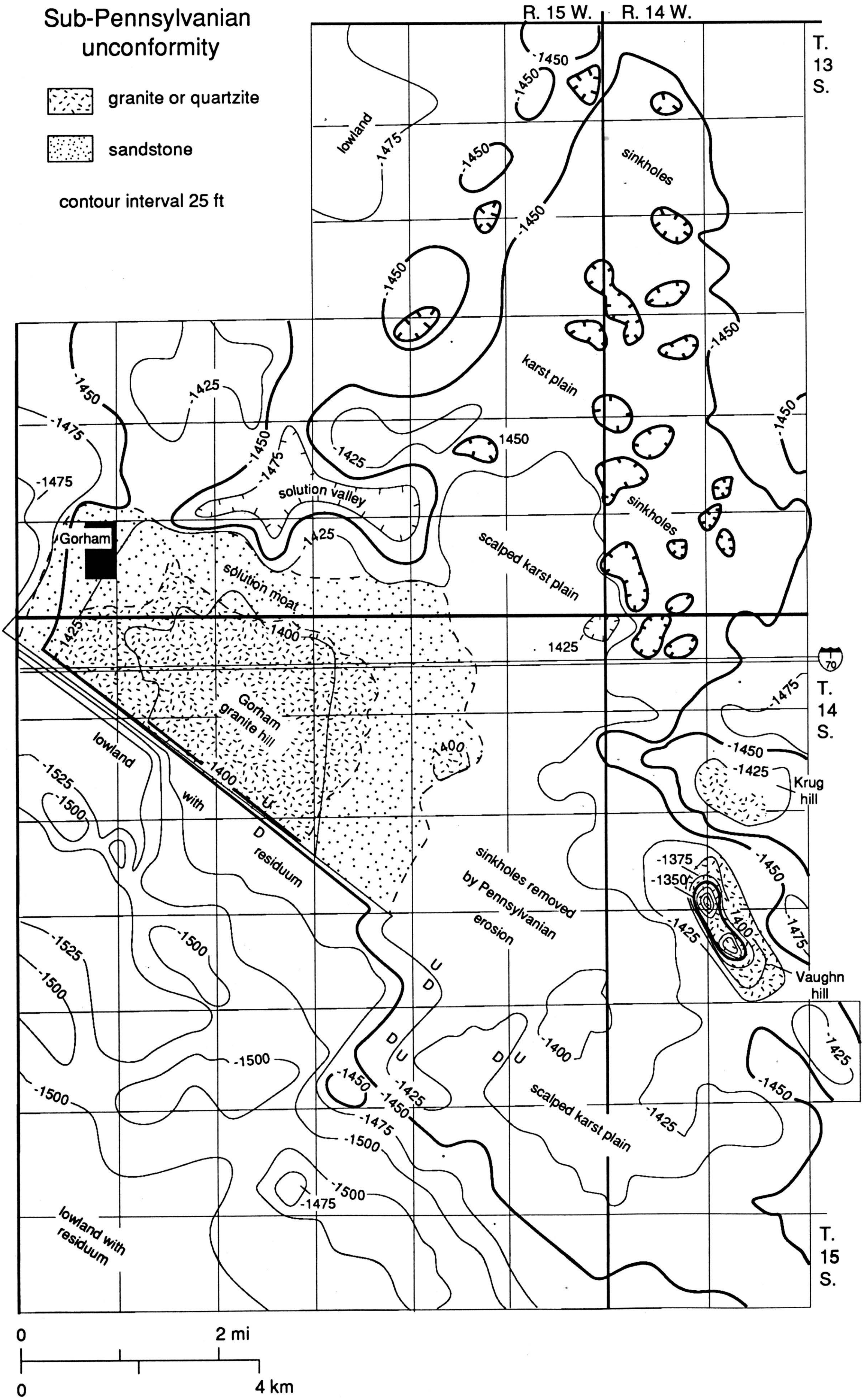
Quartzite hills

Rain falling on the Vaughn and Krug quartzite hills in Late Mississippian and Early Pennsylvanian time had little effect on the resistant quartzite. On a much reduced scale, a small topographic solution-moat was developed around each of these hills by concentrated dissolution of the sandy dolomite member onlapping those hills, leaving a residual sand with a silicified crust.

Arbuckle karst plain

Elsewhere over the broad area of outcropping flat-lying Cambro–Ordovician Arbuckle beds, rain water partially dissolved the dolomite rocks in an irregular manner forming sinkholes and leaving a regional mantle of residual clay, chert, and sand. This residuum (called "conglomerate" by operators) is preserved in a few sinkholes as shown on cross sections A–B and B–C (figs. 5 and 6, wells 2, 4, and 34). Residuum is preserved in the low areas south of the oil field shown at mile posts 1 through 3 on the cross section. Residuum also is shown by wells 29, 30, and 53. The resulting weathered lowlands were then a karst plain of low topographic relief covered by a residual mantle of oxidized shale, oolitic chert, and/or sand.

FIGURE 10—Sub-Pennsylvanian surface, or "top of Arbuckle." Map shows topography, contour interval 25 ft, and physiographic features developed on a paleo-land surface now buried under about 3,300 ft (990 m) of sedimentary rocks. Well control (omitted) is the same as in fig. 9. In Pennsylvanian time, rain water runoff from the Gorham granite hill developed a flanking solution moat by dissolving the 10% carbonate cement in the Reagan Sandstone and contributed to the development of the major solution valley in the southern part of T. 13 S., R. 15 W. Solution weathering of Arbuckle dolomite resulted in accumulation of an insoluble residual mantle now preserved in the lowlands and in the development of karst topography with sinkholes and valley sinks. Pennsylvanian marine erosion removed the residuum from the upfaulted northwest-trending anticlinal axis area, scalping off the surficial dolomite layers and most of the sinkholes, leaving a "scalped karst plain."


Sub-Pennsylvanian unconformity
granite or quartzite
sandstone
contour interval 25 ft
R. 15 W.
R. 14 W.
T. 13 S.
T. 14 S.
T. 15 S.
lowland
sinkholes
karst plain
solution valley
Gorham
solution moat
scalped karst plain
Gorham granite hill
lowland with residuum
Krug hill
Vaughn hill
sinkholes removed by Pennsylvanian erosion
lowland with residuum
70
-1350
-1375
-1400
-1425
-1450
-1475
-1500
-1525
U
D
0
2 mi
0
4 km

Time of formation of the karst plain

The time of formation of the karst plain in the Gorham oil field and throughout the extensive Central Kansas uplift can be dated as pre-Desmoinesian, Pennsylvanian, or earlier. Rocks of the Kansas City Group rest directly on Precambrian cystalline rocks over the summits of the Precambrian quartzite hills. Those areas of resistant quartzite were erosional remnants on Precambrian surface. They were hills in Cambrian and Ordovician time and were islands during the deposition of the Cambrian basal sandstone and the deposition of the Cambrian dolomites. They were not buried until Middle Ordovician time when the sandy dolomite member overlapped the hills and was deposited over them. The history of similar quartzite hills approximately 25 mi (40 km) southeast in Barton County was summarized at length in an earlier publication (Walters, 1946).

In the remainder of the greater Gorham oil field area, the Arbuckle beds on which karst topography was developed were buried under Pennsylvanian, Desmoinesian, and Marmaton Group limestones and shales. This is true even for the summit area of the Gorham granite hill which was not a topographic feature during the deposition of the Cambrian Reagan Sandstone and Cambrian portion of the Arbuckle dolomite. That area was not a topographic high until post-Arbuckle, pre-Pennsylvanian faulting raised the area relative to the remainder of the Gorham area. The time of formation of the karst plain can only be bracketed as post-Arbuckle (Ordovician) and pre- or Early Pennsylvanian (Desmoinesian).

During Desmoinesian time, eastern Kansas was intermittently a coal swamp of low relief. The abundant vegetation, now formed into coal, provides evidence of a warm humid climate. The flat plain area of central Kansas, barely above sea level in Desmoinesian time, was subject to much erosion by the dissolving power of fresh rain water. The existing karst topography was further developed with collapsed caverns, sinkholes, and disappearing surface streams going into "swallow holes" and becoming subsurface drainage. The time available for development of karst topography includes the Early Pennsylvanian, all of the Mississippian, the Devonian, the Silurian, and part of the Ordovician, totaling over 100 m.y.

Evidence from eastern Kansas indicates that solution erosion, cavern formation, and sinkhole collapse began shortly after the deposition of the Arbuckle carbonates in pre-Simpson (Middle Ordovician) time. Merriam and Adkinson (1956) described Simpson-filled sinkholes in eastern Kansas. Gore (1954) mapped sandstones of Simpson age in paleo-caverns within the Cotter dolomite in the Spavinaw Lake area of northeastern Oklahoma. Kerans (1988) described extensive karst-controlled reservoir hetrogeneity in the Ellenburger Group carbonates of west Texas. He presents evidence from oil-field cores and well logs that the Arbuckle-equivalent carbonates had extensive pre- or sub-Simpson development of widespread brecciated (broken) rocks representing collapsed caverns partially filled with Simpson-age sands and clays. These cavern systems were large-sized features, laterally extensive, intermittently for hundred of miles, and vertically for 300 ft (90 m) to even as much as 900 ft (270 m). The breccias are now buried under several hundred feet of Simpson–Viola (Ordovician) and Silurian rocks, providing clear evidence that regionally extensive paleokarst formation occurred in pre-Simpson (Middle Ordovician) time. A similar situation prevails in eastern Tennessee where the Arbuckle-equivalent carbonates are the host rock for commercial zinc and lead deposits of the Mississippi Valley type in brecciated paleokarst as described by Ohle (1985) and by others cited in his writing. In central Kansas the sub- or pre-Simpson unconformity is not obvious locally but is apparent only on a regional scale such as diagrammed in fig. 8. It is concluded that the now-buried paleokarst surface at the top of the Arbuckle in the Gorham oil field commonly considered as Early Pennsylvanian in age had its initial development in Middle Ordovician time.

Scalped karst plain

The Gorham anticline in Early Pennsylvanian time was a positive area formed by intermittent upward vertical movement relative to surrounding lower areas. The faulting of the southwest flank of the Gorham oil field anticline in post-Arbuckle–pre-Pennsylvanian time provides evidence for such differential movement. While the Pennsylvanian seas were transgressing across the shoal area of the future Gorham oil field, much of the weathered, leached residual mantle was removed by wave erosion. As a result, the future oil-producing area of the Gorham oil field became a scalped karst plain. On it, Pennsylvanian marine limestones (incorporating a few sand grains and chert pebbles) were deposited directly on fresh dolomite. Relatively few sinkholes were preserved as the regional regolith was eroded and removed. Only a few Arbuckle test holes in the present Gorham oil field are dry holes because of encountering residuum-filled sinkholes instead of fresh, porous dolomite. This situation is in sharp contrast to the situation in the Kraft–Prusa oil field about 25 mi (40 km) southeast in Barton County (Walters and Price, 1948), where one-fourth of all oil test holes drilled were dry holes because they encountered sinkholes in the Arbuckle regardless of whether the test wells were drilled on 10-acre, 20-acre, or 40-acre (4-, 8-, or 16-hectare) spacing.

For the buried paleokarst topographic surface mapped in fig. 10, it is not feasible to indicate individual sinkholes or even interconnected sinkholes forming valley sinks, because of the scale of the map. Detailed criteria for distinguishing among marine conglomerate, locally transported conglomerate or landwash, and residuum weathered in situ were described in an earlier publication (Walters, 1946, p. 690–699).

Common oil reservoir

Please refer again to fig. 10 (p. 21), which illustrates the low-relief topography of the sub-Pennsylvanian unconformity surface even after being modified slightly by later uplift, tilting, and arching. Note that the entire oil-producing area of the Gorham oil field is defined by the –1,450-ft contour. There is less than 50 ft (15 m) of relief except over the two areas of the Precambrian buried hills. This contour, 1,450 ft (435 m) below sea level, parallels the original oil-water contact near subsea –1,440 ft (–432 m), which unites the vast sub-Pennsylvanian common oil reservoir of the Reagan Sandstone and the Arbuckle Group dolomites in the greater Gorham oil field. It marks the spill point for oil migrating long distances through the subsurface porosity developed beneath this ancient land surface. The oil, which migrated into, through, and beyond the Gorham anticline, moved in mid-Permian time in response to regional loading and tilting (Walters, 1958 and 1987), until differentially entrapped in the Arbuckle dolomite reservoirs of central Kansas, including the Gorham anticline which was filled to the spill point. This unified, extensive sub-Pennsylvanian unconformity oil reservoir, with its originally uniform oil-water contact, justifies the term "Gorham oil field" for an oil-producing area of 50 mi^2 (130 km^2).

Long-distance migration of Arbuckle oil

John L. Rich (1931) first discerned that Ordovician oil in Kansas had migrated a long distance (several hundred miles) from Oklahoma to the Kansas oil fields. Gussow (1954) established the principle of differential entrapment of oil and gas during such migration. Walters (1958) applied Gussow's principles to central Kansas oil fields, demonstrating long-distance migration by the evidence of differential entrapment in central Kansas oil reservoirs. Recent investigations by Burrus and Hatch (1987, 1989) of crude-oil geochemistry provide additional confirmation for the long-distance migration of Ordovician crude oil from the Anadarko basin of southern Oklahoma into the central Kansas "shelf" area, including the Gorham oil field. They state that "Oils from the Kansas shelf are similar to the Anadarko oil types except that they have only traces of toluene and no detectable benzene. These compounds are removed by water washing and, hence, could have been lost by contact with formation water during long-distance migration. The lack of mature source rocks in southern and central Kansas and the loss of benzene and toluene is consistent with oil migration from the central Anadarko basin. . ." in southern Oklahoma. Note that Ordovician (Arbuckle and Simpson) crude oil, but not Pennsylvanian (Lansing–Kansas City) crude oil, is described as migrating from Oklahoma into Kansas.

Trapping and accumulation of Arbuckle oil

The Arbuckle dolomite and Reagan Sandstone common oil reservoir is the principal oil reservoir in the Gorham oil field. Although these formations were deposited in Cambrian and Ordovician time and their porosity enhanced by subareal karst-forming solution erosion in Early Pennsylvanian and earlier time, oil could not have accumulated until after the truncated trap was sealed by the deposition of mid-Pennsylvanian sealing beds, shale, and limestone. Evidence from elsewhere in central Kansas (Walters, 1958) established that the principal time of migration and accumulation of oil in the Cambrian–Ordovician oil reservoirs of central Kansas was mid-Permian. Thus, rocks forming the principal reservoir of the Gorham oil field of Cambrian age (Reagan Sandstone) and of Ordovician age (Arbuckle dolomite) were eroded in Pennsylvanian and earlier time with enhancement of porosity, were sealed in mid-Pennsylvanian Missourian time, and were filled in mid-Permian time with oil which migrated from what is now Oklahoma. The reservoir was tilted and the oil shifted in Cretaceous, Tertiary, and Quaternary time, yet the accumulation of about 100 million barrels of recoverable oil was confined until drilled in 1926.

Lansing–Kansas City Group

Map, Lansing–Kansas City structure

Pennsylvanian limestones interbedded with shales unconformably overlie the sub-Pennsylvanian surface, resting on Arbuckle beds over most of the area but resting directly on Precambrian rocks in the highest area. Oil production is derived from the porous, often oolitic, limestones in the Lansing–Kansas City Group. Structural attitude of the top of the Lansing–Kansas City is mapped in fig. 11 with a 25-ft contour interval. Oil wells known to have produced from these rocks are indicated by solid dots. Test holes, which penetrated the Lansing–Kansas City beds but did not produce oil from the Lansing–Kansas City Group, are mapped as open circles.

Oil fields, Lansing–Kansas City

Outside the official boundaries of the Gorham oil field, but within the area mapped in fig. 11, are several small, named oil fields producing from the Lansing–Kansas City limestones. These are mapped in fig. 2 and include

T. 13 S., R. 15 W.
Air Base East; Kune; Kune S; Kune SW; Lacey; Lacey N; Lacey NE; Lacey SE; S and S Ranch

T. 13 S., R. 14 W.
Rogg; Salt Creek

T. 14 S., R. 15 W.
Aley; Aley N; Baxter; Baxter E

T. 14 S., R. 14 W.
Hall–Gurney (part)

T. 15 S., R. 15 W.
Donovan N

Within the official limits of the Gorham oil field are several clusters of Lansing–Kansas City oil wells. Geologically these are individual Lansing–Kansas City oil fields, completely separated from each other and functioning as discrete unrelated oil reservoirs. Two of the largest of these oil fields, the Gorham area (secs. 32 and 33, T. 13 S., R. 15 W. and secs. 3, 4, 5, 8 and 9, T. 14 S., R. 15 W.) and the Vaughn area (secs. 17, 18, 19, and 20, T. 14 S., R. 14 W.) are designated "areas" rather than oil fields on the Lansing–Kansas City map (fig. 11) for convenience of discussion. These two areas are further discussed in connection with secondary-recovery operations by waterflooding.

Oil reservoirs

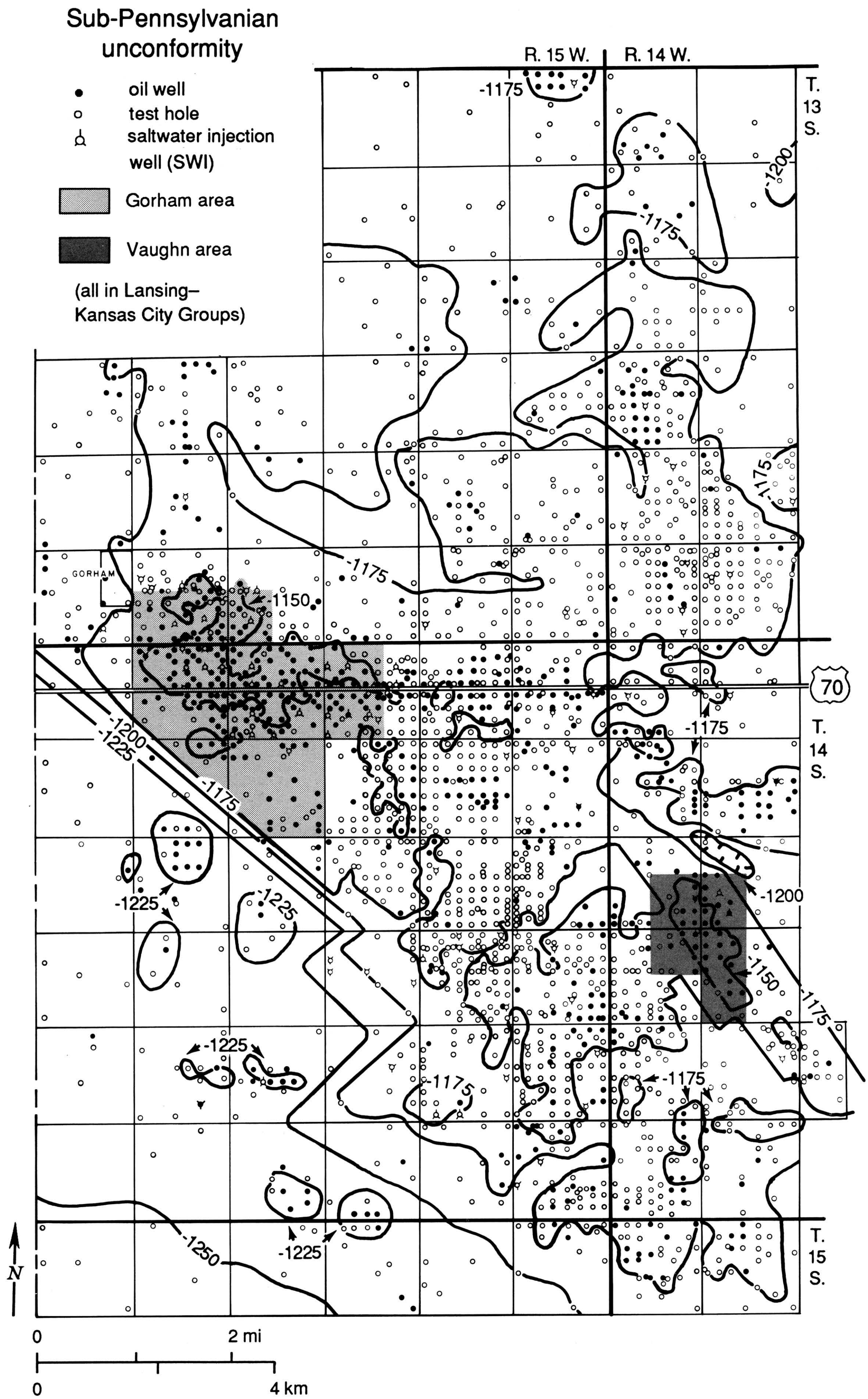
In general, oil in the Lansing–Kansas City is structurally trapped on anticlines but production is also dependent on the development of porosity. The original reservoir mechanism for the Lansing–Kansas City reservoirs was solution-gas drive. This resulted in high initial production (the flush production stage) followed by rapid decline to less than 25 BOPD per well (the settled production stage), then to the "stripper" stage of less than 10 BOPD per well.

In the 1920's and 1930's, if a market could be found, wells were produced at their maximum capacity or "potential" until the reservoir energy became depleted. Often the gross ultimate recovery was only 10% of the oil in place. Secondary recovery by waterflooding added considerably to the cumulative oil recovery, sometimes doubling the production.

Lithology

In the Gorham oil field, Lansing–Kansas City rocks are encountered near 3,000 ft (900 m). They consist of 230 ft (69 m) of alternating limestone and shales. The limestone beds, often oolitic where oil-productive, provide individual oil reservoirs. Watney (1980a) has described the cyclical nature of the Lansing–Kansas City beds and discussed the environments of deposition, the diagenetic changes, and the lithologic properties, all illustrated with photographs of core slabs. For convenience in his study, limestone zones were designated alphabetically from A to K downward. The same or nearly identical nomenclature has been applied by operators in the Gorham oil field. Each porous limestone "zone" within the Lansing–Kansas City Group is a separate oil reservoir isolated from the other limestone beds by interbedded cyclical shales. However, once the beds have been drilled, the borehole itself serves as an interconnection, often even when oil-string casing has been set and cemented through the Lansing–Kansas City beds.

FIGURE 11—STRUCTURE OF THE LANSING–KANSAS CITY GROUP, Pennsylvanian, contour interval 25 ft. Solid dots indicate oil wells known to the author to have produced from the Lansing–Kansas City limestones. Open circles indicate other test holes penetrating, but not producing from, the Lansing–Kansas City beds. Small closed areas outside the Gorham oil field are individual named oil fields (see fig. 2, p. 3), but within the Gorham oil field such areas are classified as a common source of supply for regulatory purposes. Of the total relief of 120 ft (36 m), over 60 ft (18 m) is due to the post-Lansing–Kansas City movement on the northwest-trending basement faults with less movement in the area of northeast cross faulting in the south-central part of T. 14 S., R. 15 W. Within the Gorham oil field proper, about 24 million BO, or one-fourth of the field's total production, was produced from the Lansing–Kansas City limestones.



Sub-Pennsylvanian unconformity
oil well
test hole
saltwater injection well (SWI)
Gorham area
Vaughn area
(all in Lansing–Kansas City Groups)
R. 15 W.
R. 14 W.
T. 13 S.
T. 14 S.
T. 15 S.
GORHAM
70
-1150
-1175
-1200
-1225
-1250
N
0
2 mi
0
4 km

This is in part due to hole enlargement opposite the shales during drilling and to the difficulty of getting a tight cement bond opposite shales. In addition, the Lansing–Kansas City carbonate zones are customarily acidized. The acid may dissolve cement and channel up or down the hole interconnecting the zones. The Kansas Corporation Commission has ruled that all oil produced from the Lansing–Kansas City Group is a common source of supply and no distinction is made on a bed-by-bed basis as regards their regulation of allowed production, the keeping of statistics, or the issuing of permits for drilling of wells or for secondary-recovery operations by waterflooding.

Well-completion procedures

Lansing–Kansas City producing zones are evaluated today by drilling through one or more zones with oil shows detected by well-site examination of well cuttings or by logging of oil in the drilling mud. The zone drilled may then be evaluated by a drillstem test in which the drill pipe serves as temporary casing permitting actual recovery of oil and the recording of reservoir pressures. Drilling then proceeds and the testing is repeated until the full section has been drilled and evaluated after which wire line open-hole logs are recorded, casing set and cemented, cased-hole logs recorded, and one or more zones perforated, tested, acidized, and put on production. Zones are selectively perforated from the lowest upward as it is easier to set a plug inside the casing and work above the plug. Otherwise, to test a deeper zone below perforations, it is necessary to squeeze off the perforations with cement (a costly procedure) before testing a deeper zone. Alternatively, the perforations can be isolated by using a packer and tubing.

The situation was quite different in 1926 when the Gorham oil field was discovered. All drilling was by cable tools. Fluids encountered during drilling, whether oil or saltwater, moved directly and immediately into the borehole while drilling. Thus when the first, most shallow oil-producing zone in the Lansing–Kansas City was encountered, oil was "struck," pipe set, and the well completed "natural," i.e. without acidizing. The zone was then produced "wide open" if a market could be found, resulting in high original production, rapid decline, and the recovery of only a small percentage of the oil in place. Note that the production graphs (fig. 4) show oil production in the 1920's averaging 80 BOPD per well in 1928, declining rapidly in the early 1930's to 18 BOPD per well. Prior to 1928, all the oil produced in the Gorham oil field was from the "Oswald" formation near 3,000 ft (900 m) as the Lansing–Kansas City Group was then called. Some "Oswald" oil wells were depleted and the wells abandoned before it was recognized that wells drilled deeper might "discover" another pay zone in the "Oswald" or a still deeper pay zone in the Arbuckle or basal sand. Almost all of the early Kansas City oil wells drilled with cable tools were deepened later, sometimes by a new operator after abandonment by the original owners.

Acidization

A major breakthrough occurred in January 1933, when Central Petroleum Co., operated by Nathan Appleman, introduced to the U.S. oil business the application of inhibited hydrochloric acid to increase oil production from limestones (Oringderff, 1984). The acidization of two oil wells in the Fairport oil field, 9 mi (14.4 km) north of the Gorham oil field, was successful and Appleman, who held an option to purchase most of the oil-producing leases in the Fairport oil field, exercised his option. Acidization by his company of the original western Kansas discovery well, the Oswald No. 1, increased production from 2 BOPD to 108 BOPD. Similar spectacular results were obtained from acidizing 33 more wells. Appleman then applied this form of secondary recovery by acidizing his Central Petroleum Company's Gorham leases in 1933 with similar results. Other operators immediately acidized their oil wells. The acidization of oil wells producing from limestone and dolomites is no longer viewed as a secondary-recovery process but is a routine part of new well completion.

Accidental waterflooding, 1940's

In the 1940's in the Vaughn area of the Gorham oil field (known then as the Vaughn oil field), accidental waterflooding of Lansing–Kansas City zones in oil wells resulted in a great increase in the production from surrounding oil wells (Roy P. Lehman, personal communication, 1975). This was initiated by the accidental break-in of corrosive natural brines from the Cheyenne or Cedar Hills Sandstones at depths of 500 to 800 ft (150–240 m) below the surface through holes corroded in the oil-string casing. Water from those zones poured down inside the oil-string casing and flooded the open-hole Lansing–Kansas City producing zones near 3,100 ft (930 m), causing dramatic production increases in surrounding oil wells. When operators realized what was causing such increases in oil production, some illicit midnight well-perforating of casing opposite the Cheyenne–Cedar Hills Sandstones took place.

The production graph (fig. 4, top graph) shows the all-time high in annual oil production for the Gorham oil field in 1942. Production in that year increased 38% over the prior year, 1941, even though there were four fewer oil wells. A considerable part of this increase was due to the break-in of "Dakota" water through corroded casing causing accidental waterflooding of the Lansing–Kansas City beds.

An example of such accidental production increase is the six-well Carroll lease, the SE sec. 18, T. 14 S., R. 14 W., which produced oil from structurally high Lansing–Kansas City beds overlying the Vaughn quartzite hill. The Carroll lease, developed in 1937–39, had a production decline of 17% per year for the years 1939 and 1940, declining to an average daily production of 18.7 BOPD per well in 1940. During 1941, the same six wells increased production by 50% to 28 BOPD per well. In the following year, 1942, production increased by an additional 73% to 106,880 BO or an average of 48.8 BOPD per well from the same six wells. This was followed by a decline to 7.4 BOPD per well by the end of 1946. From 1937 through 1946 inclusive, the cumulative production was 578,076 BO or nearly 100,000 BO per well. Secondary recovery by waterflood was responsible for 244,000 BO or 42% of the production. Ultimately, after drilling the wells deeper into additional Lansing–Kansas City production zones, and installing a planned waterflood in 1957, the Carroll lease produced 1,348,989 BO or 224,000 BO per well from the six wells. The structurally high Lansing–Kansas City limestones in the Carroll lease, located on a sharp anticline above the Vaughn quartzite hill, are representative of the best Lansing–Kansas City oil production in the Gorham oil field.

A second area where accidental waterflooding occurred was the E/2 sec. 3, T. 14 S., R. 15 W. on the Foster–A, Foster–B, and Witt leases. "Dakota" water disposed in nearby shallow saltwater-distribution (SWD) wells moved past the uncemented casings of oil wells, corroding holes in the casing of some wells. The corrosive waters flooded down the casing of those wells, out into the Lansing–Kansas City porosity, causing dramatic increases in oil production from adjacent oil wells as described in detail in the environmental section of this book on p. 73.

Waterflooding, 1960's–1970's

In 1962, Homestake Production Co. of Tulsa initiated an extensive secondary recovery project by waterflooding 1,800 acres (720 hectares) south and east of the town of Gorham (Bass, 1966) in secs. 32 and 33, T. 13 S., R. 15 W. and secs. 3, 4, and 5, T. 14 S., R. 15 W. The area, which had been essentially abandoned since the 1940's, included the original Gorham oil field of the 1920's and 1930's, located on the summit of the Gorham granite hill and on its north and east flanks. Homestake's oil wells were drilled mostly in the center of 40-acre (16-hectare) tracts on a five-spot pattern centered among four abandoned oil wells each in the center of a 10-acre (4-hectare) tract. Injection wells were drilled at the corners and the center of each 160-acre (64-hectare) quarter section. Most wells drilled directly out of Pennsylvanian limestones and shales into "granite wash."

The maximum number of water-injection wells was 46 in 1965, the same year that the maximum 58 oil wells were active. Water was injected into the Lansing–Kansas City zones near 3,050 ft (915 m; and some into the Shawnee–Topeka zones near 2,750 ft [825 m]) under well-head pressures from a low of 364 lbs/inch^2 (psi) in 1965 to a high of 550 psi in 1966–68. Source of water was a 600-ft (180-m) "Dakota" water-supply well used in 1962 to 1965. While drilling new oil wells and water-injection wells, an unexpected bonus was obtained when several new wells encountered an undrained updip wedge edge of Reagan or Gorham sand in sec. 32, T. 13 S., R. 15 W. Thereafter, beginning in 1965, water produced with oil from the Gorham sand oil wells was introduced into the Lansing–Kansas City flood because it was available and was less corrosive than the Dakota water (Bass, 1966). Statistics for secondary or enhanced recovery of oil from the Homestake project are quoted from annual publications at the Kansas Geological Survey (appendix, table 8) to 1982, at which time the service was discontinued. Oil produced by secondary recovery in the Homestake project reached a maximum of 287,442 bbls during 1964, the second year after water was injected. Production declined about 12% per year to 71,720 bbls per year in 1972 from 32 oil wells with 10 injection wells. Production in the range of 66,000 bbls per year prevailed in the five years to 1977, then declined to 20,000 BO in 1982. Ultimate production was 2,513,000 BO. Not all of the oil recovered can be attributed to secondary recovery by waterflood because the statistics quoted include oil production from Reagan Sandstone wells drilled in the project area.

Other successful Lansing–Kansas City waterflood projects were undertaken throughout the Gorham oil field in the 1960's and 1970's. These included projects in secs. 17, 18, 19, 20, 30, 31, and 32, T. 14 S., R. 14 W. Other projects were located in secs. 10, 11, and 36, T. 14 S., R. 15 W. and in sec. 6, T. 15 S., R. 14 W.

The beneficial results of this period of extensive secondary recovery by waterflooding can be seen in fig. 4 (p. 6), the top graph, where the increase in production is labeled "waterflood."

Summary

Oil wells producing from Lansing–Kansas City limestones flowed gassy oil initially in structurally high areas such as the Vaughn area and the Gorham granite hill area, the oldest part of the Gorham oil field. The Lansing–Kansas City oil wells were characterized by vigorous natural production followed by rapid decline with a recovery of only a small portion of the oil in place, perhaps 10%. The reservoir energy was solution gas drive, with little water produced. In 1933, it was discovered that the Lansing–Kansas City oil wells responded to acidization. In the 1940's, accidental waterfloods greatly enhanced oil production from these nearly water-free solution-gas reservoirs. This was followed in the 1960's and 1970's by extensive and successful planned waterflooding of many separate areas within the Gorham oil field.

Oil production from the Pennsylvanian Shawnee Group

About 60 oil wells in the Gorham oil field produce oil from limestones in the Shawnee Group. Shawnee limestone oil production falls into two classes: wells producing from intercrystalline porosity (not mapped) and wells producing from fracture porosity (fig. 12, solid dots).

Toronto and Plattsmouth oil production

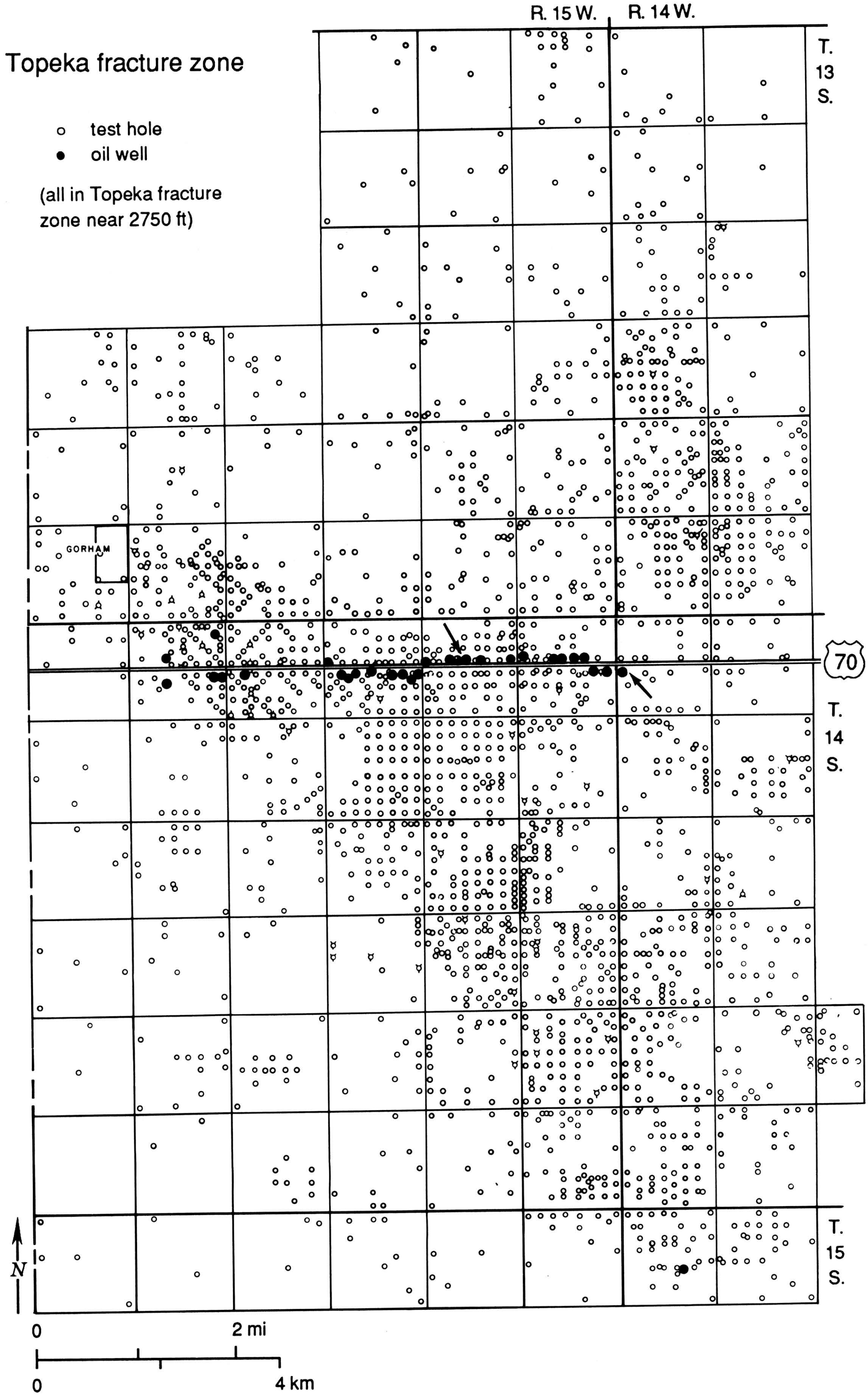
Within the Shawnee Group, the lowest bed, the 18-ft (5.4-m)-thick Toronto Limestone Member of the Oread Formation, occurs below the Heebner Shale, a 4-ft (1.2-m)-thick, black, carbonaceous, highly radioactive shale, depth near 2,900 ft (870 m). The Heebner Shale is used as a dependable, persistent, stratigraphic correlation point. Just above the Heebner Shale is the 80-ft (24-m)-thick Plattsmouth Limestone Member of the Oread Group. When these formations were drilled with cable tools in the 1920's and the 1930's, "oil shows" were noted but usually the holes did not fill with oil. These oil shows were passed up and the wells drilled to the deeper, more prolific Lansing–Kansas City limestone reservoirs. However, during the period from 1960 to the late 1980's, excellent wire line logs became available. These logs recorded various properties through measurement of gamma radiation, neutron radiation, resistivity, conductivity, spontaneous potential, density, and sonic velocity, or often combinations of these curves, making it possible to localize and partially evaluate oil-productive porous zones from the logs. Extensive acidizing of what were formerly just "oil shows" has resulted in small but commercial oil wells. Production data are difficult to impossible to obtain. For the most part, these wells are in structurally high areas, which also produce from the Lansing–Kansas City and the oil production is commingled. Shawnee oil production from intercrystalline porous zones is largely due to technical advances during the second half of the 60-year history of the Gorham oil field. Operators often term all such production "Topeka" and do not distinguish between it and the fracture production next discussed, which occurs 200 ft (60 m) higher in the section.

Topeka fracture-zone oil production

Fig. 12 shows the unusual distribution of Topeka Limestone oil wells producing from a fracture zone (solid dots). Most of the wells known to have produced from the Topeka fracture zone are aligned in a nearly straight east-west line, which by chance coincides with the location of I–70 through the centers of sec. 6, T. 14 S., R. 14 W., and secs. 1, 2, 3, 4, and 5, T. 14 S., R. 15 W. The following facts confirm that Topeka oil production is associated with a large-scale fracture zone:

A) The Topeka production is from the limestone, depth near 2,750 ft (825 m), which shows no intercrystalline porosity and no oil staining.
B) The alignment of 29 oil wells is in a nearly straight east-west line 5 mi (8 km) long and such wells are generally absent elsewhere.

FIGURE 12—Location of wells that produced oil from the Pennsylvanian Topeka fracture zone near I–70. Solid dots in a west to east alignment indicate the location of 29 oil wells that produced an average of over 200,000 BO per well from a fracture zone in the Topeka Limestone, depth near 2,700 ft (810 m). The Topeka oil well in sec. 6, T. 15 S., R. 14 W., may indicate a second fracture zone (p. 30). Open circles indicate the location of the other 2,138 test holes penetrating the Topeka without finding oil production in the fracture zone. Thin slanting arrows mark the two giant oil wells described on p. 30.


Topeka fracture zone
test hole
oil well
(all in Topeka fracture zone near 2750 ft)
R. 15 W.
R. 14 W.
T. 13 S.
T. 14 S.
T. 15 S.
GORHAM
70
N
0
2 mi
0
4 km

C) Oil occurrence is erratic and limited. Operators carefully watched offset wells in locations north or south of the producing zone but failed to find Topeka production even when the offset wells were structurally flat with, or higher than, the Topeka fracture-zone oil wells.

Two unique giant oil wells are marked in fig. 12 by thin, slanting arrows. They are Topeka fracture-zone wells that have large oil-producing capacity. One of the giant oil wells is Phillips Petroleum Company's Amelia No. 2, drilled in September 1937 in the C NW NW SW sec. 6, T. 14 S., R. 14 W., which has produced over one-half million barrels of oil from the Topeka fracture zone, depth 2,766 to 2,771 ft (830–831 m), and was still producing 18 BOPD in 1986. The Amelia lease has a cumulative production of 579,108 BO to January 1, 1987, nearly all of which is from Amelia No. 2. This giant oil well has been offset by carefully watched dry holes drilled 1,200 ft (360 m) northwest in 1952, 660 ft (198 m) north in 1938, 933 ft (280 m) northeast in 1981, 660 ft (198 m) east in 1987, and 737 ft (221 m) southeast in 1941. Only the west offset, Dumler No. 4, on-trend 660 ft (198 m) west in the NE NE SE sec. 1, T. 14 S., R. 15 W., encountered Topeka fracture-zone production. Amelia No. 2 is considered to have encountered an open fracture zone, oil-filled, presumably (judging by the unusually large production) part of an extensive fracture system.

The second giant oil well is the Hartman and Blair Roubach No. 1, C SE SE NW sec. 2, T. 14 S., R. 15 W. It is discussed in the historical section of this report and illustrated by figs. 32 and 33. The Roubach No. 1, drilled with cable tools as a wildcat well, is believed to have produced about one million barrels of oil from the Topeka, depth 2,787–2,793 ft (836–838 m). This giant oil well had an official stated potential of 4,076 BOPD on April 29, 1935. The well blew the cable tools halfway out of the hole and flowed a solid 8-inch stream of oil the night of April 22, 1935; the well flowed uncontrolled for two days, dumping an estimated 450 BO per hour upon the ground. The 160-acre (64-hectare) Roubach lease produced 2,563,014 BO to January 1, 1987, and was then producing 7.28 BOPD from the last well on the lease. The early flush production on the Roubach No. 1 well was closely watched by offset owners (Virgil B. Cole, personal communication, 1977), who immediately drilled 10-acre (4-hectare) offset wells 660 ft (198 m) east, 660 ft (198 m) south and 733 ft (220 m) southeast, respectively; however, all failed to encounter the fracture zone and found the Topeka nonproductive.

All but four of the Shawnee oil wells producing from the described Topeka fracture zone were discovered in the 1930's by drilling with cable tools. When the fracture was drilled into, the open cable-tool holes filled several hundred feet with oil or flowed oil. It is probable that many additional undiscovered fractures or fracture zones exist within the Gorham field, but subsequent development wells were drilled with rotary tools circulating a hole full of mud making recognition of fracture zones difficult.

Topeka oil from a fracture-zone reservoir was discovered in 1976, in a rotary-drilled hole, the No. 1 Mudd, in the C E/2 W/2 NW SE sec. 6, T. 15 S., R. 14 W. After unsuccessful testing of lower formations, the Topeka limestone was perforated from 2,646 to 2,648 ft (794–795 m), on the recommendation of the well-site geologist M. F. "Hap" Pryor (personal communication, May 20, 1976), based on his knowledge of the potential for production from Topeka fracture zones, his observation that during drilling circulation was lost at 2,675 ft (802 m), and that in "rebuilding the mud system, free oil was noted in the pits." The Mudd No. 1 was reported as completed for a modest 25 BOPD from the Topeka. It produced 13,834 BO in seven months of 1976 before the No. 2 and 3 wells producing from the Arbuckle were completed and their production comingled in the lease tank battery with the Topeka oil.

Analogy, Topeka fracture zone and Wisconsin fractures

The fracture system encountered by the oil wells producing from the Topeka fracture zone in the Gorham oil field (fig. 12) may be compared to similar fracture systems in Wisconsin where commercial deposits of zinc and lead are localized by fracture systems. Fig. 13A is a map of the zinc and lead mines, now mostly depleted and abandoned, in a portion of what is known as the "upper Mississippi Valley zinc-lead district." The map is adapted from the classic paper by Heyl et al. (1959). Comparable disseminated zinc and lead deposits in sedimentary rocks are now recognized the world over as MVT (Mississippi-Valley-type) ore deposits from this area. Host rocks are Paleozoic carbonates, principally the Platteville and Galena formations of Middle Ordovician age. The formations are characterized by low dips, commonly one-fourth of 1° (25 ft/mi). Ore-bearing fluids migrating through the regional fracture porosity were sodium chloride brines similar to midcontinent oil-field brines. The brines migrated in late Paleozoic time in both the midcontinent oil-field area and in the zinc-lead district. In Wisconsin, dissolution of carbonate rock occurred in connection with brine flow during migration. Studies since this 1959 classic have recognized the major role of dissolution slumping as a tectonic force, forming not only normal (tensional) faults but also reverse faults by gravitational compression. Contemporary studies of such ore deposits use fluid inclusions in crystals for analyses of the fluid itself (sodium chloride brine, sometimes hydrocarbons) and as indicators of paleotemperatures (commonly low—almost in the range of temperatures of brines produced with oil in Kansas).

The two districts, upper Mississippi Valley and midcontinent oil fields (including the Gorham oil field), have much in common. Fig. 13b is a diagram of the Topeka fracture zone in the Gorham oil field based on the well control shown in fig. 12. Note that the Wisconsin mine map and the Topeka fracture-zone map have the same scale, cover the same size area, and both have fracture systems with individual fractures to 1 mi (1.6 km) long.

Why are so few fracture zones recognized in the Gorham oil field and elsewhere in central Kansas? For a partial answer to that question, one of the many mines described by Heyl et al. (1959), the Liberty mine, is illustrated in fig. 14. In the plan view of the Liberty mine, the hachured areas are the unmined pillars and walls. The mined areas are blank in both the plan and the cross section. High-angle reverse faults merge in the roof area into bedding-plane faults. The mine ceiling is about 40 ft (12 m) high. The important vertical fault in the mid-part of the cross section has *no* vertical movement at all. Within the mine, one could step right across this important ore-controlling fault with no change in the floor level. However, note the 25 ft (7.5 m) of lateral or horizontal movement. The cross section is drawn to natural scale; the horizontal and vertical scales are the same in both the plan and the cross section. The length of the mapped area is 330 ft (99 m). All of this faulting, slumping, solutioning, and localized ore mineralization occurs within 330 ft (99 m), only one-half of the 660-ft (198-m) distance between oil wells drilled on 10-acre (4-hectare) spacing, as is the case in much of the Gorham oil field. It is understandable that a small-diameter 7–7/8-inch nearly vertical oil test hole has only a slight chance of encountering a fracture or fault system comparable to the mineralized fractures of the upper Mississippi Valley district.

Waterflooding, Shawnee Group, Toronto and Plattsmouth formations

Recovery of additional oil by waterflooding these Shawnee or "Topeka" reservoirs was attempted by Homestake Production Company in 1963 in connection with its major Lansing–Kansas City waterflood of 1,800 acres (720 hectares). A Topeka injection well was completed in the C NW sec. 3, T. 14 S., R. 15 W., and offset producing wells were open to the Topeka with some favorable response in the reservoir resulting from water injection, according to Bass (1966). He stated that "two later wells drilled in the center and on the west edge of the [1,800-acre] project had initial production tests of over 250 BOPD per well from the Topeka." These two large Topeka wells were probably drilled into fractures related to the 5-mi (8-km) fracture zone previously described.

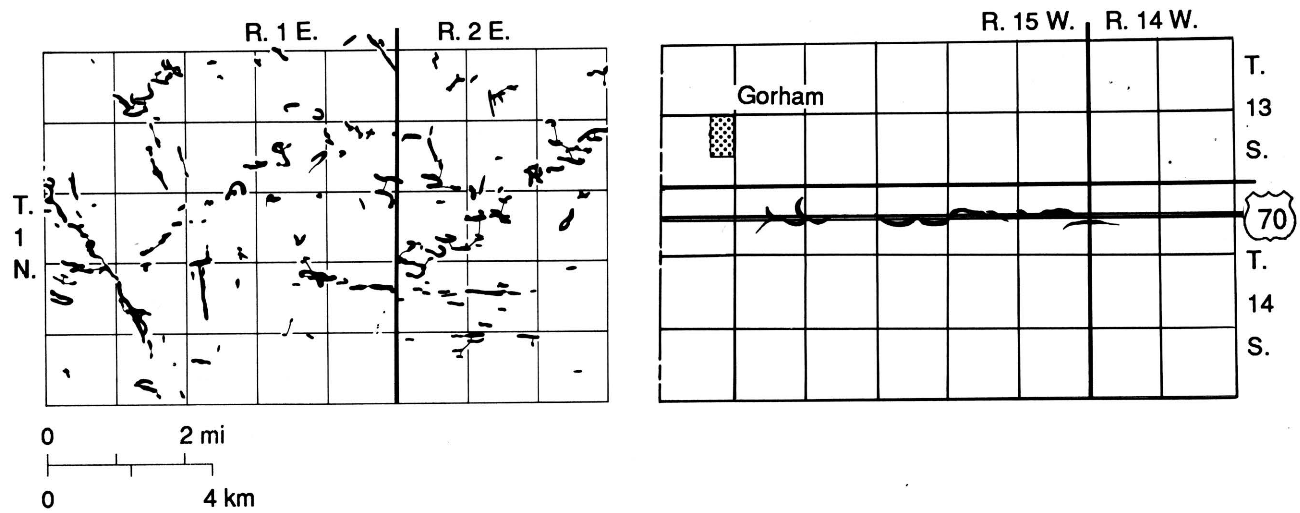


FIGURE 13a (left)—ZINC AND LEAD MINES (BLACK) IN THE UPPER MISSISSIPPI VALLEY ZINC-LEAD DISTRICT, LAFAYETTE COUNTY, WISCONSIN, T. 1 N., R. 1 and 2 E., from Heyl et al. (1959, plate 5). Ore distribution is controlled by fracture systems in nearly flat-lying Ordovician carbonate rocks of the Decorah and overlying Galena formations. 13b (right)—TOPEKA FRACTURE ZONE IN THE GORHAM OIL FIELD (black), redrawn diagrammatically from well control in fig. 12. The scale and area (40 mi^2 [104 km^2]) are identical in figs. 13a and 13b.

Subsidence areas

As discussed in the environmental section of this report, subsidence areas affecting I-70 are located exactly on the principal Topeka fracture zone in secs. 1–5, T. 14 S., R. 15 W. The subsidence areas are related to the fracture zone (Walters, 1978, p. 68–73).

Pennsylvanian–Wabaunsee Group

In oil-field usage, the term "Tarkio" is applied to oil production from any of several formations within the Wabaunsee Group. Tarkio oil production is obtained from fine-grained sandstone or silty sandstone. Within the cyclical formations of the Wabaunsee Group, various limestones are the most laterally persistent members and, hence, the most readily recognized formation on cable-tool driller's logs or on wire line geophysical logs. Shales separate these limestones. Within the shale, a lenticular series of silty sand lenses are developed, sometimes filling incised channels. Formations in oil-field terms are

Limestone	Shale	Silty sand facies
Grand Haven	"Dry shale"	first Tarkio sand
Dover	Langdon (renamed Pillsbury)	second Tarkio sand
Tarkio	Willard	third Tarkio sand

These formations occur within a 135-ft (40.5-m)-thick section drilled from 2,440 to 2,570 ft (732–771 m) near the town of Gorham or at even more shallow depths of 2,300–2,435 ft (690–730.5 m) in topographically low valley areas.

Tarkio oil is stratigraphically, not structurally, trapped. It was largely noncommercial during the cable-tool drilling years, approximately 1926–1946, as these "tight sands" had "oil shows" but the formations usually did not yield oil into the cable-tool open hole. Tarkio oil wells in the former Sullivan oil field in sec. 1, T. 14 S., R. 15 W. were early exceptions in 1935. The post-war technical development of hydraulic fracturing in the late 1940's, patented by Stanolind Oil Company Research Laboratories and licensed to

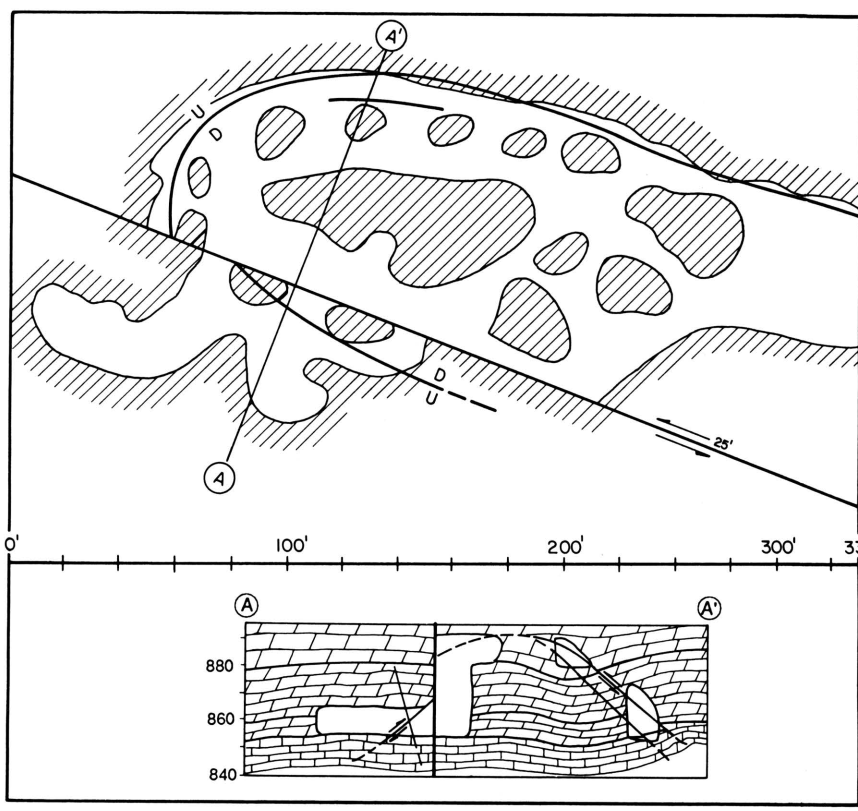


FIGURE 14—Map and cross section of the Liberty mine, NE sec. 16, T. 2 N., R. 1 E., Lafayette County, Wisconsin, from Heyl et al. (1959, fig. 23, p. 38). The diagonally shaded areas are pillars or mine walls. The mined area is blank. Cross section A–A′ is drawn natural scale with no vertical exaggeration. The cross section and the map are the same scale in feet. The three high-angle reverse faults are due to gravity compression in response to slumping from partial dissolution of underlying carbonate beds. The vertical fault has no vertical displacement but has 25 ft (7.5 m) of horizontal movement. Faults and fractures controlled flow paths of low-temperature saline solutions carrying zinc and lead in solution.

various service companies, was a stimulation process that led to major Tarkio development drilling in the 1950's, mostly in the adjacent Hall–Gurney oil field, but extending into the Gorham oil field. Tarkio oil reservoirs have solution-gas drive as the oil-producing mechanism. The Tarkio oil wells are gassy and are characterized in the field by their smaller pumping equipment and by their gas flares.

The Kansas Corporation Commission recognizes the Gypsy Oil Company's #1 Erhlich in the SW SW NW sec. 1, T. 14 S., R. 15 W., drilled in 1935, as the discovery well for the Wabaunsee Group, Tarkio oil, in the former Sullivan Pool, which straddled the Topeka fracture zone. Ver Wiebe (1938) noted that "a large amount of the total oil produced to date has come from the Tarkio."

Permian Council Grove and Chase Groups

Oil production rarely was obtained in the Gorham oil field from limestones of the Council Grove and Chase Groups. The occurrences are related to the 5-mi (8-km)-long fracture zone in the north part of T. 14 S., R. 15 W. The Kansas Corporation Commission recognizes as the discovery well of the Council Grove Group, the Hartman et al. #1 Roubach, SE SE NW sec. 2, T. 14 S., R. 15 W., August 7, 1936.

The Chase Group of rocks, thickness 350 ft (105 m), encountered near depths of 1,800 ft (540 m), consists of cherty limestones and interbedded shales. No discovery well is recognized for the Chase Group rocks, but rare noncommercial oil and gas shows have been recorded in cable-tool holes. While drilling with cable tools through the Chase Group in 1935, the Hartman et al. Roubach #3, C NE SE NW sec. 2, T. 14 S., R. 15 W., caught fire from a gas show and burned with a loss of rig and of drilling records for the depths 1,875–2,060 ft (562.5–618 m). Apparently no gas was sold from the Roubach lease or elsewhere in the Gorham oil field.

Permian Sumner Group

Sumner Group, an aquitard

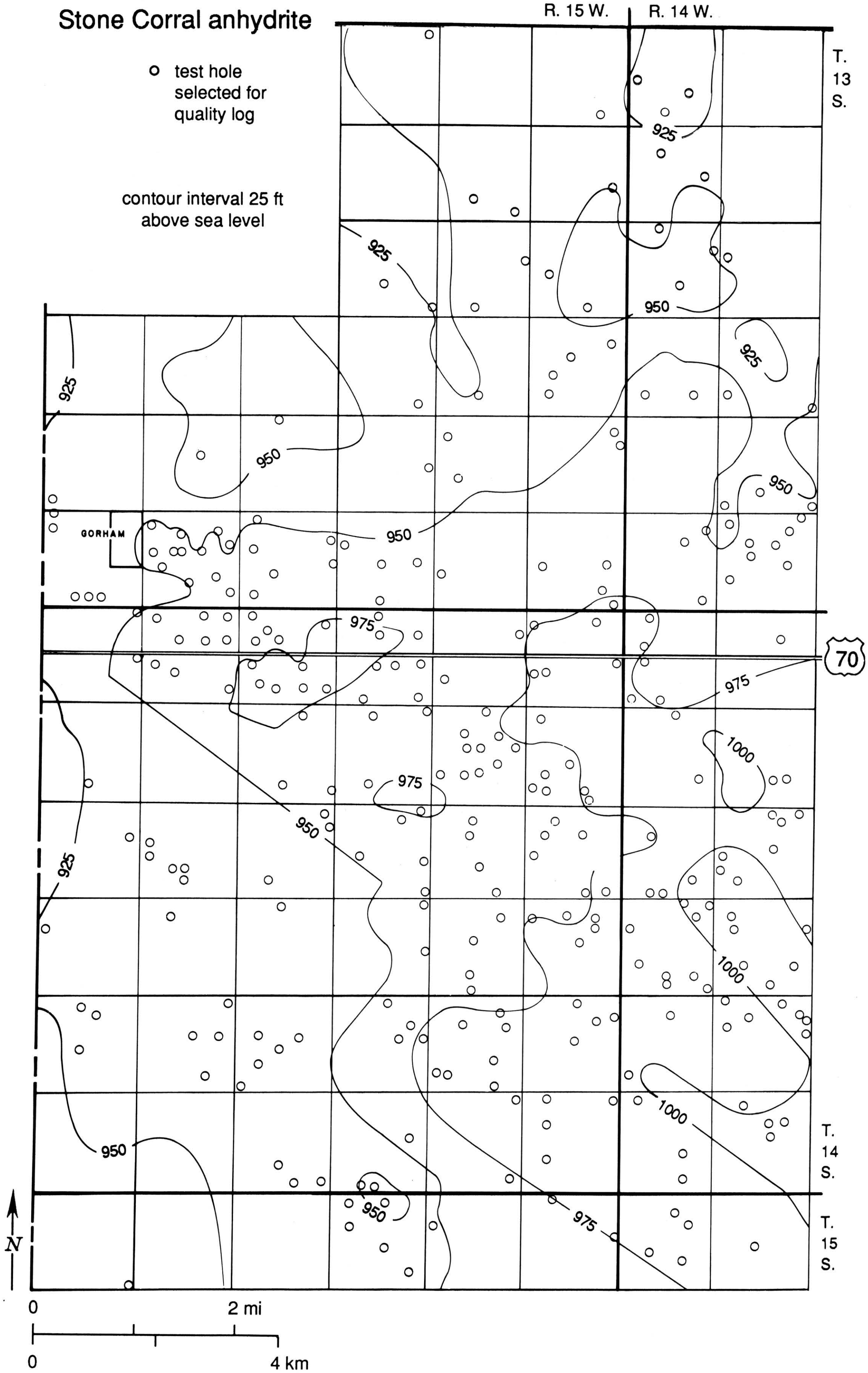
The Sumner Group has a thickness of 800 ft (240 m). The rocks consist, in upward sequence, of interbedded shales and anhydrites of the Wellington Formation; the Hutchinson salt; and silty shales and siltstones ("red beds") of the Ninnescah Formation. The Stone Corral anhydrite marks the top of the Sumner Group.

No oil occurs in the Sumner Group rocks and there are no oil shows. The Sumner Group is an aquitard—a non-water-bearing, non-reservoir, "tight" formation that is as devoid of permeability, hence, water, as any unit of sedimentary rocks of comparable thickness. The capping or confining role of the Sumner Group in the Gorham oil field was summarized by Walters (1978): "It is noteworthy that all of the porous zones or aquifers below the Sumner Group from the Chase Group next below to and including cracks in the Precambrian granite, depth near 3,350 feet, are in some area of the Gorham oil field, an oil or gas reservoir, indicating general saturation of the anticline with hydrocarbons and indicating upward leakage probably through fracture systems such as that known in the Topeka Limestone of the Shawnee Group. None of the porous zones or aquifers above the Chase Group have any hydrocarbon shows testifying to the imperviousness of the Sumner Group red beds and salt as a seal inhibiting fluid movement, either up or down, of hydrocarbons or water."

Hutchinson Salt Member

The Hutchinson Salt Member of the Wellington Formation, Sumner Group, has been described and mapped by Watney (1980b) and Watney and Paul (1980). Walters (1978, fig. 32, p. 62) published a map showing the thickness of the Hutchinson salt in the Gorham oil field. These salt beds, drilled at depths near 1,300 ft (390 m) are shown on cross sections A–B and B–C (figs. 5 and 6). The thickness varies from 322 ft (96.6 m) in the structurally low area near mile 1 to as little as 250 ft (75 m) in the structurally high area, mile 5 on the cross sections. About one-third of the total salt section consists of interbedded shale. The Hutchinson salt affects the drilling operation and evaluation process in that all oil test holes drill through 250 ft (75 m) or more of salt; thus rotary-drilling fluids are converted from freshwater-based systems to brine systems. This restricts the use of certain wire line logs such as the self-potential log.

As shown on the oil-field map (fig. 2), 2,168 oil test holes have been drilled through the Hutchinson salt in the Gorham area. Many oil test holes were abandoned in unplugged or poorly plugged condition (Walters, 1978, p. 66). As a result, dissolution of the salt has occurred. Areas affecting I–70 are discussed as the Witt, Crawford , and Roubach sinks in the environmental section of this report and are shown on a cross section (fig. 45).


Stone Corral anhydrite
test hole selected for quality log
contour interval 25 ft above sea level
R. 15 W.
R. 14 W.
T. 13 S.
T. 14 S.
T. 15 S.
GORHAM
70
925
950
975
1000
N
0
2 mi
0
4 km

Stone Corral Formation

The Stone Corral anhydrite encountered near 900 ft (270 m) marks the top of the 800-ft (240-m)-thick Sumner Group. It is a 40-ft (12-m) bed made up of two massive anhydrites separated by a shale. The structural attitude of the Permian Stone Corral anhydrite is mapped in fig. 15 with a contour interval of 25 ft above mean sea level. The map is based on selected control points of wells having excellent wire line logs through the Stone Corral section. Fig. 15 shows about 50 ft (15 m) of post-anhydrite faulting and/or differential compaction of the underlying shaly Permian red beds where they are draped over the Gorham anticline or over the buried Precambrian quartzite hills of the eastern portion of the Gorham oil field. The map also shows the regional northwest dip on the anhydrite here interrupted by the prominent Gorham anticline.

The major migration of petroleum into the Gorham oil field, filling all available porosity below the seal of the Sumner Group, took place in mid-Permian time (Walters, 1958), about contemporaneously with the deposition of the Stone Corral Formation of the Sumner Group.

The Stone Corral is important in the oil business because it provides an easily recognized formation for structural mapping and is a strong reflecting zone for seismic studies. Most seismic studies use the Stone Corral as a reference plane for making thickness maps from the Stone Corral to various lower horizons. In shallow geophysical work investigating subsidence along I–70 (Steeples et al., 1986), the Stone Corral provided a definitive reflection, permitting mapping of downfaulted blocks of anhydrite in areas where salt has been partly removed by dissolution.

Permian Nippewalla Group

Nippewalla Group rocks also are largely "red beds," forming a shaly, silty aquitard except for the Cedar Hills Sandstone, an aquifer that is the uppermost bed in this group. This westward-dipping porous sandstone, thickness of as much as 90 ft (27 m), thins eastward due to truncation at the sub-Cretaceous unconformity and is absent in the northeastern portion of the area mapped. Cross sections A–B and B–C (figs. 5 and 6) illustrate about 200 ft (60 m) of northeastward thinning of the Permian section by pre-Cretaceous truncation. The Cedar Hills Sandstone is absent in wells 47 to 53 at miles 12 to 14 at the northeast end of cross section B–C.

The Cedar Hills Sandstone directly underlies the Cretaceous Cheyenne Sandstone throughout much of the Gorham oil field. The two formations are difficult to distinguish, particularly in rotary-drilled holes even with the use of wire line logs. The two formations were differentiated by cable-tool drillers in the 1920's and the 1930's by the color difference, an aspect that is not detectable on wireline geophysical logs. Cable-tool drillers looked for the red color of the Permian Cedar Hills Sandstone (which "washed red"), while drilling through the white Cheyenne sand. It is interesting to note that after detailed mineralogical and petrographic study, Swineford and Williams (1945) concluded that "the outstanding distinguishing characteristic of the Permian redbeds is their red color," and that "the red color and the associated scarcity of pyrite are the only features determinable by us which serve to differentiate between the Permian sands and the rounded facies of the Cheyenne."

In cross section A–B (fig. 5), wells 9, 20, and 24 were formerly used as shallow SWD wells into which waste oil-field brine was injected under pressure into the Cedar Hills Sandstone and the Cheyenne Sandstone.

The Kansas Corporation Commission is still permitting the Cedar Hills Sandstone to be used for shallow disposal of waste oil-field brines in new SWD wells except in the vicinity of the subsidence areas affecting I–70 (Don Butcher, personal communication, January 1990).

Cretaceous rocks

Structure, Fence-post limestone

Cretaceous rocks crop out within and near the Gorham oil field. The structural attitude of these surface and near-surface rocks is illustrated in fig. 16, contour interval 10 ft. The prominent Gorham anticline as contoured on the Fence-post limestone or "post rock" has 30 ft (9 m) of closure in a critical southwest direction. Outcrop control is excellent and detailed in the rugged hill and valley terrain of northern parts of T. 13 S., R. 14–15 W., as shown by the pattern of continuous outcrops. Control also is

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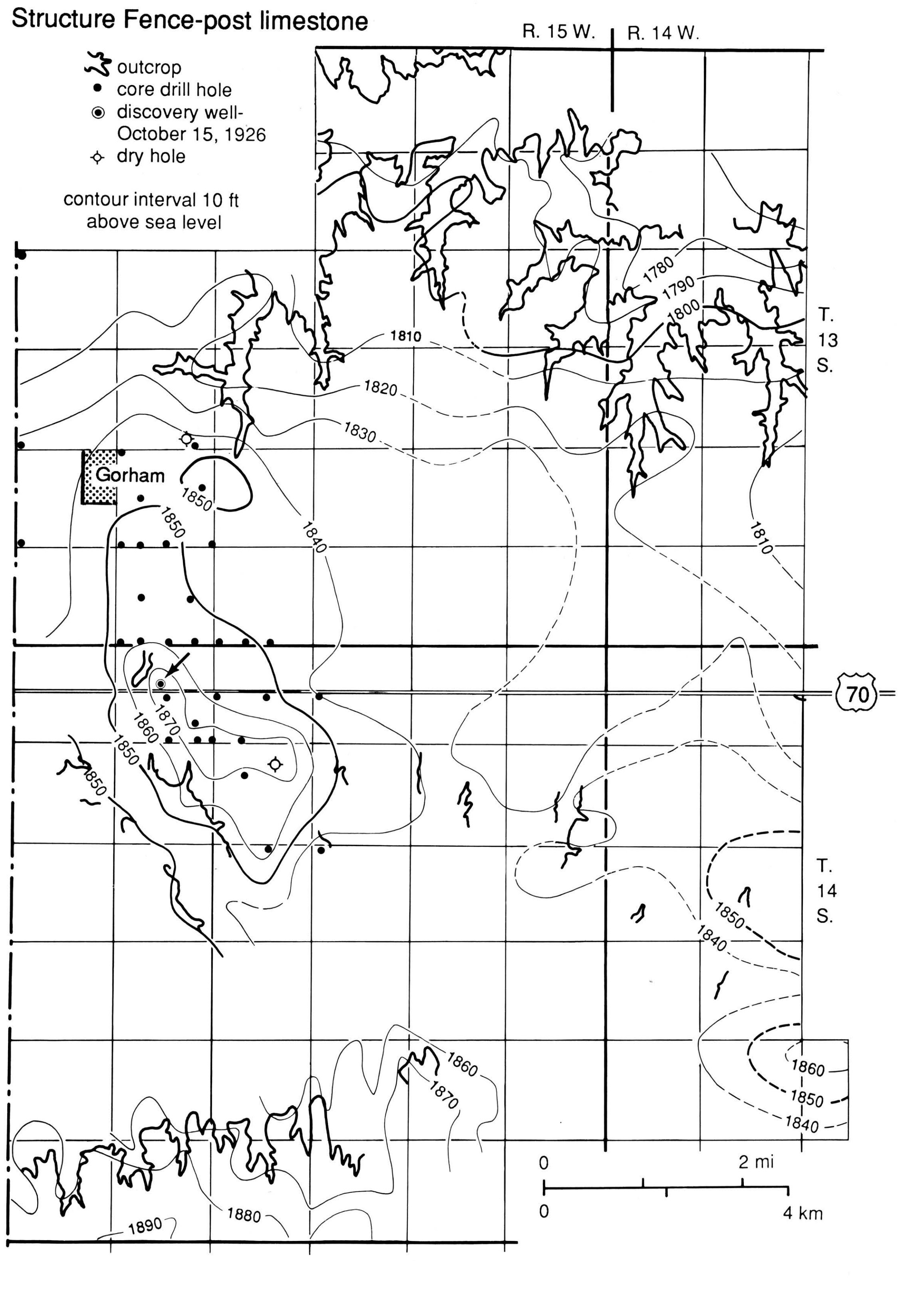
FIGURE 15 (left)—STRUCTURE OF THE STONE CORRAL ANHYDRITE, PERMIAN, depth near 900 ft (270 m), contour interval 25 ft above sea level. A structural closure marks the northwest-trending axis of the Gorham anticline with about 50 ft (15 m) of post-anhydrite faulting and/or differential compaction of the Permian red beds. The Stone Corral mapping shows movement on both the northwest major fault zone and the northeast cross fault zone.


Structure Fence-post limestone
outcrop
core drill hole
discovery well-
October 15, 1926
dry hole
contour interval 10 ft
above sea level
R. 15 W.
R. 14 W.
T.
13
S.
T.
14
S.
Gorham
70
1780
1790
1800
1810
1820
1830
1840
1850
1860
1870
1880
1890
0
2 mi
0
4 km

excellent in the hills in the southern portion of T. 14 S., R. 15 W. Scattered small outcrops within the oil-field area indicated that closure was present as later confirmed by the core drill holes shown on the map. Control is lacking in the mid-portion of T. 14 S., R. 15 W. along the Big Creek bottomlands and is almost entirely lacking in that portion of T. 14 S., R. 14 W. mapped in fig. 16 in a reconnaissance manner (dashed lines).

Aquifers; the Dakota and Cheyenne Sandstones

The Fence-post limestone and other members of the Greenhorn Formation are underlain by 40 ft (12 m) of black Graneros Shale which, in turn, rests on a thick sandstone-shale series shown on cross sections A–B and B–C (figs. 5 and 6) as undifferentiated Dakota–Kiowa formation. Sandstones in the upper portion of the Dakota–Kiowa formation were orginally a freshwater aquifer, whereas sandstones in the lower portion were and are brine-bearing. These crossbedded fluvial and massive channel sandstones with interbedded brightly colored shales are readily distinguished from the underlying white horizontally bedded marine Cheyenne Sandstone, a brine-bearing aquifer. The Cheyenne Sandstone and the lower Dakota Sandstone, east of the wedge-edge of the Cedar Hills Sandstone, are interconnected hydraulically in the northeastern portion of the study area. Saline waters from this system discharge under natural conditions into the alluvium of Salt Creek, an east-flowing tributary which joins the Saline River just 2 mi (3.2 km) northeast of well 53, cross section B–C (fig. 6). Both streams were named by settlers more than 50 years before the discovery of oil in western Kansas at the Fairport oil field in 1923. This saline aquifer system was penetrated in 1894 by the Fay artesian well (Bailey, 1902) in the SE sec. 14, T. 12 S., R. 15 W., 3 mi (4.8 km) north of the study area. The Fay well, drilled to a depth of 121 ft (36 m), flowed 30 gallons per minute of saline water, specific gravity 1.0109, with 16,146 mg/L total solids, and with a shut-in pressure of 15 psi.

The basal Cretaceous Cheyenne Sandstone was extensively licensed for use as a shallow saltwater-disposal zone from the 1930's to the 1960's. Only during the 1940's did the State Board of Health allow disposal of oil-field brines into the lower part of the Dakota for a brief time.

The casing program in wells drilled through the Cretaceous beds was determined by the water-bearing properties of those beds. In holes drilled with cable tools, casing was set when a hole full of water was encountered, in order to be able to drill deeper. When drilling with rotary tools, surface casing was commonly set at 250 ft (75 m) to protect the freshwater beds, but not deep enough to case off the brine-bearing lower sandstones of the Cretaceous. In recent years, however, surface pipe has been set near 500 ft (150 m). In wells drilled specifically for secondary recovery by waterflooding or for use as a saltwater-disposal well, the Kansas Corporation Commission requires surface pipe set in the "red beds"; however, operators commonly set surface pipe deeper into the Stone Corral anhydrite, depth from 850 to 950 ft (255–285 m), shutting off all the Cretaceous and Permian aquifers that now carry corrosive saline waters of mixed origin.

FIGURE 16 (left)—STRUCTURE OF THE FENCE-POST LIMESTONE OR "POST ROCK," CRETACEOUS; contour interval 10 ft. Based on outcrops (heavy black lines) and core holes (solid black dots) drilled to the "post rock" in 1924–25. Arrow indicates the discovery well of the Gorham oil field, completed October 15, 1926. A previously drilled dry hole is located 1.5 mi (2.4 km) southeast, within the top closing contour (Hintze, 1928). A second prior dry hole is mapped 2.5 mi (4 km) north. This is a historical map, redrafted from a copy of the original core-drill map used by Tom Allan (deceased 1985) to locate the discovery well. This map shows 30 ft (9 m) of post-Cretaceous closure in a critical southwest direction directly above the northwest-trending Precambrian fault zone (fig. 7).

Structural growth of the Gorham anticline

The structural growth of the Gorham anticline is delineated literally from the "granite to the grass roots" by the series of structural maps. These include the Precambrian map (fig. 7), the Arbuckle maps (figs. 9 and 10), the Lansing–Kansas City map (fig. 11), the Stone Corral anhydrite structural map (fig. 13), and the near-surface structural map on a datum of the outcropping Cretaceous Fence-post limestone (fig. 16).

Precambrian rocks provide the basement tectonic framework. Their influence can be read in all shallower maps. Deformation was episodic throughout geologic time and closely adhered to an original template. The prominant northwest-trending fault or fault system, which has a displacement of 400 ft (120 m) on the Precambrian surface (fig. 7), is reflected in shallower beds in diminishing amounts. On the Arbuckle (figs. 9 and 10), faulting accounts for perhaps 100 ft (30 m) of the total relief of 150 ft (45 m) on the buried sub-Pennsylvanian topographic surface. On a datum of the top of the Pennsylvanian Lansing–Kansas City beds (fig. 11), faulting is still evident to the extent of 60 ft (20 m) of the total relief of 120 ft (36 m). Within the Permian, on a datum of the top of the Stone Corral anhydrite (fig. 15), structural relief is 50 ft (15 m) due to differential compaction and/or faulting. The steepest dips, one-half of 1°, occur directly above the position of the fault in the Precambrian rocks. On the Cretaceous Fence-post limestone near the surface (fig. 16), the steepest near-surface dips also occur in a position above the locus of the fault zone in the Precambrian and sub-Pennsylvanian beds. Closure on the near-surface anticline in the Cretaceous rocks is 30 ft (9 m).

This sequence confirms the structural growth of the Gorham anticline by intermittent or episodic fault movement plus differential compaction over millions of years, controlled by a template of basement-rock configuration, movement, and faulting.

Regional mapping by Berendsen and Blair (1986) found similar basement control of the structural history. They mapped a study area measuring 120 by 60 mi (192 × 96 km) extending to the western edge of Ellsworth County just east of Russell County. Their contour maps of multiple horizons revealed that present-day structural configurations have resulted from repeated episodic re-activation of Precambrian trends. They concluded that brittle deformation played an important part in the tectonic development of Kansas, that the structural complexity of each mapped interval increases with depth, and that the structure of the less well known Precambrian basement must be considerably more complex than the Arbuckle or sub-Pennsylvanian surface. In the Gorham oil field, structural mapping of the 100 mi^2 (260 km^2) study area shows the same pattern of increasing complexity with depth. There, too, the overlying sedimentary rock sequence records basement movements with increasing intensity downward. It is quite likely, based on analogy with regional mapping of Berendsen and Blair, that the Precambrian basement under the Gorham oil field is complexly faulted by high-angle normal and reverse faults as a result of brittle deformation. The relative structural flatness of the Gorham oil field structures, with Pennsylvanian dips of only a fraction of one degree and with Arbuckle dips of 2° or less, makes recognition of small-displacement basement faults difficult to confirm from subsurface structural mapping. It is concluded that the Precambrian basement rocks under the Gorham area are much more faulted than shown in the conservatively mapped fig. 7, p. 11.

Oil production

Oil production by years 1926–1986

Cumulative production

The Gorham oil field produced 93,860,011 barrels of oil (BO) in 60 years from October 24, 1926, through December 31, 1986. During 1986, oil production was officially reported as 520,292 BO from 531 oil wells. These official figures calculate to 1,425 barrels of oil per day (BOPD) or an average production of 2.68 BOPD per well during the year 1986.

The author counted wells in the field in October 1986, and found 444 oil wells in actual production. Using that figure, the production calculates as 3.21 BOPD per well. Twelve years earlier, in December 1974, the official production figures showed 448 oil wells producing 3.46 BOPD per well. At that time, the author conducted a field check and counted 341 pumping wells. Using the well-count figure, the production calculates at 4.55 BOPD per well. Both field checks confirm that there is an appreciable lag from the time a well is shut down to the time that it is reported as plugged and abandoned.

The Gorham oil field has been in the stripper classification since 1955. A stripper oil-well is defined as an oil well that produced on the average less than 10 BOPD for 365 consecutive days of actual operation. The term "stripper" is applied to an oil field with an average production of less than 10 BOPD per well for a year. In spite of the low average production per well, the Gorham oil field is a substantial contributor to Kansas oil production by providing 1,425 bbls of domestic oil per day for Kansas refineries in 1986.

Sources of oil-production statistics

Kansas Corporation Commission records are the source of oil-production statistics. Operators are required to report the barrels of oil produced each month on a lease-by-lease basis. The current and recent monthly records of oil and gas production are available to the public in the offices of the Kansas Corporation Commission. Records from 1931, the advent of proration, through the following decades, are poorly preserved on film with somewhat uneven indexing. Although these older records are theoretically available for public use, they are difficult to access. Commercial service companies use the current Kansas Corporation Commission oil-production records to abstract and publish monthly oil and gas production data which are sold by subscription. Two companies are Dwight's Energydata, Inc. of Tulsa and other cities, and Petroleum Information, a company of the Dun and Bradstreet Corp. of Denver, Houston, and other cities. Production statistics available from these commercial sources provide oil and gas production records indexed geographically (by section, township, and range) on a lease-by-lease basis. Their statistics include cumulative lease production to the date of the report for active leases. A separate report is available for abandoned leases. The Kansas Geological Survey utilizes the Kansas Corporation Commission records and the commercial reports to compile annual summaries of oil production for the state on a county-by-county basis and by individual oil fields. Publications by the Kansas Geological Survey are listed in the appendix, table 8, "Petroleum-production statistics for the state of Kansas." These publications are listed by the year of statistical data, not by the year of publication, which may be from one to five years later.

There are no generally available records preserving oil-production information on a well-by-well basis. None preserve production records by formation. All listings in this report of production by formations are based on the judgment of the author and are allocations or estimates. For each lease, the cumulative oil production in barrels to December 31, 1986, was recorded on a spreadsheet as were the number of oil wells, the lease area in acres, the producing formations, and the author's estimated allocation of cumulative oil production among the formations for each lease. From data on the spreadsheet, the production from each formation was calculated for the entire oil field and for discrete areas within the oil field as needed for examples.

Annual production statistics from which the graphs in fig. 4 were made are summarized in the appendix, table 2. Oil-production data from the early years are difficult to compile. Like other major oil fields in central Kansas, the present Gorham oil field was formed by merging many former smaller oil fields, each with its own discovery well. Thirty-seven of these recognized discovery wells of former oil fields now merged into the Gorham oil field are mapped in fig. 3 and listed in the appendix, table 1. The author had access to unpublished oil-company production records for western Kansas oil fields to 1940. The production figures in table 2 were assembled by diligently compiling a "genealogy chart" accounting for the merging of the 37 named oil fields into the present Gorham oil field. Some ambiguities remain. For example, Atherton oil field was at one time a separate oil field. It was then combined with the Russell oil field by the Kansas Corporation Commission Oil Field Nomenclature Committee, but later part of the former Atherton oil field was reassigned by that committee to the Gorham oil field. Some production records may have been lost in this and other comparable transfers, but the production figures by formations are reasonably correct as presented. If stripper production continues for about 15 more years, oil production from the Gorham oil field will reach 100 million BO qualifying it for the rank of a domestic "giant oil field."

Oil production by formations

General statement

In general, two-thirds of the oil sold from the Gorham oil field to December 31, 1986, was produced from the unconformity-related Arbuckle dolomite and Reagan Sandstone. One-fourth of the oil was produced from the Pennsylvanian Lansing–Kansas City limestones. The Topeka fracture zone is considered to have produced about 7% of the total oil. A little more than 1% came from the Permian (Tarkio, etc.) reservoirs. A small amount of oil was produced from Precambrian granite and quartzite. The percent of production, by formations, and the gross oil production figures in barrels of 42 U.S.A. gallons are shown in the appendix, table 4, p. 100.

Oil production, Reagan Sandstone

Statistical data summarized in table 4 may be analyzed further. Oil recoveries from the Reagan Sandstone averaged about 88,000 BO per well but varied widely depending on the updip or downdip location of the oil wells as shown by the following specific examples:

Oil production, Reagan Sandstone

Location in T. 14 S., R. 15 W.	BO produced	No. of wells	BO / well	Acres	BO/ acre
sec. 15	4,692,730	35	134,078	500	9,385
sec. 10	4,146,820	45	92,152	450	9,215
sec. 11	669,285	45	14,240	500	1,339

The Reagan Sandstone wells in secs. 10 and 15 are located either in the updip or the midportion of the sandstone-producing area in T. 14 S., R. 15 W. In contrast, the wells in sec. 11, some of which have a few feet of dolomite above the sand, are located near the downdip edge of sandstone oil production. They went to 100% water early, after only producing about 11% as much oil as the best of the updip wells.

The sec. 15 area was drilled on irregular wider spacing, averaging 14 acres (5.6 hectares) per well, compared with the regular 10-acre (4-hectare) spacing of sec. 10 oil wells. Per-acre production in sec. 15 was comparable to that from the 10-acre-spaced oil wells, but the per-well recovery was 45% higher in sec. 15; hence, wells were much more profitable with the wider spacing.

It is not possible to transfer this information into barrels of oil per acre foot because of the method of production. All of the Reagan Sandstone oil wells in T. 14 S., R. 15 W. were drilled in the 1930's, mostly with cable tools. When oil entered the borehole while drilling the very first foot or two in the sand, drilling was stopped. The thickness of the sand at most locations was and is unknown. Pipe was then set and the well put on production. No permeability measurements are available, but it is probable that the excellent permeability of the leached Reagan Sandstone is measurable in Darcy's—not in millidarcies. Reagan Sandstone oil production had an enormously effective water drive for energy. In the Gorham oil field in 1975 (Walters, 1978, p. 68), three Reagan Sandstone oil wells in a late stage of production history were equipped with 3-inch tubing and were pumping 900 bbls of fluid per day (BFPD) each. One well with a bottomhole Reda pump was observed lifting 2,000 BFPD, mostly saltwater.

Comparable figures for oil production per well or per acre are not available for the Reagan Sandstone or "Gorham sand" production in the vicinity of the 1928 discovery well in sec. 33, T. 13 S., R. 15 W. At that time, wells were pumped at capacity, subject only to finding a market for the crude oil. This situation changed abruptly May 28, 1931, when House Bill 387 became effective. With that bill, the State regulated oil production by proration. Koester (1934) stated that it was for the purposes of "the prohibition of waste, including gas energy; the regulation and prevention of discrimination of purchasers; and the marketing of oil ratably from wells in each field when the daily production is above fifteen barrels of oil per well." No mention is made of price; rather, the banner under which price controls were achieved in Kansas through all the years of the Gorham oil-field history after May 1931 was "prohibition of waste."

Annual oil-production figures published by Folger (1933) for production from the Reagan Sandstone (Gorham sand) around the discovery well in sec. 33, T. 13 S., R. 15 W., on a lease-by-lease and well-by-well basis for the years 1928 and 1929 were used for calculations of the daily production per well for those years. In 1928, the first 10 "Gorham sand" wells (called "Pennsylvanian basal conglomerate" by Folger) had a daily average oil production of 149 BOPD per well for the year. Highest production was from the Johnson and Vickers #1 Gorham (the well from the derrick of which the cover photo was taken in April 14, 1928), which produced and sold 56,173 BO in 226 days after its completion May 18, 1928, or 248 BOPD. Production from that well declined to 45 BOPD in 1929. During 1929, the same 10 wells averaged 59 BOPD per well, a 60% decline. Folger (1933, p. 98), to whom monthly figures were available, stated in more detail that,

> It is significant that the average production of the Pennsylvanian basal conglomerate wells declined from 580 barrels per day in February, 1928, to 57 barrels per day in December, 1929. Part of this is normal decline, and part appears to be due to the fact that since the producing sand is connected, as each new well is completed it reduces the production of all the wells.

Thus it was early recognized that the Gorham sand reservoir was being overdrilled and overproduced, justifying the curtailment of production by regulated well proration in 1931. During the general economic depression affecting the country in the early 1930's, devastatingly low oil prices bottomed at 22¢ a barrel in July 1930. These low prices led to waste when viewed from the historical vantage point of 60 years of oil production from the Gorham oil field.

The 1928–29 production figures cited are in contrast to the situation after May 28, 1931, when production was limited to a ratable portion of the well's capacity or a minimum of 15 BOPD per well. Development in the mid-1930's of the Reagan Sandstone oil wells in T. 14 S., R. 15 W. was slowed. These regulations did, however, enforce regular well spacing in the 10-acre (4-hectare) pattern, 660 ft (198 m) between oil wells and with each oil well 330 ft (99 m) from the lease boundary. The regulations also inadvertently encouraged the over-drilling of the Reagan Sandstone wells in T. 14 S., R. 15 W. and elsewhere. This is due in part because the cash flow from one oil well with the reduced allowed-production of a maximum of 25 BOPD to a minimum of 15 BOPD per well was quite low for economically viable operation. Leases with more wells had more profitable cash flow. Weak wells, producing less than 15 BOPD, were sometimes helped, illicitly, by overproducing stronger wells.

Oil production, Arbuckle dolomite

Further analysis can be made from the figures for oil production from the Arbuckle dolomite shown in table 4, p. 100. Oil production is stated separately for Arbuckle lithologic units B, C, D, and E. There is no production from Unit F within the Gorham oil field. For the most part, Arbuckle dolomite oil wells are spaced on regular 10-acre (4-hectare) locations so that the per-acre production can be approximately projected as 10% of the per well recovery figures. The per-acre recovery range is, therefore, from 3,500 BO/acre for the cherty dolomite E member to 7,000 BO/acre for the sandy dolomite C member. The average for the 829 Arbuckle wells is 5,247 BO/acre. The rounded figure of 5,000 BO/acre is useful in approximating oil reserves in the Arbuckle dolomite, particularly where the amount of reservoir porosity within the oil column is not known, as is often the case.

The Arbuckle dolomite–Reagan Sandstone reservoir in the Gorham oil field has a strong water drive so that the oil column is approximately the distance from the top of the Arbuckle or Reagan Sandstone to the oil-water contact, originally near subsea –1,440 ft (–432 m). The oil column is defined as the vertical interval from the top of the structurally highest oil-bearing porosity to the base of the producible oil. The oil column in the Arbuckle dolomite reservoir in the Gorham oil field had a maximum thickness of 42 ft (12.6 m) with the same thickness in the Reagan Sandstone area. Although the lithologic subdivisions of the Arbuckle are a factor affecting relative oil recovery, the structural position of the oil well and the local development of porosity are far more important. Structurally high wells have more oil column. They, therefore, have a greater thickness of reservoir porosity after eliminating tight, nonporous zones or beds. It is the author's opinion that the high per-well and per-acre recovery of the sandy dolomite C member, 70,000 BOPW and 7,000 BO per acre, is largely due to its fortuitous subcrop position along the southeast axis of the Gorham anticline. Along this anticlinal axis, 22 oil wells producing from the sandy dolomite member encountered the top of the Arbuckle above subsea –1,400 ft (–432 m), and thus had more than 40 ft (12 m) of oil column or "pay." This is the thickest Arbuckle production zone within the Gorham oil field.

Oil production, Lansing–Kansas City

Lansing–Kansas City limestone reservoirs provided 25% of the total oil production of the Gorham oil field. The amount produced is 24 million barrels of oil from 477 wells known to the author to have produced oil from the Lansing–Kansas City beds. These figures were obtained by first ascertaining which wells produced from any part of the Lansing–Kansas City. For the first 20 years (1926–1946), the era of predominantly cable-tool drilling, this is rather easily determined. When a well encountered or "discovered" oil, drilling stopped. The scout tickets and record cards give total depth even though they do not always indicate the pay zone. For the last 40 years, Lansing–Kansas City oil production is not so clearly ascertained. Most rotary-drilled holes drill to the deeper Arbuckle formation, testing the Lansing–Kansas City on the way down. Only when deeper oil production either is not present or is later depleted are such wells plugged back to produce oil from the Lansing–Kansas City, Toronto, Topeka, etc., in upward sequence without necessarily publicly recording the plug-back operation. The second step was to ascertain the lease or section production and the third step was to attempt to make a reasonable allocation of the total production to the appropriate producing zone. This is not precise on a lease-by-lease basis but does give a reasonable order of magnitude figure for the whole oil field.

No effort was made to distinguish among zones in the Lansing–Kansas City or among separate Lansing–Kansas City producing areas within the Gorham oil field, for the reason previously stated—the Kansas Corporation Commission, the regulatory agency, considers all Lansing–Kansas City wells in the Gorham oil field to be producing from a common source of supply regardless of the zone within the Lansing–Kansas City; hence, no separate zone-by-zone figures are required to be kept for the public record.

Oil production by enhanced-recovery methods, Lansing–Kansas City

It is difficult to know how much of the Lansing–Kansas City oil produced is due to secondary recovery by waterflooding. Even the owner or operator of the lease is usually not certain. For 23 years (1959–1982), the Kansas Geological Survey recorded such information. It discontinued publishing secondary-recovery series annual reports in 1983 because of the low demand for the information, the high personnel-time cost of collecting the information, and the questionable reliability of some of the volunteered information, according to Larry H. Skelton (personal communication, 1988), who formerly assisted in compiling annual secondary-recovery reports. A reasonable order of magnitude figure is that one-third, or 8,000,000 bbls, of the Lansing–Kansas City oil was recovered by waterflooding.

With new technologic development, substantial improvements have been and will be made in the recovery of additional oil. For example, acidizing of carbonate rocks during well completion has provided a tremendous boost in well-production capacity. Although acidizing was introduced as a secondary-recovery method to depleted "Oswald" wells in the Fairport and Gorham oil fields in the 1930's, it is now a routine part of well completions. Certain methods of tertiary oil recovery—notably miscible polymer injection and carbon dioxide miscible injection process—have significant potential but are on "hold" for the future because of the low price of crude oil.

One of these tertiary oil-recovery processes was investigated by Poyser (1988). She reviewed the Lansing–Kansas City oil production in seven major central Kansas oil fields, including the Gorham oil field, and found that "the range for primary recovery. . . was between 6.1% and 34.2% of the original oil in place. For waterflooding, the recoveries were 5.7% to 19.6% of the original oil in place." She concluded that the application of the carbon dioxide miscible process to Lansing–Kansas City oil reserves can increase incremental oil production by as much as 10–20% of the original oil in place, but estimated that the oil price must be $24 a barrel or higher for the process to be economically attractive.

Oil production, Shawnee Group—Oread and Plattsmouth

Shawnee oil production from intercrystalline porosity in the Oread (Toronto) and Plattsmouth ("Topeka") is commonly comingled with Lansing–Kansas City production. No separate production figures are available. Topeka oil wells producing from the Oread and Plattsmouth limestones are not mapped in fig. 12.

Oil production, Topeka fracture zone

Topeka production from fracture zones was obvious in cable-tool drilling in the 1930's. However, additional oil production from fracture-zone porosity has seldom been found during the past 50 years, probably because of the difficulty in detecting it using rotary-drilling equipment with mud-filled holes. Figures given for production from the 30 mapped Topeka fracture-zone wells (fig. 12) are derived from surviving well records plus arbitrary allocation. The figure 6,500,000 BO is considered correct as an order of magnitude figure for oil production from this zone. Although regarded as "freak" production, Topeka fracture-zone production amounts to a sizable estimated 7% of the total oil produced from the Gorham oil field.

Oil production, shallow formations

No specific figures are available for oil production from formations encountered at depths less than 2,500 ft. Most of the shallow oil production is from the Tarkio (Pennsylvanian, Wabaunsee) and results from technical advances in formation fracturing. Ver Wiebe et al. (1953) provided a brief description of fracturing when there was much interest in this then-innovative well-completion process:

Production from Tarkio sands in earlier years (then called Indian Cave sand) was small. In sand fracturing, special sand is suspended in prepared heavy oil and pumped into the producing formation under pressure, forcing the mixture of sand and oil into the producing sandstone. When the prepared oil is later removed, the suspended sand grains remain in the producing zones holding the grains in the sandstone apart and thus providing avenues of migration for the oil.

Crude oil, well-head prices, 1926–1986

Flush and settled production stages, 1926–1956

The well-head price of crude oil is a decisive factor affecting the amount of crude oil that will be produced from an oil well. Oil wells generally run out of profit before they run out of oil. Crude-oil prices in dollars per barrel are shown graphically in fig. 17 by years from 1901 to the 1980's. The annual mid-year figures from which the graph in fig. 17 was

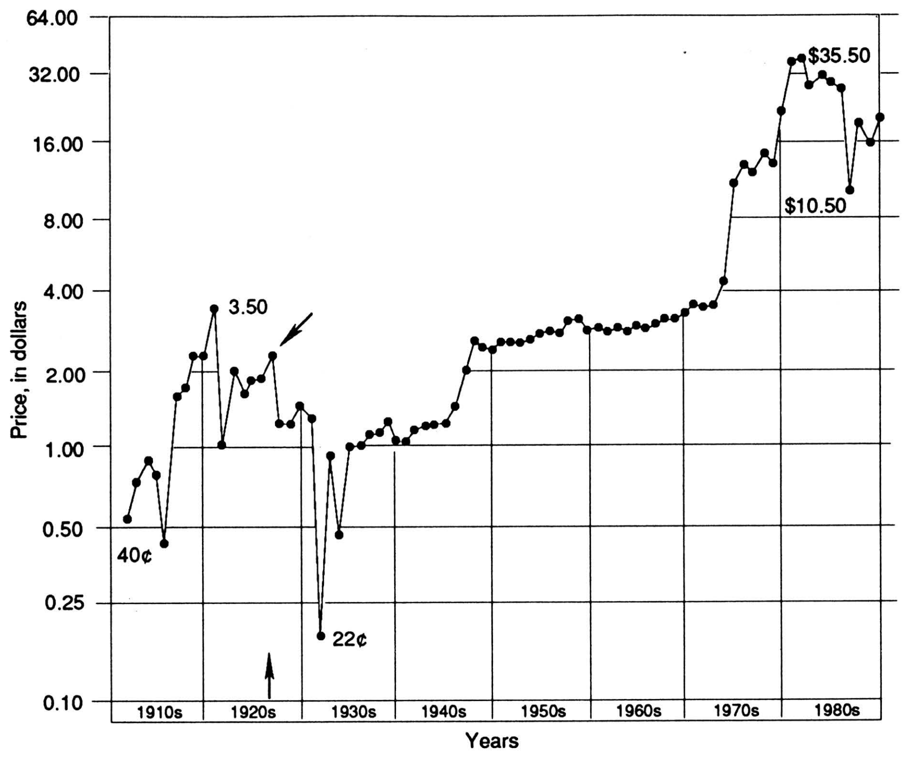


FIGURE 17—POSTED PRICE IN DOLLARS, PAID FOR KANSAS CRUDE OIL AT THE WELL HEAD, 1910's–1980's. Based on average mid-year price for 42-gallon (U.S.) barrel of crude oil, gravity 40°. Figures from which the graph were prepared are given in the appendix, table 5. Arrow indicates 1926, the year of discovery of the Gorham oil field.

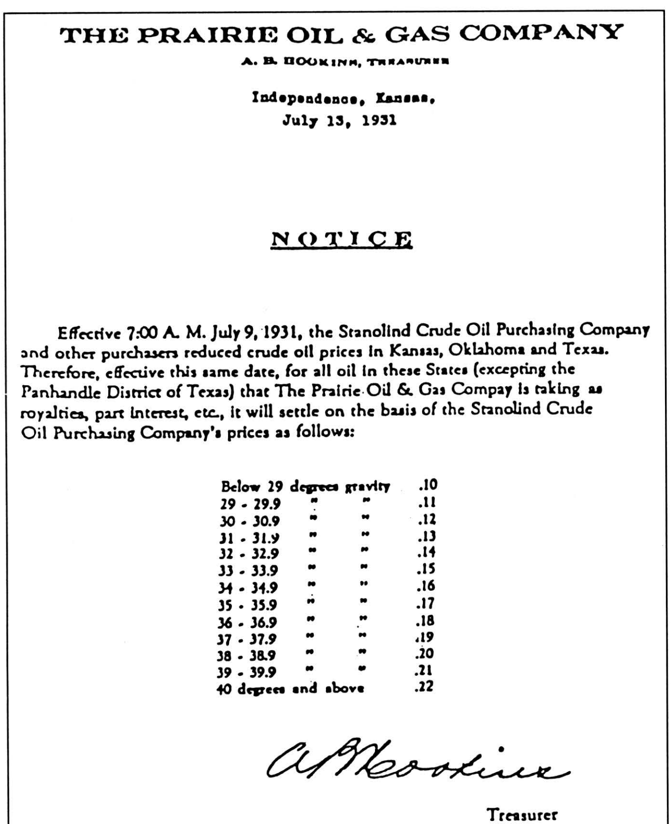
prepared are listed in the appendix, table 5. In fig. 17 the arrow shows the year 1926 when the Gorham oil field came on production. During the Gorham oil field's flush production stage in the 1920's and 1930's, crude oil well-head prices were depressed. Crude oil prices were $1.80 (1926) to $2.00 (1927) a barrel, declining to $1.25 a barrel one year later when the big oil wells were completed in the Gorham sand. Shortly thereafter, the stock market crash of 1929 occurred and was followed by the economic depression of the 1930's. Many major oil fields were being discovered including the Oklahoma City field in December 1928, and the giant east Texas oil field in 1930. Miner (1987, p. 188) summarized:

> The effect of the sudden shift in supply and demand for energy affected the price structure in a dramatic way. Kansas crude averaged $1.32 in 1930, 69¢ in 1931, 91¢ in 1932, and 66¢ in 1933. It ranged between $1 and $1.20 a barrel—about one-half the mid-1920's price—until 1946. There were times when spot prices were much lower. On July 8, 1931, for example, the posted price for high gravity Mid-Continent crude of the finest quality was 18¢ a barrel.

A photocopy of an actual "posting" dated July 13, 1931, is included as fig. 18. These low crude-oil prices resulted from uncontrolled overproduction that led to the formation of the Interstate Oil Compact Commission (IOCC), the curtailment of Kansas oil production under State laws, and to regulations concerning well spacing and production prorationing to prevent waste. This, in turn, led to relatively steady crude oil prices, near $3.00 a barrel, in the settled production stage of the Gorham oil field in the late 1940's, the 1950's, and the 1960's.

Stripper stage of production, 1956–1986

As shown on the bottom graph of fig. 4, the Gorham oil field entered the stripper stage of its production history (averaged less than 10 BOPD per well) in 1955. Twenty years later in 1975, production had declined to an average of 4.56 BOPDPW. Many hundreds of Gorham oil-field wells were at or near their economic limit and would have been abandoned except that the Mideast oil crisis caused domestic crude-oil prices to rise dramatically in the mid-1970's as graphed in fig. 17. The high crude-oil prices of the second half of the 1970's and the first half of the 1980's, reaching $36/bbl, prolonged the production of many of those Gorham oil-field stripper wells for an additional 10 years and caused the drilling of many infill and re-entry wells. Note that there were 341 active oil wells in 1975, averaging 4.56 BOPD per well, increasing to 444 active oil wells in 1986, but averaging only 3.21 BOPDPW. The severe drop in the price of crude oil in 1986, the 60th year of the Gorham oil-field production, to as low as $10.50 a barrel in July of that year, may cause these small oil wells to be abandoned. This development may prevent the Gorham oil field from reaching the domestic "giant oil field" status of 100 million barrels of oil production.



THE PRAIRIE OIL & GAS COMPANY

A. B. HOOKINS, TREASURER

Independence, Kansas,
July 13, 1931

NOTICE

Effective 7:00 A. M. July 9, 1931, the Stanolind Crude Oil Purchasing Company and other purchasers reduced crude oil prices in Kansas, Oklahoma and Texas. Therefore, effective this same date, for all oil in these States (excepting the Panhandle District of Texas) that The Prairie Oil & Gas Compay is taking as royalties, part interest, etc., it will settle on the basis of the Stanolind Crude Oil Purchasing Company's prices as follows:

Below 29 degrees gravity	.10
29 - 29.9 " "	.11
30 - 30.9 " "	.12
31 - 31.9 " "	.13
32 - 32.9 " "	.14
33 - 33.9 " "	.15
34 - 34.9 " "	.16
35 - 35.9 " "	.17
36 - 36.9 " "	.18
37 - 37.9 " "	.19
38 - 38.9 " "	.20
39 - 39.9 " "	.21
40 degrees and above	.22

Treasurer

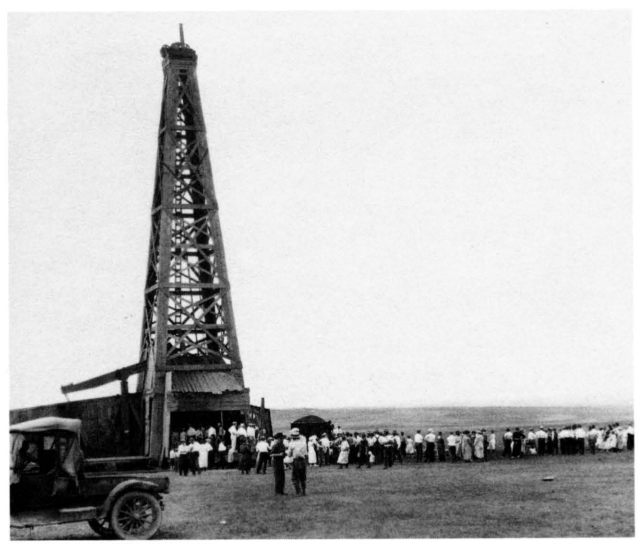
FIGURE 18—FACSIMILE OF NOTICE "POSTED" BY THE PRAIRIE OIL AND GAS COMPANY, JULY 13, 1931, reducing the price for Kansas crude oil to 22¢ a barrel for 40° gravity crude oil with penalties for lower gravity oil down to 10¢ a barrel.

History

The beginning—Fairport oil field, 1923

The history of the Gorham oil field begins with the discovery of the nearby Fairport oil field November 23, 1923. As described in an early report (Allan and Valerius, 1929), the Fairport discovery well was 120 mi (192 km) west and north of the nearest oil production, the Covert–Sellers oil field in Marion County. Development of the Fairport oil field was rapid. Demand for crude oil was strong and the price was firm, $1.60 to $2.00 a barrel. Excellent oil wells with few dry holes were drilled along the "Fairport ridge." The oil field grew to be 4 mi (6.4 km) long and 0.5 mi (0.8 km) wide. By October 1926, 99 oil wells, each with its wooden derrick, were evenly spaced on regular 10-acre (4-hectare) spacing, 660 ft (198 m) apart. Production in 1926 was 1,847,785 BO or an average of 51 BOPD per well for the year.

The famous discovery well of the Fairport oil field, the Carrie Oswald #1 in the SW SW SE sec. 8, T. 12 S., R. 15 W., is located 9 mi (14.4 km) north of Gorham. Interest was high among the local land owners. The much-reproduced photograph (fig. 19a) of the Carrie Oswald #1 on the Sunday afternoon after Thanksgiving shows 102 visitors in clean white shirts or long skirts. In the right foreground the discoverer, M. M. Valerius (hat in hand) is standing with the senior Mr. and Mrs. Oswald and friends. A second view of the Carrie Oswald #1 (fig. 19b) better illustrates the cable-tool standard rig with its derrick, enclosed derrick floor, belt house, water-storage tank, steam boiler, and coal pile, the latter partly concealed by an automobile. All the early wells in the Fairport oil field were drilled with similar equipment, characterized by the wooden derricks that were left in place on the producing oil wells. Figs. 20a and 20b are two additional views of standard rigs drilling in the Fairport oil field. Most of the automobiles belonged to the many visitors. The 102-well Fairport oil field of 1928 (before merging with Fairport North and Fairport South oil fields) was the last major oil field in Kansas to be drilled entirely with cable tools.



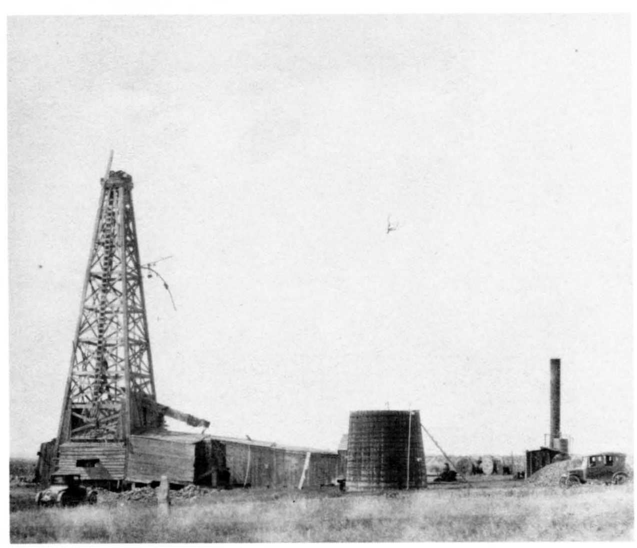
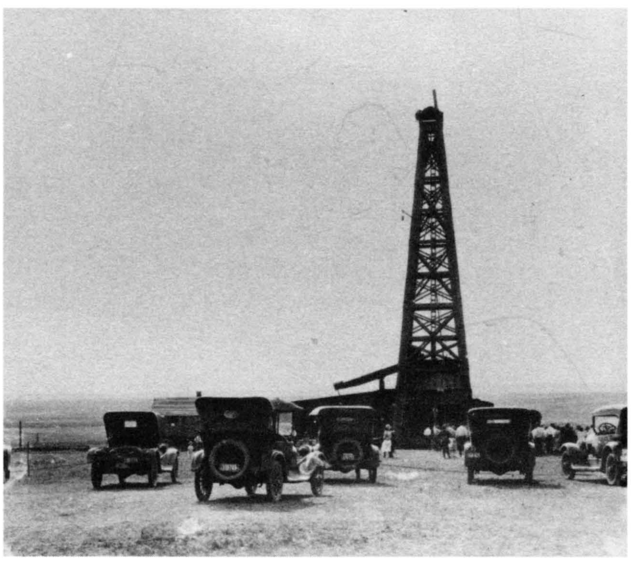
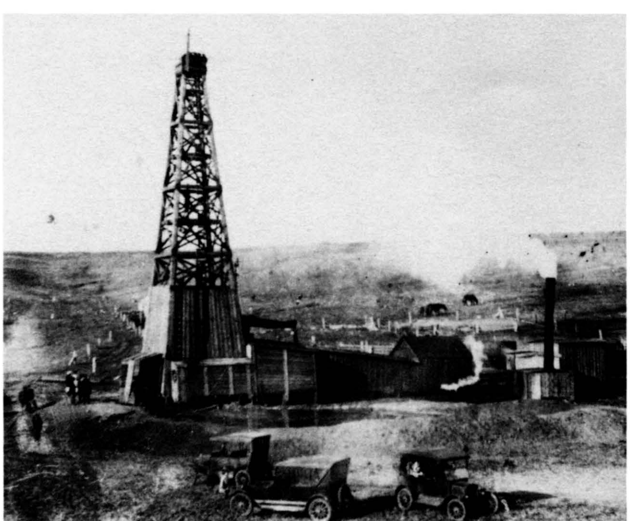


FIGURE 19a (upper)—CARRIE OSWALD NO. 1, NOVEMBER 23, 1923, the discovery well of the Fairport oil field and of oil in the west ranges of Kansas. It was located 120 miles west of the nearest oil production. Local interest was high as shown by the 102 Sunday visitors. 19b (lower)—CARRIE OSWALD NO. 1, a second view showing the cable-tool standard rig, the wood derrick, belt house, water-storage tank, and coal-fired steam boiler. Photographs courtesy Russell County Historical Society.

Exploration by surface geology

Among the oil companies, the completion of a 200 BOPD wildcat well 120 mi (192 km) from production caused much excitement. It was known that the discovery of the Fairport oil field was not due to random drilling but to careful surface mapping of an anticline based on excellent outcroppings of Cretaceous rocks in the river valley and canyon country around the town of Fairport. Following the discovery of the Fairport oil field, oil companies sent many geologists into the area to do field mapping of surface rocks in search of other anticlines. From 1923 to 1926, geologists were a common sight as they swarmed over the area in their Model "T" Fords, wearing broad-brimmed World War I hats, high boots, or leather puttees and knee-length army pants. They squinted through their alidades (fig. 21), making plane-table structure contour maps. The "post rock" or Fence-post limestone quarried by pioneer settlers in the then-treeless prairie for use as fence posts was a reliable correlation bed. Such mapping by J. S. Irwin and F. F. Hintz "led to the discovery of the Gorham structure and the drilling of the first well on it by the Producers and Refiners Corporation" (Hintz, 1928). Unfortunately, the first "well" was a dry hole in the SW NW SE sec. 9, T. 14 S., R. 15 W.





As shown on the structural contour map of the Cretaceous Fence-post limestone (fig. 16) by the heavy lines following the pattern of the outcrop of the "post rock" in the canyon areas of the north part of the map, control for surface mapping was excellent, detailed, and continuous. Along the south edge of the map, the heavy lines show that the control was also excellent in the hills on the southern portion of T. 14 S., R. 15 W., south of Big Creek. In the mid-portion of the mapped area, only scattered small outcrops occur. There are no outcrops at all in the flat wheat fields occupying much of the area of fig. 16.

Exploration by core drill

Surface geologists could not map in flat wheat fields. Tom Allan (personal communication, 1975; deceased, 1985) was a resident of Russell, Kansas, in 1925 and field geologist for the Midwest Exploration Company. He had the idea that shallow test holes drilled in wheat fields with a "core drill machine" would permit mapping of the structural position of the buried post rock and other marker beds. In an innovative move he went to the Mesabi Iron Range in Minnesota in 1924, and hired an expert in coring and setting diamonds in drilling bits. These donut-shaped drilling bits studded with commercial diamonds scratched away the rock leaving a "core" or cylinder of undisturbed solid rock in the "hole" of the donut-shaped bit. In Russell, he had a drill mounted on a truck making the historic first "core drill machine" in Kansas and perhaps the entire midcontinent. Photographs (figs. 22a, b, c, and d; reproduced by courtesy of the Russell County Historical Museum) show his "core drilling machine" from all angles. The shed served not only for

FIGURE 20a (upper)—FAIRPORT OIL FIELD, 1923, WITH VISITORS' AUTOMOBILES. 20b (lower)—FAIRPORT OIL FIELD; photographs courtesy Russell County Historical Society.

shelter but for privacy from rival oil company scouts when the recovered core was removed from the core barrel.

Discovery of the Gorham oil field, 1926

Using his core-drilling machine, Tom Allan cored the holes mapped in fig. 16. After he examined and correlated the cores, he mapped the Gorham anticline as shown and staked the location for the Midwest Exploration Company's Dortland No. 36 in the C SE SE NE sec. 5, T. 14 S., R. 15 W. (arrow, fig. 16). The well was commenced (spudded) on August 8, 1926, and completed October 15, 1926, as the discovery well of the Gorham oil field. It produced 120 BOPD of 37° gravity oil from a depth of 3,057 ft (917 m) in the "Oswald" formation. The Cretaceous map (fig. 16), itself a "historic map," is redrafted directly from a copy of the original map used in the discovery work and given to the author by Tom Allan in 1975. Supplementing Allan's original work and included in fig. 16 is outcrop information from contemporaneous surface-geology maps prepared by three other rival oil companies. The maps also show two early dry holes. The first is the Producers and Refiners Corporation #1 Mermis, previously mentioned, drilled in April 1925, in the SW NW NE sec. 9, T. 14 S., R. 15 W. The second is the Keyes Petroleum #1 Sloan in the SE SW SE sec. 20, T. 13 S., R. 15 W., which was spudded August 23, 1925. Fig. 14, therefore, shows the complete development of the Gorham area at the time of the discovery, October 15, 1926.

Gorham oil field, 1926–27

The completion of Midwest's Dortland #36 as the discovery well of what came to be the greater Gorham oil field did not create much excitement. The well produced from the same formation that was producing in the Fairport oil field, the "Oswald lime" (now Lansing–Kansas City). People living locally were accustomed to oil-well drilling. They had seen 99 oil wells drilled in the Fairport oil field and watched it produce over three million barrels of oil in three years. There was less demand for oil; the price of oil had declined to $1.28 a barrel and there was no pipeline. (The Fairport oil field pipeline was not available as it went north to the Southern Pacific railroad at the town of Paradise.) "Development progressed very slowly, only four producing wells being completed by the end of 1927. No dry holes have been drilled," according to Kesler (1928).

Drilling with standard cable tools

Wells were drilled in the Gorham oil field in the 1920's, 1930's, and early 1940's with cable tools, usually powered by steam. As many as 60 days were required to drill each well to a depth of 3,300 ft (990 m). A heavy drill bit and tools, hung on a cable (hence the term "cable-tool drilling"), were lifted up and down, pounding a hole in the rock. Cuttings were removed in a "bailer," an elongated bucket (to 30 ft [9 m] in length) with a hoop-shaped handle or bail at the top. Wooden derricks similar to those used in the Fairport oil field were used for the first wells, but no identifiable photographs were available in the Russell County Historical Museum. Fig. 23 is a

FIGURE 21—Empire Gas and Fuel Company surface geologists, about 1918. The plane tables and alidades were used for surface mapping of rock outcrops; photograph courtesy Kansas Independent Oil and Gas Association (KIOGA).

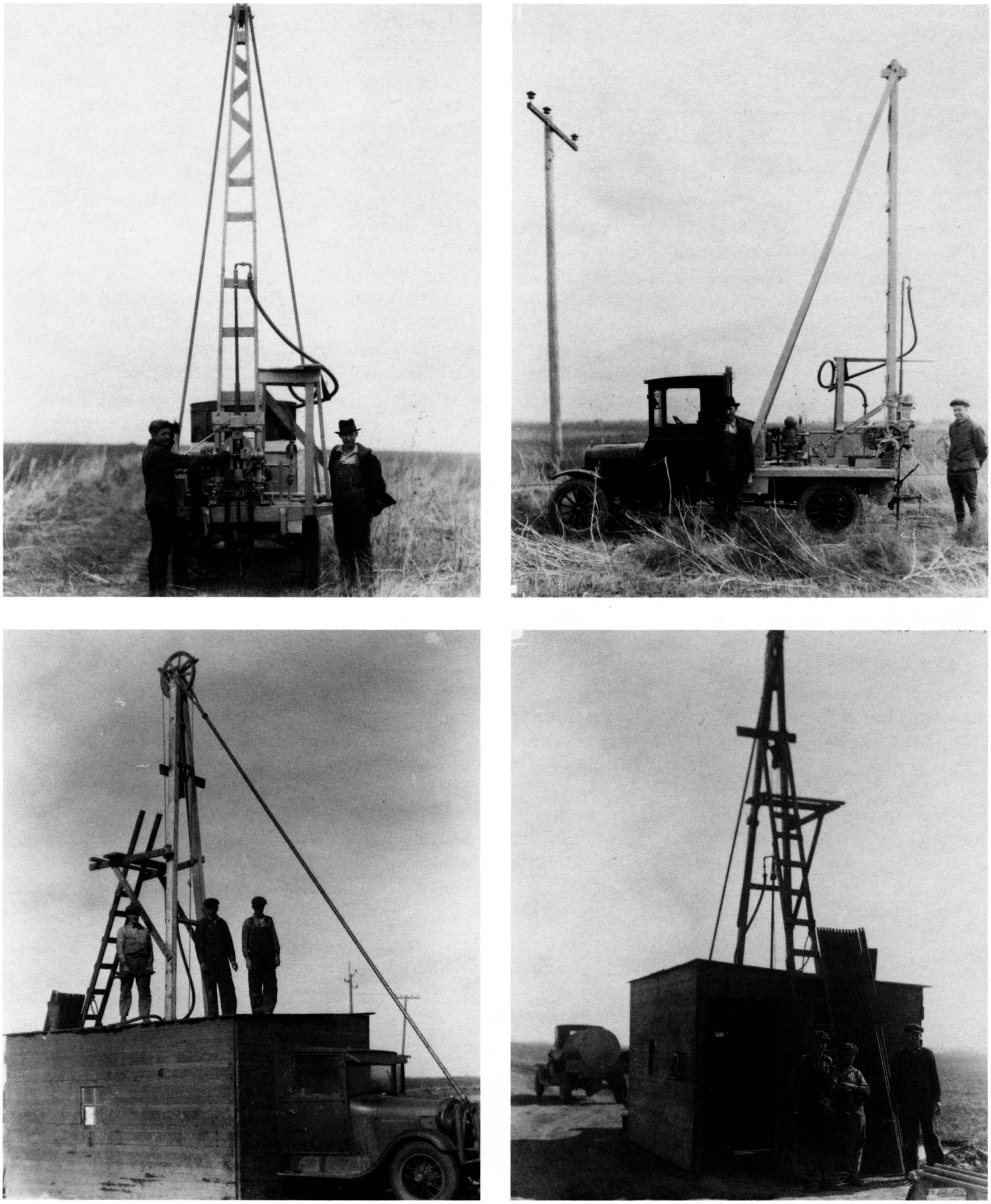


FIGURE 22a–d—FOUR VIEWS OF THE "CORE-DRILLING MACHINE," assembled by Tom Allan for Midwest Exploration Company, 1924, Russell, Kansas. This is possibly the first core drill used in the midcontinent oil fields. The shed served not only for shelter but for privacy from rival oil company scouts when the core was removed from the core barrel; photographs courtesy Russell County Historical Society.

closeup of a 1926 wood derrick left in place over a producing oil well. Each wood derrick was erected by rig builders, the most skilled and highest paid oil-field workers. Working high above the ground and hanging on with one arm, rig builders did most of their construction work one-handed. The boards were attached by metal spikes that were started in the wood with a strong shove of a gloved hand that held both the spike and the heavy rigbuilder's hatchet; the rigbuilders then drove the big spike completely into the wood with three blows (John T. Heisler, Jr., whose father operated an oil-field lumber-supply company at Russell, personal communication, 1986 and later). By 1928 (cover photograph), bolted steel derricks were in use.

After the well was spudded (meaning actual drilling had commenced), the cable-tool drilling rig was manned by two crews of two men each. They worked around the clock, seven days a week, dividing the day into two tours (pronounced as "towers") of 12 hours each. The driller was in charge and the tool dresser was his assistant. The heavy metal drilling bits were "dressed" (sharpened) by heating them red hot in a forge just off the derrick floor and forging (pounding) the red-hot tools in shape with heavy sledge hammers. During forging, the bits were calipered (measured) by a round ring gauge to ensure that the bit would pass through the casing (pipe) in place in the hole. Cable tools are discussed more fully in the Kansas oil-field history book *Discovery* (Miner, 1987, p. 64–70). Figs. 24a and b are from that reference. They show interior views of the cable-tool derrick floor. The large cable, from which cable-tool drilling received its name, is shown in the hole in both pictures. Steam from a sharpened bit being quenched after forging obscures part of the lower photo. Representative tools used in normal drilling are shown in fig. 25 (Moore, 1917). The "bailer" (#4) is not shown for its full length. Bailers were 8–30 ft (2.4–9 m) long with a trip valve on the bottom and a bail on the top.

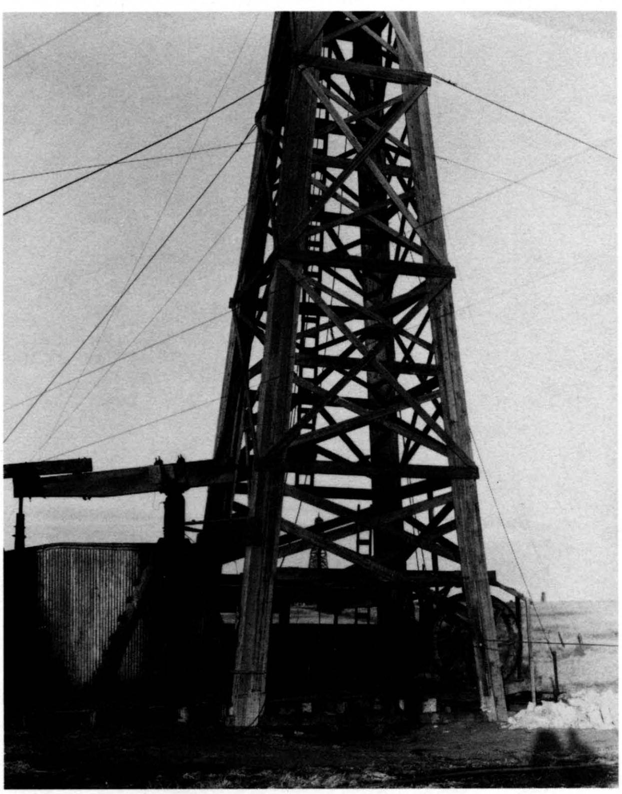


FIGURE 23—CLOSE-UP VIEW OF WOODEN DERRICK AND CABLE-TOOL EQUIPMENT LEFT ON LOCATION AFTER DRILLING TO TOTAL DEPTH TO BE USED FOR PUMPING OIL, Fairport oil field, approximately 1925; photograph courtesy Russell County Historical Society.

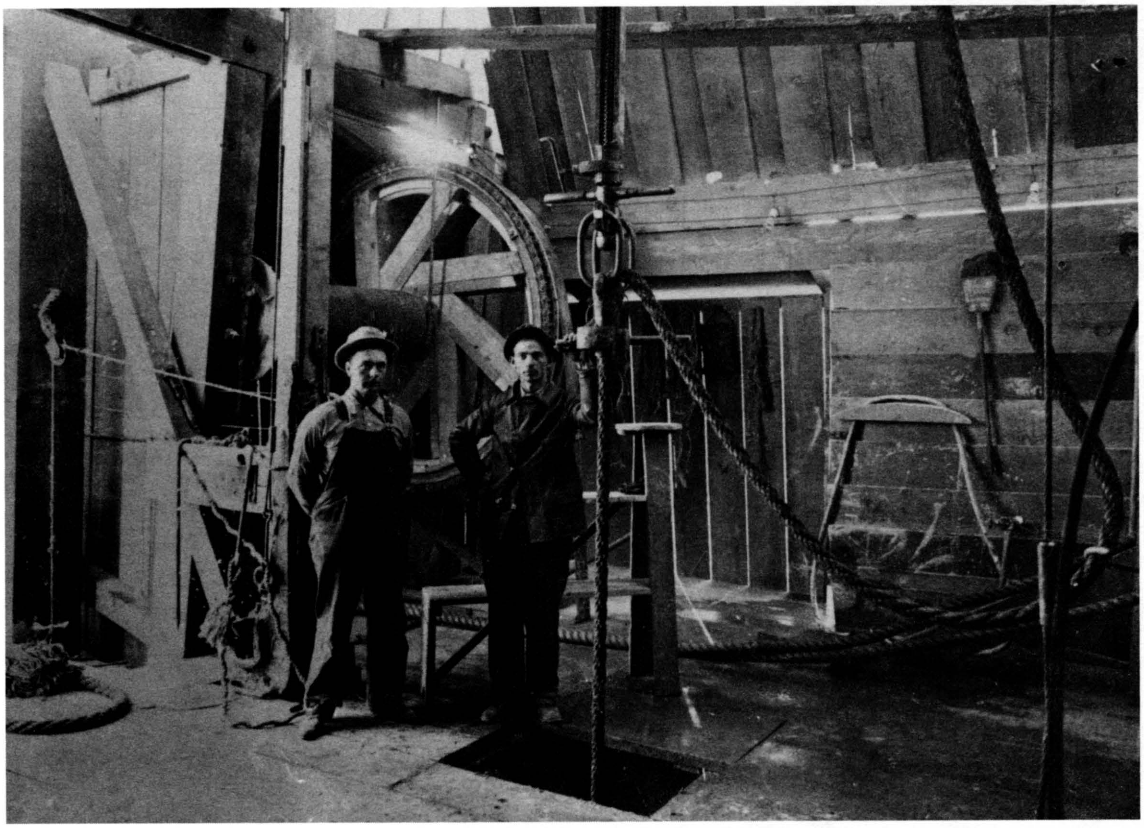
Drilling was accomplished by raising and lowering the cable; attached to the cable were jars, drillstem, and a heavy bit that pounded and pulverized the rock. When enough hole had been made—that is, when sufficient rock had been crushed to impede progress—the bit was pulled from the hole and the bailer run to bottom to remove rock cuttings and fluid. Testing of fluids, called "bailing," was done by repeated runs of the bailer. The results were logged as 4 BWPH, for example, meaning 4 bailers of water per hour, not 4 barrels of water per hour. A bailer could hold either more or less than one barrel depending on its diameter. For example, three bailers each 30 ft (9 m) long have the following capacity in oil-field barrels of 42 U.S. gallons:

bailer 4-inch interior diameter	0.465 barrels
bailer 6-inch interior diameter	1.050 barrels
bailer 7-inch interior diameter	1.428 barrels

Recovery of tools or objects lost in the hole was called "fishing" and required specially designed "fishing tools" not shown.

Advantages and disadvantages of cable-tool drilling

Cable-tool drilling was the only method used at the El Dorado oil field in 1918, the Fairport oil field in 1923, and at the discovery of the Gorham oil field in 1926. Advantages of cable-tool drilling include excellent short samples (when saved) of rocks in the interval drilled, immediate response when fluid was encountered, and direct detection of "oil shows" by odor, sight, and actual recovery of oil in measurable amounts in the bailer. Cable tools began to be



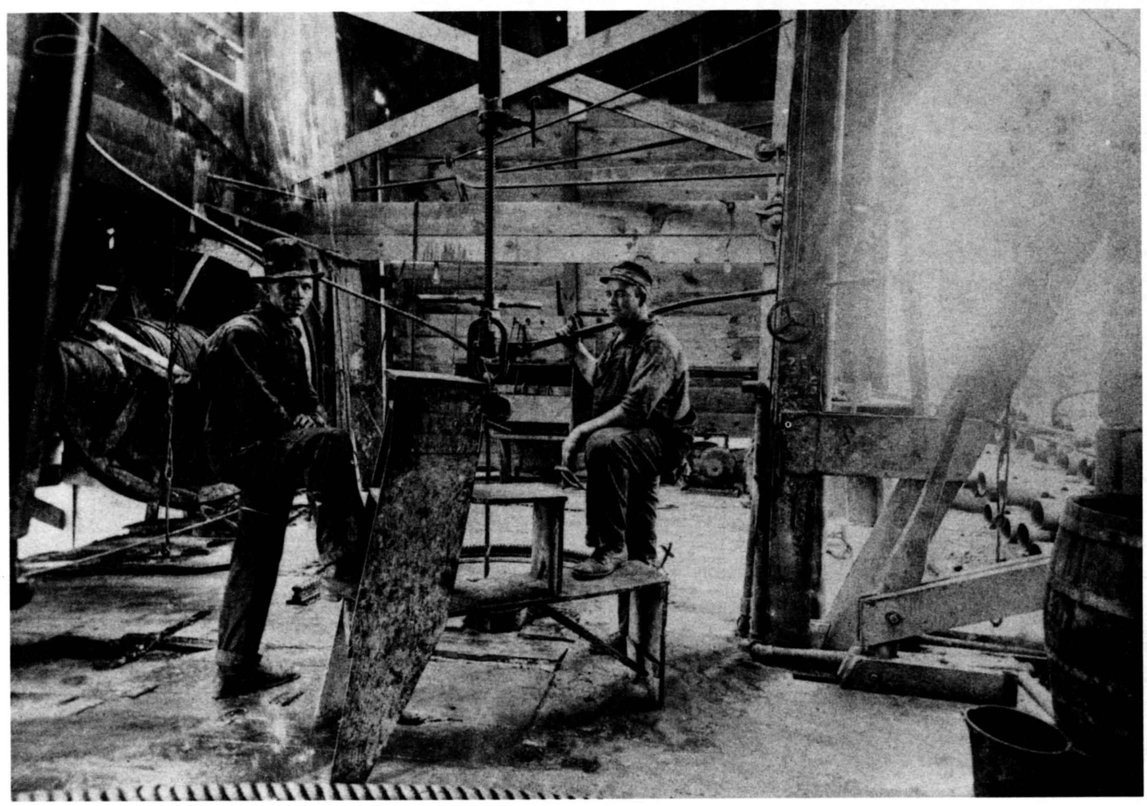


FIGURE 24a—INTERIOR VIEW, CABLE-TOOL DRILLING EQUIPMENT, showing the cable (vertical) from which a heavy bit, auger stem, and jars were suspended. A hole was drilled by lifting and dropping the bit, pounding on the rocks. 24b—INTERIOR VIEW, CABLE TOOLS. Steam from quenching a newly forged (sharpened) bit obscures the right portion of the picture. Both photographs are courtesy KIOGA.

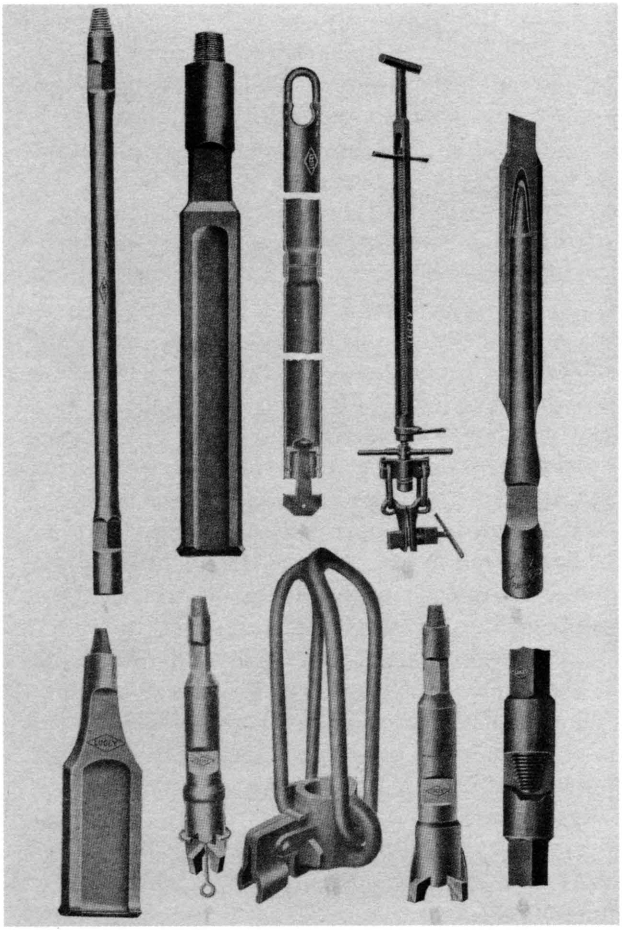


FIGURE 25—TOOLS USED IN CABLE-TOOL DRILLING (Moore, 1917, plate VIII).

displaced by rotary rigs in the late 1920's in the midcontinent but continued in use for full-hole drilling in the Gorham oil field and in Russell County throughout World War II (1941–45), long after they were obsolete elsewhere. In those years, when labor and materials were in short supply, cable-tool drilling was advantageous because cable tools could be operated by a two-man crew. Old drilling units were available and could be repaired with parts salvaged from junk tools. Although casing was in short supply, most of the various sizes of pipe used in the many strings of casing could be "pulled" (recovered) and reused.

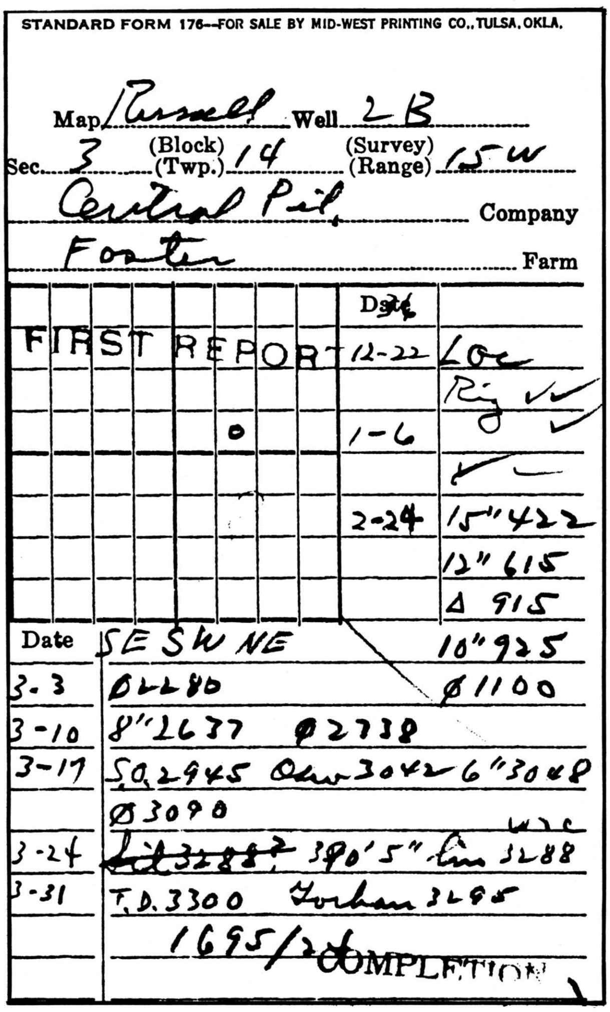
The disadvantage of cable-tool drilling included the slow drilling—up to two months to drill a 3,300-ft (990 m) hole—and the depth limitation. Each time an aquifer was drilled, the hole filled with water (the "HFW" of drillers logs). Drilling could not be continued because the water in the hole slowed the dropping of the bit, pulverizing the accumulated cuttings, without making new hole. This situation required the setting of casing inside previously set casing, thus reducing hole size so that sometimes the cable-tool rig "ran out of hole" before the objective was reached. The disadvantage of depth limitation was overcome in Russell County by starting with a larger hole size, 24-inch diameter or more. Probably the greatest disadvantage, and the one that most affected the oil-field history of the Gorham oil field, was that cable-tool holes were drilled to find oil and when oil was "struck" (found), drilling was discontinued without knowledge of what might be encountered deeper. It was dangerous to continue drilling with a hole full of oil because of the fire hazard (see description of an oil-field fire, p. 63–64). Thus well after well was drilled into a relatively shallow pay zone such as the upper part of the Lansing–Kansas City, only to require deepening years later (often by another owner) into a deeper pay zone such as the lower Lansing–Kansas City, the Arbuckle, or the Reagan Sandstone. For example, the Sullivan oil field was discovered with considerable fanfare by Hartman and Blair in sec. 2, T. 14 S., R. 15 W. in February 1935. Production was from oil encountered by cable-tool drilling near the top of the Lansing–Kansas City, 3,060–3,070 ft (918–921 m). The property was sold in 1943, leaving the prolific deeper "Gorham sand" pay, 3,316–3,319 ft (995–996 m), to be produced in 1949 by Murfin Drilling Company, the purchaser. Such experiences were common. For several years, about 5% of the drilling rigs active in the Gorham oil field were re-drilling old wells, cryptically designated by scouts in their hastily handwritten notebooks as OWWO or OWDD meaning "old well worked over" or "old well drilled deeper."

Another disadvantage of drilling with cable tools was that when oil was "struck," wells that flowed oil or gas could not be controlled. The much-photographed "gushers" of the early oil fields were glamorous but dangerous, uncontrollable flowing wells. In the Gorham oil field in 1935, when the Roubach No. 1 "struck oil" in the Topeka fracture zone, the well was a "gusher" flowing out of control for five days as described on p. 60–62.

Information from cable-tool drilling

Information from cable-tool drilling was used in constructing the cross section A–B–C (figs. 5 and 6). The open circles indicate the recovery of water during drilling, thus marking the aquifers. Also the drillers' logs were correlated from well to well. What information is preserved? As the drilling progressed, the driller grabbed a handful of well cuttings after the bailer was dumped. He looked at the well cuttings, squeezed the well cuttings, felt and smelled the cuttings, and then sometimes bit into them checking grittiness with his teeth. He then either threw the handful of cuttings away or deposited them in a pile on a convenient plank lined up in depth sequence with previously caught samples. It was part of his job to record the depth and a one or two word description of the rock drilled such as "sand," "lime," or "shale and shells." The handwritten cable-tool driller's logs also recorded water as "HFW," translated "hole full of water." The holes were not completely full of water but filled to a static level at some interval below the surface of the ground as discussed for various formations by Walters (1975). This is known locally as a "Kansas hole full of water." The logs also, of course, recorded oil shows or actual oil recovered or unusual incidents or accidents. An extreme case is the Hartman and Blair #2 Roubach. A rig fire is recorded on the written driller's log as "rig fire, log burned."

Rival oil companies, eager to learn of new oil discoveries, kept track of drilling progress. They hired scouts to go to the well, talk to the driller, and


STANDARD FORM 176—FOR SALE BY MID-WEST PRINTING CO., TULSA, OKLA.

Map Russell Well 2 B
Sec. 3 (Block) (Twp.) 14 (Survey) (Range) 15 W
Central Oil Company
Foster Farm

	Date	
FIRST REPORT	12-22	Loc
		Rig
0	1-6	
	2-24	15" 422
		12" 615
		Δ 915

Date	SE SW NE	10" 925
3-3	Ø 2280	Ø 1100
3-10	8" 2637 Ø 2738	
3-17	SO 2945 Oliv 3042 6" 3048	
	Ø 3090	WOC
3-24	~~Lit 3288?~~ 390' 5" lim 3288	
3-31	T.D. 3300 Gorham 3295	
	1695/24 COMPLETION	

hand-copy the written drillers' log. Sometimes on "tight holes," they were barred from such information and had to rely on their own observations of oil or water dumped from the bailer, of oil in the pits, petroleum odor, or of the approximate depth of the hole by timing the bailer runs. Most often they were given information and reported it by telephone or in person at their company headquarters. With the increase in drilling, a scout could not cover all of the activity. He developed a network of friends, dividing the area among several scouts, "You check this well, I'll check the other well, and Joe will check the third well. We'll meet for lunch in Russell and trade logs." By the 1940's, this system had evolved into a formal organization known as the Kansas Log Check Association or "scout check." Each of the 15–26 major company oil scouts had an assigned district that he covered in person on Monday, Tuesday, and Wednesday of each week. He then reported to "scout check" on Thursday. The scouts gathered around a large table and each in turn read his scout report, largely condensed to well locations, drilling depths, formation tops, and oil recoveries or oil shows. Each of the other scouts seated around the table furiously wrote down the spoken information in his own shorthand. Each scout in turn gave his report. These handwritten notes were called "scout tickets" and they were usually kept in a looseleaf notebook (fig. 26a).

Geologists were the principal users of cable-tool drillers' logs and information from scout reports. They organized the Kansas Geological Society in 1922, and in 1925 organized the Kansas Well Log Bureau for the purpose of collecting and distributing cable-tool drillers' logs of oil and gas tests in Kansas and adjoining states. George H. Bruce was the manager for two years and in 1927, Harvel E. White became the paid manager for both organizations. He diligently sought out records of cable-tool drillers' logs, traveling to oil-company offices throughout the state to obtain this material and secure its release for publication. The reproduction of a log was a problem in those days and mimeographed copies were treasured. The geologist using the typewritten cable-tool drillers' logs usually plotted the information on a strip log at a scale of 100 feet to the inch. The colored plotted strip logs laid side-by-side presented a visual cross section and permitted correlation from well to well if the information had been accurately

FIGURE 26a—Handwritten scout ticket, 1936, from an oil scout's notebook. 26b (right)—Typewritten cable-tool drillers' log, 1936; courtesy Kansas Geological Society.

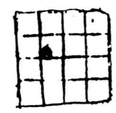
WELL LOG BUREAU - KANSAS GEOLOGICAL SOCIETY.
412 Union National Bk Bldg., Wichita, Kansas.

CENTRAL PETRO. CORP.
Foster No. A-3

SEC. 3 T.14 R.15W
SW SE NW
330' fr. SL 330' fr WL

Total Depth. 3130' PB 3109'
Comm. 9-21-36 Comp. 10-19-36
Shot or Treated.
Contractor. Harry Gore
Issued. 11-7-36

County. Russell



CASING:
15½" 405'
12½" 600'
10 " 925'
8¼" 2505' UR 2772'
6 5/8" 3035'

Elevation.

Production. Pot.462 B.

Figures Indicate Bottom of Formations.

cellar	10	lime white	2205
sand	25	shale blue	2210
slate blue	130	red rock	2220
slate black	160	lime white	2240
shale light	190	slate blue	2255
sand	225	lime white	2290
iron & sand	235	slate & shells	2320
shale	255	shale blue	2340
sand	265	shale dark	2365
red rock	280	shells & slate	2420
slate blue	305	shale	2435
slate light	325	slate & shells	2450
sand	340	sdy shale	2470
slate	360	shale blue	2485
slate blue	370	lime white	2490
shale & iron	390	slate dark	2500
sand	400	lime white	2505
shale light	405	shale dark	2550
slate blue	435	lime white	2555
shale	450	slate light	2565
sand	470	lime light	2580
slate	490	shale	2585
sand	500	lime white	2595
shale	505	shale	2605
sand	530	lime	2625
red rock	560	slate light	2630
iron	565	slate & shells	2665
lime	570	shale blue	2675
red rock	905	shale & shells	2685
lime anhydrite	960	lime	2690
shale red	1095	slate dark	2695
shale	1280	lime white	2730
salt	1570	shale dark	2750
lime	1580	lime	2755
lime shells & slate	1690	shale blue	2764
red rock	1715	lime	2785
lime sdy	1740	shale	2790
red rock	1750	lime	2830
lime white	1795	shale	2840
shale dark	1805	lime	2935
red rock	1820	shale	2945
lime white	1940	lime sdy	2978
slate	1955	shale	2988
red rock	1970	lime	2994
slate dark	1975	shale	3003
slate light	1995	lime Dodge	3019
lime white	2010	shale brown	3035
slate blue	2020	lime Oswald	3053
lime white	2025	shale green	3058
red rock	2035	lime	3120
lime white	2065	lime sdy	3130
shale	2070	Total Depth.	
shale & shells	2085		
lime white	2095		
slate dark	2115		
lime white	2135		
slate white	2140		
red rock	2150		

WATER RECORD

HFW 225
HFW 450
3 BWPH 2450-70
1 BW 2755

SAND RECORD

Dodge Lime Top 3003-19
Oswald Lime " 3035-53
Plugged back to 3109'

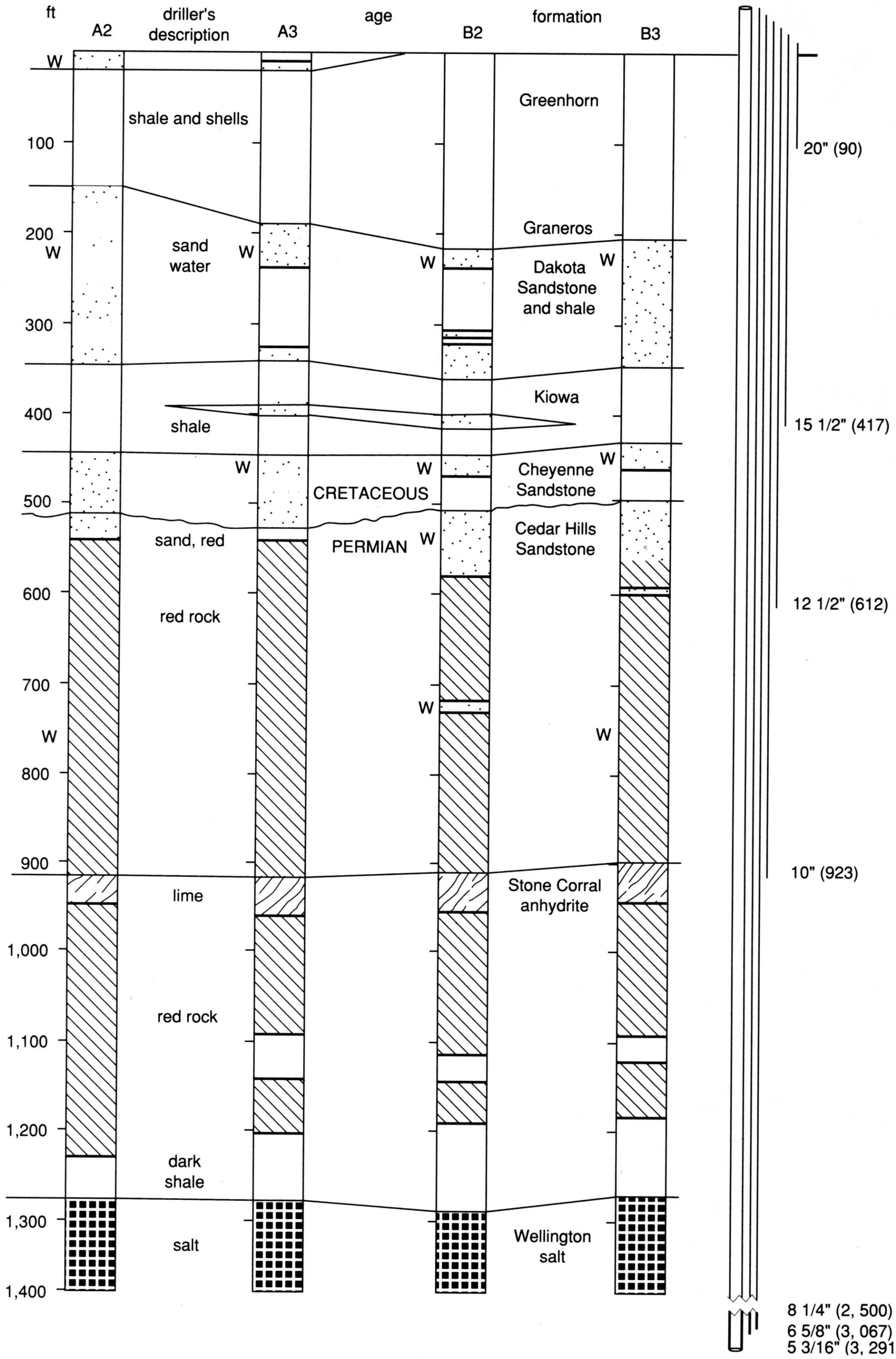


FIGURE 27—Cross section made from four plotted cable-tool drillers' logs. "W" is water encountered during drilling; logs are from the Kansas Geological Society Library. Multiple casing strings are shown diagrammatically at the right with diameter of casing in inches and the depth set in feet. After setting the deepest string, all other strings of casing were commonly pulled except the 20-inch surface pipe. It was while pulling the 6-inch casing that the derrick collapsed as shown on the cover and in fig. 29.

recorded by the drillers. Examples of "scout tickets," a typewritten drillers' log, and a cross section made by placing three plotted cable-tool strip logs side by side are included as figs. 26a, 26b, and 27.

Samples of drill cuttings

In the late 1920's, geologists realized that examination of cable-tool well cuttings would add much information beyond that recorded in the drillers' logs. However, samples of well cuttings were regularly thrown away after the drillers inspected them. Geologists were seldom on location. With the combination of slow drilling by cable tools and the immediate recovery of gas, oil, or water by cable-tool drilling, geologists were not needed at the well site to find oil. It was difficult to get the drillers to change their ways. They resented the extra chores of collecting, saving, sacking, and labeling samples of the well cuttings. The change was gradually accomplished by providing cloth sample sacks at the rig, by having management add a clause to the drilling contracts requiring samples to be caught, sacked, and saved, and by the distribution of small gifts, usually in liquid form, to the drillers. This task was more comfortably performed during the winter months inside the boiler house where it was warm. At times it was even more comfortable to skip the sample catching except for one big bucketful. Then just before the tool dresser went off tour at midnight, he filled the required number of sacks from the one bucket and labeled them for the various depths drilled during the shift. Such samples were described as "boiler housed" by geologists. The practice became much less frequent when the drillers learned that the geologists could and did recognize the mislabeled samples.

In 1929, the Kansas Log Check Asssociation adopted a systematic and cooperative plan to secure the well cuttings from the important wildcat or deep wells drilled in Kansas. Each of the 26 major oil companies was responsible for seeing that its well samples were distributed to other companies (Harvel E. White, personal communication, April 1986). No central place or organization existed to make such distribution. Each major oil company had its own facility for washing, drying, and dividing or "cutting" well samples and placing the separate "cuts" in labeled paper envelopes for exchange with other major companies. This work was done even in high-rise office buildings with gas stoves blazing away drying the washed samples. In the late 1930's and in the pre-World War II 1940's, some geologists working for major companies were transferred from out-of-doors jobs when surface field parties and core-drill crews were shut down. They became largely office-bound except for occasional well-supervision work ("well sitting") on rotary-drilled holes. They spent whole days looking at rock cuttings through 10 to 20× binocular microscopes, plotting the results in fine print on strip logs, scale 100 feet to the inch, a scale inherited from the cable-tool drillers' logs. Their offices were not air conditioned. On summer days the heat was oppressive from the gas burners and it was difficult to keep the well log neat, dry, and unstained from perspiration. Not until 1944 was the central "sample cut" established by the Kansas Geological Society under the business name of Kansas Well Sample Bureau. Only then were the many gas stoves in major oil-company offices shut down.

In the 1930's, other geologists were needed to examine samples of well cuttings at the well site in the few holes drilled with early rotary tools. Often these geologists were production department employees, and many lived in company-provided housing in oil-field camps at such locations as Chase, Kansas, a carry-over from the 1910's and early 1920's when transportation was a problem before the common use of automobiles.

Each of the 26 major oil companies also stored boxes of samples of well cuttings, usually renting warehouse space. As major oil companies closed their Kansas exploration offices in the 1940's and 1950's, leaving only production department offices in Great Bend, Russell, and Liberal, etc., they donated their accumulated boxes of samples to the Well Sample Library managed by the Kansas Geological Survey in Lawrence. The Kansas Geological Survey opened a sample library for well cuttings in Wichita in 1938, in addition to its permanent collection of well cores at the Survey's Lawrence headquarters.

Gorham oil field, April 14, 1928

On January 28, 1928, a big oil well was completed in a new and deeper pay. The Gorham area instantly became the most exciting place in the oil fields of Kansas. The discovery well, Stearns and Streeter et al. #1 Mermis in the SW NW SW sec. 33, T. 13 S., R. 15 W., tested 1,000 BOPD from a sand at 3,317 ft (995 m). The producing formation was named the "Gorham sand" after nearby Gorham. Average actual production from the Mermis #1 in February 1928 was 580 BOPD (Folger and Hall, 1933). On April 14, 1928, photographer E. J. Banks climbed to the crown block of the derrick of Johnson Vickers #1 Gorham, a drilling well, carrying his bulky camera to photograph the oil field. The cover photograph of this report is part of his panoramic photograph reproduced through the courtesy of the Russell County Historical Society and Oil Patch Museum. The view is to the west over three derricks in a row with the town of Gorham in the background and with workers' automobiles parked in the foreground. Steam is coming from the Day Petroleum Co. #2 Joe Mermis where rigging-up operations are underway. Behind it, the Day #1 Mermis is producing oil from the "Oswald," depth 3,091 ft (927 m). The third and most distant derrick is a drilling well, the Keyes Petroleum #14 Mermis. Fig. 28 is a view to the south and southwest showing the older portion of the Gorham oil field with wells producing from the "Oswald." The section-line road runs north-south. To the east (left) of it, the derricks of three wells are so precisely aligned that it is difficult to distinguish them. The closest is the Stearns and Streeter Mermis #2, testing the Gorham sand. The second is the Stearns and Streeter #1 Anton Mermis, the discovery well, pumping 580 BOPD from the Gorham sand. The third is Keyes Petroleum #12 Mermis, drilling. Note the similarity of a drilling well, a well being tested, and a pumping oil well due to the practice of leaving the derrick erect after completion of drilling for use in production work.

FIGURE 28—GORHAM OIL FIELD, APRIL 14, 1928, a portion of a panoramic photograph; view to the southwest. In the left foreground, Stearns and Streeter's Mermis No. 2 is testing the Gorham sand. Directly aligned behind it (south), the Mermis No. 1 is pumping 580 BOPD from the Gorham sand and south of it a third well, the No. 12 Mermis is drilling; courtesy Russell County Historical Society. See back cover.

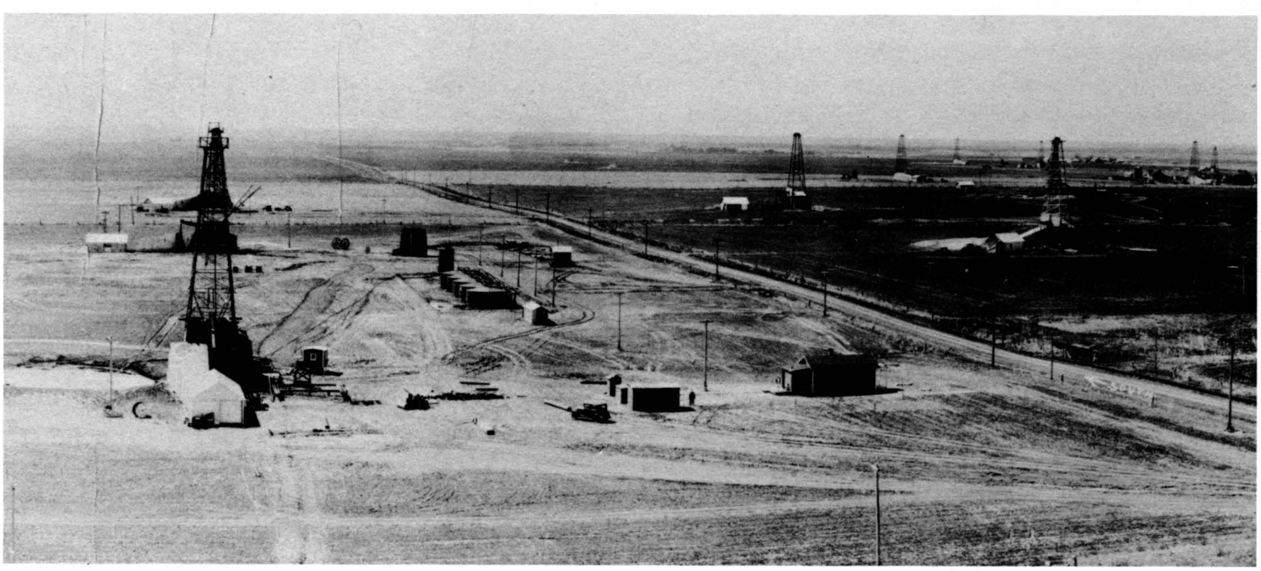
Note, too, that no saltwater ponds are present. Saltwater production was not a problem at this time but became one soon after. The shallow pit (left foreground, fig. 28) is a receiving pit for cuttings dumped out of the bailer.

Fig. 29 is also reproduced on the front cover. An arrow designates the collapsed derrick of the Midwest Oil and Refinery Company Mermis #4, enlarged in the inset photograph. "The 6-inch casing parted while lifting it," said the *Russell County Daily News*, May 17, 1928.

On the date of the photograph, April 14, 1928, the Gorham oil field had seven oil wells producing from the "Oswald," depth just below 3,000 ft (900 m); one Gorham sand oil well, depth 3,317 ft (995 m); eight drilling wells, three dry holes, and one abandoned Oswald oil well. Fig. 30 is a historical map for that date. It was prepared by redrafting a contemporary oil-company production map, retaining the style and lettering of that map, and by correcting the production map to that date from contemporary newspaper files. Indicated by dashed lines are the three segments of the panoramic photograph.

Oil production, 1928–1933

The wide-open flush production in 1928 can be illustrated by the wells shown in the cover photograph. The Day #2 Mermis, foreground, was completed in June 1928 for an estimated 700 BOPD but with a reported 26% water. The Day #1 Mermis, second well in the cover photo, was drilled deeper in June 1928, and completed for 600 BOPD from the Gorham sand. The two wells together produced 1,300 BO in one day, July 2, 1928. The Johnson and Vickers #1 Gorham, from the crown block of which



the panoramic picture was taken, was completed in the Gorham sand for 50 BO per hour in May 1928. It produced and sold 56,173 BO in the remainder of 1928 or an average of 245 BOPD. Such high production rates resulted in the lifting of saltwater along with the oil, requiring large surface "evaporation ponds" as discussed in the environmental section of the report. Oil production was sharply curtailed after May 28, 1931, when regulations were imposed by the Kansas Corporation Commission as discussed in the oil production section.

Crude-oil prices were depressed by such overproduction in Kansas and similar overproduction from newly discovered oil fields in Oklahoma and Texas. Koester (1933) quotes the following posted prices for 40° Kansas crude oil:

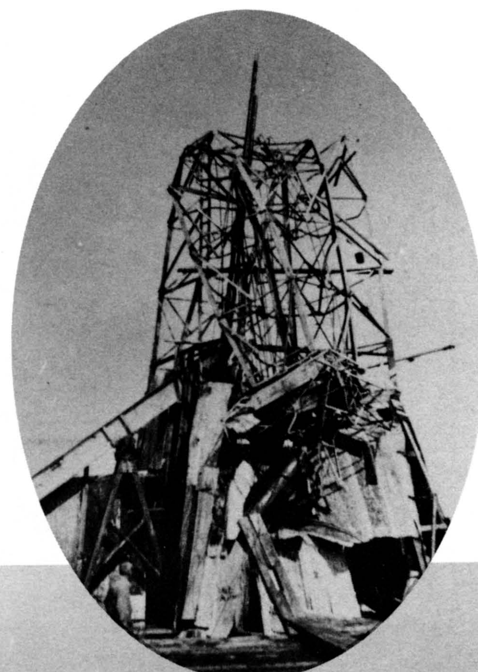
1931	January 1	$1.07
1932	April 1	1.00
	March 5	.67
	Oct. 5	1.12
	June 1	.37
	Dec. 16	.77
	July 3	.22
	July 24	.42
1933	Jan. 18	.52
	Aug. 22	.70
	Nov. 2	.85

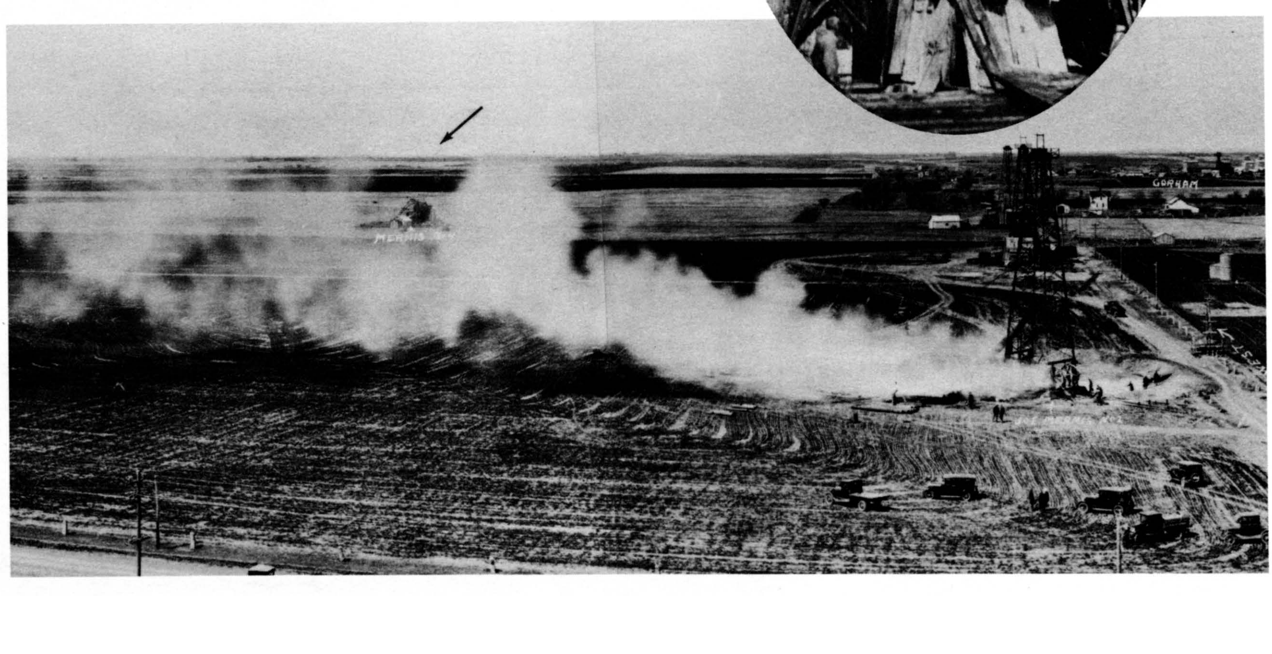
A facsimile of the July price notice is included as fig. 18.

The depressed crude-oil prices, the general Great Depression of the 1930's, the glut of crude oil in the midcontinent, and the restriction of allowed production by proration regulated by the Kansas Corporation Commission all discouraged development. Only three wells were completed in the Gorham oil field in 1931–32 (Koester, 1933). Although production for 1928 reached 587,110 BO from 23 wells in the Gorham oil field, production declined each year thereafter to about one-third as much in 1933 as shown on the oil-production graph (fig. 4) and as listed in the appendix, table 2.

Fig. 31 is a photograph of the Gorham oil field in 1928 viewed toward the south from the Union Pacific Railroad tracks. The nearest oil well is the Keys # 11 Joe Mermis. The Mermis residence and barns are in the right middle distance. In the foreground, the stone fenceposts are made of "post rock." Core drilling in 1927 along this road encountered the

FIGURE 29—Gorham oil field, April 14, 1928. This and fig. 28 are portions of a panoramic photograph by E. J. Banks (the middle portion with one oil well is omitted). Arrow points to the Mermis No. 4 with collapsed derrick. Inset shows close-up view of cable tools with a collapsed derrick; courtesy Russell County Historical Society and KIOGA. See front cover.





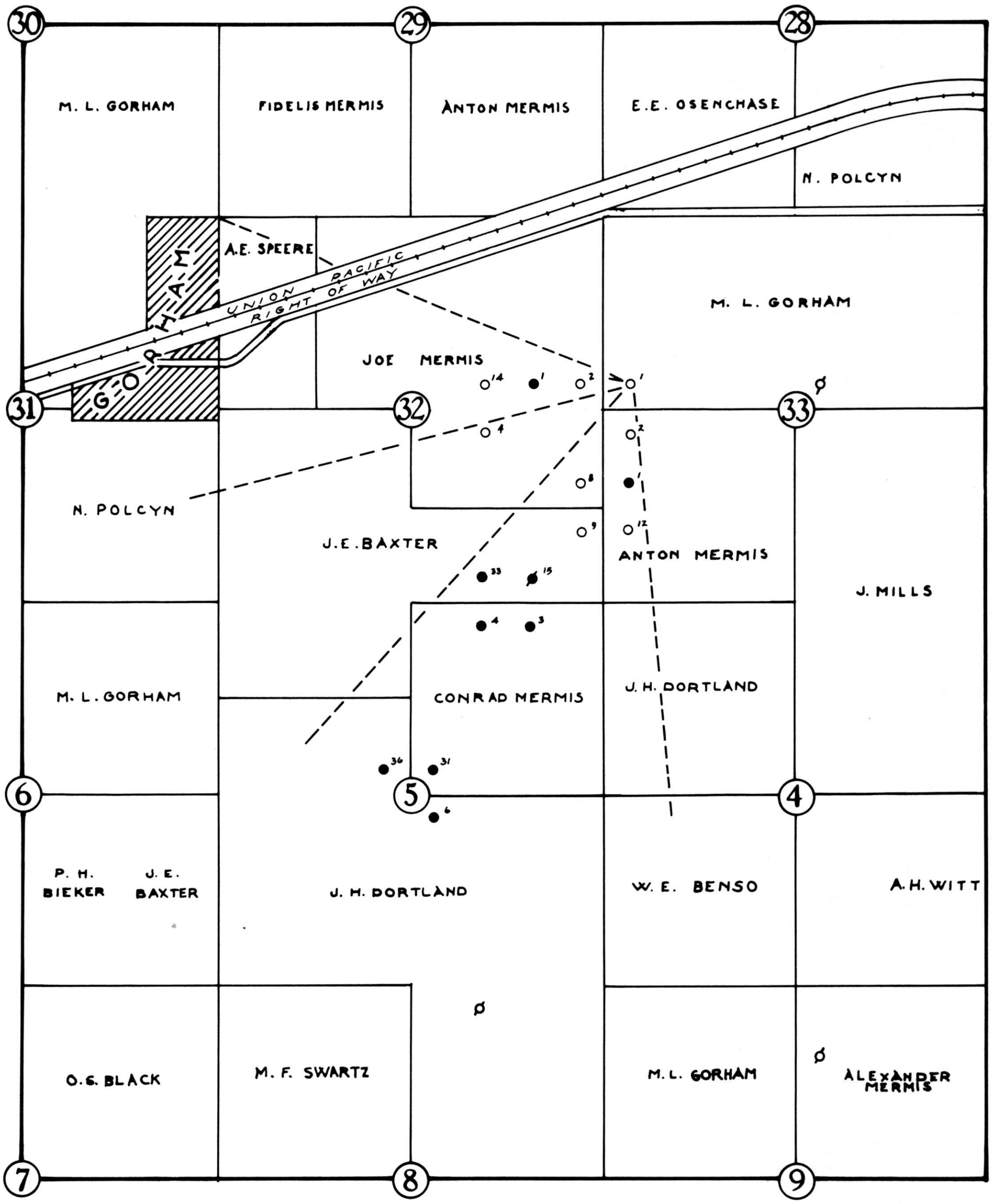


FIGURE 30—Historical map of the Gorham oil field, April 14, 1928. Dashed lines show area of panoramic view reproduced on front and back covers and in figs. 28 and 29. Redrafted in the style of an original 1931 map that was corrected to April 14, 1928, from newspaper accounts and scout tickets.

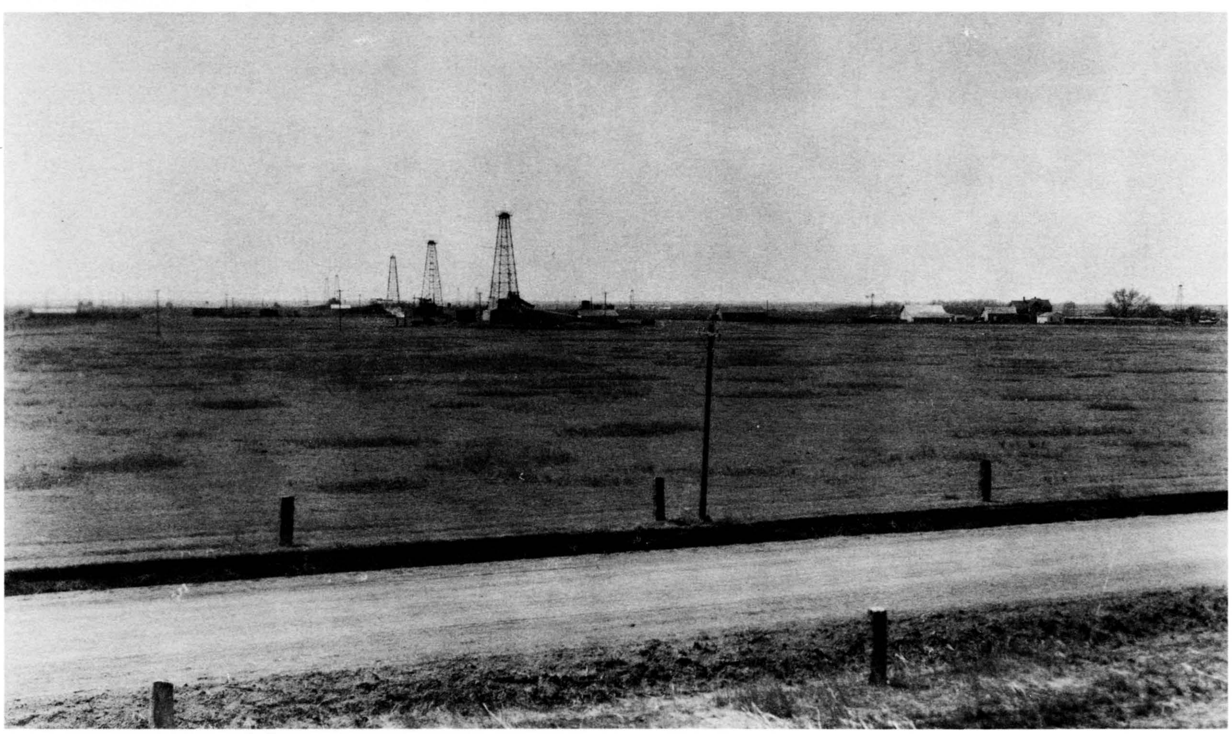
Fence-post limestone at a depth of 55 ft (16.5 m). The nearest oil wells are less than one-half mile (0.8 km) from the railroad on which all the crude oil was shipped to refineries. There were no pipelines in western Kansas other than the previously noted Fairport oil field pipeline running 8 mi (12.8 km) northwest to connect with the Southern Pacific Railroad at the town of Paradise.

Acidization of Oswald oil wells, 1933–34

A new process of pumping acid down the well casing into the limestone formation to increase oil production was the most important development affecting the Gorham oil field in 1934. Oil production in that year increased to 555,655 BO, more than double the production of 220,246 BO in 1933. Although the number of oil wells increased by 50% from 32 in 1933 to 47 in 1934 (including three oil wells in the newly discovered Neidenthal oil field), by far the biggest factor was the acidization of Lansing–Kansas City oil wells.

One year earlier, January 1933, oil wells in the Fairport oil field were "treated" by pumping inhibited hydrochloric acid under pressure down the casing and into the oil-producing Oswald limestone formation. The results were spectacular. For example, production from the Carrie Oswald #1 had declined to 2 BOPD. Acid increased production to 108 BOPD. This historic event is described (Anonymous, 1983) in a booklet *Six decades of derricks* distributed by the Russell County Historical Society. It was the first commerical application of acid to wells in midcontinent oil fields, a process that totally changed well-completion procedures in carbonate rocks such as the Lansing–Kansas City (Oswald) or Arbuckle dolomite. A second source of information is a telephone interview 50 years later with Mr. Nathan Appleman by reporter Barbara Oringderff (1984). Production of all the oil wells in the Fairport field had declined as exemplified by the Carey Oswald #1. Nathan Appleman, owner of Central Petroleum Company, acquired an option to buy many of the leases in the Fairport oil field. Oringderff asked Appleman, "What gave you the idea?" Appleman answered, "I read in a magazine article where Dow [Chemical Company] was applying inhibited acid, acid that couldn't corrode the pipe, in brine wells in Michigan. I remembered that some of the Fairport field I looked at in Kansas had the same limestone formation as that in Michigan, and I just had a hunch that the same technique might work with oil wells. So, I took my limestone samples to Dow, in Michigan, and asked them to build me an acid wagon."

FIGURE 31—GORHAM OIL FIELD, 1928. View to the south from the Union Pacific Railroad track. In the foreground are stone fenceposts made of "post rock." All crude oil was shipped on the railroad as there were no pipelines; photograph courtesy Russell County Historical Society.



The reporter then asked if the acid wagon on display at the oil show in Russell in 1983 was his. "I don't know," he said. "I never saw it. My superintendent, Charles Gilpert, did the actual acidizing that January [1933] while I waited in a hotel room in Wichita with a cashier's check in my hand! The check was for money loaned to my father on a character loan by the First National Bank of Tulsa. Gilpert and I had it all worked up so that he could tell me through code how things were going. It took two or three days for the acidization process to work, and I stayed in my hotel room by the telephone until I got the final word to go ahead and exercise that option." Appleman's company, Central Petroleum Company, then acidized 33 more wells in the Fairport oil field with equally spectacular results. In the following year, Central Petroleum Company's leases, the Benso "A," the Benso "B," and Dortland "B" in sec. 4, T. 15 S., R. 14 W. contributed to the increased production from the Gorham oil field by development drilling and acidization.

"The biggest oil well ever struck in western Kansas," 1935

The caption is quoted from the Wichita *Beacon*, Wednesday, April 24, 1935, which carried the news in headlines 1-inch-high across the front page:

GUSHER OPENS NEW KANSAS POOL

with subtitles:

BIGGEST WELL IN REGION HITS RICH OIL LIME

Crude Spurts Over Derrick as Tools Bite into Pay Horizon

The following quotation is condensed from the exuberant reporting of the *Beacon* as this discovery was announced:

> Belching an eight inch stream of high gravity oil into the derrick top Hartman and Blair's #1 Roubach, SE-SE-NW Sec. 2-14S-15W, Russell County, the biggest oilwell ever struck in western Kansas was flowing wild Wednesday forenoon.
>
> Field men estimated the flow variously at 2,000 to 5,000 barrels daily. It was making a huge flow despite the fact that tools were wedged in the hole.
>
> Coming in unexpectedly in a horizon (Topeka lime) that never before produced a flowing well in Kansas, the owners were caught unprepared. There was no tankage on the lease. Oil began flowing down a ravine on the Roubach land.
>
> Teams and workmen were recruited at 10 o'clock Tuesday night to harrow up an embankment to impound the runaway oil and prevent damage to adjoining farm lands.
>
> The Topeka Lime, the formation from which the oil is gushing, is tapped at 2,780 feet. The first oil was struck 2,790 feet and the well began flowing when a depth between 2,795 and 2,800 was reached.
>
> FIRES ARE EXTINGUISHED
>
> Fires in the boilers were extinguished immediately. This left the drillers without power to pull the tools. Early Wednesday the well was still running wild but Harvey H. Blair who made a flying trip to Russell between midnight and 8:00 this morning said upon his return that he hoped to have a control head in place within a few hours.
>
> Due to the fact the oil is coming from an entirely new producing horizon, the strike is regarded as one of the most sensational ever to be made in western Kansas.

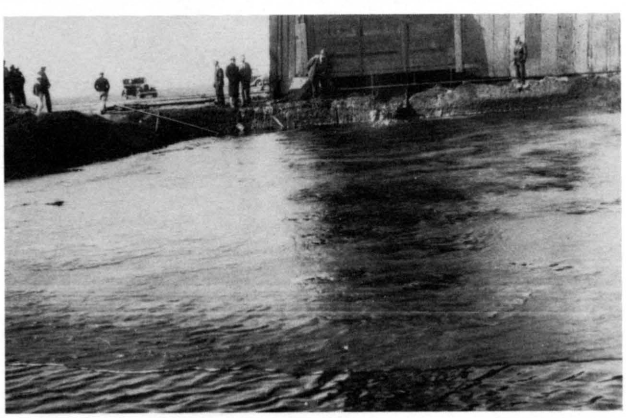
Fig. 32a is a photograph of oil flowing into the pits on April 24, 1935. The drilling tools were pushed upward, kinking the cable, and wedging the heavy bit, jars, and iron drillstem inside the pipe while the oil flowed past them out of control. Fig. 32b shows a few of the many spectators. A huge 55,000-barrel tank of the kind usually constructed for refineries and pipelines was hastily constructed on the Roubach lease as illustrated in figs. 33a, b, and c. This was the largest tank in western Kansas. It was filled in 12 days (average 4,583 BOPD). For many years the tank was a landmark visible from old US-40, 1 mi (1.6 km) north where the Russell Refinery Company built a refinery on the NE sec. 35, T. 13 S., R. 15 W. The *Russell Record*, October 31, 1935, states: "The first oil to be used by the Russell Refinery Company was run yesterday when the plant was started. Crude for the refinery is being run through the company's own pipeline from the Roubach lease owned by Hartman–Blair." The refinery produced gasoline and kerosene, sold locally. It operated for less than three years.

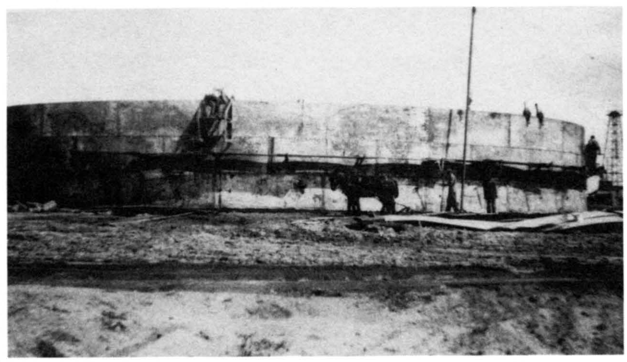
Fig. 34a is a photograph of the Roubach lease showing the flat farmland. It was probably taken from the top of the 55,000-barrel tank in 1935. Fig. 34b is a close-up of the Roubach #1 pumping oil. Note the steel (not wood) derrick left on location for production use as were the heavy wood sampson post (vertical) supporting the massive wood walking beam (horizontal), which is connected by the pitman (vertical) to the belt-driven band wheel (not visible) in the shed. The Roubach #1 was indeed a giant oil well, producing over one-half million barrels of oil from the Topeka Formation. It was disappointing and perplexing when the east, the southeast, and the south offsets, only 660–933 ft (198–280 m) distant, all failed to find production in this zone although they were closely watched during drilling (Virgil B. Cole, personal communication, 1975). All were completed as oil wells in deeper "pays." The offset well, 660 ft (198 m) west, Hartman and Blair's #4 Roubach (SW SE NW), and the Roubach #5 further west (SW SW NW) flowed oil from the Topeka in 1936 and the #7 (C SL SE NW, a twin to the #1) produced Topeka oil in 1937. However, by the time #12 Roubach was drilled (C SW NW) in May 1977, the Topeka zone was depleted. Gassy oil-cut saltwater was recovered. Charles Steincamp (personal communication, September 14, 1978), who was the well-site geologist, remembered that the tools dropped 8 ft (2.4 m) into a void in the Topeka zone.

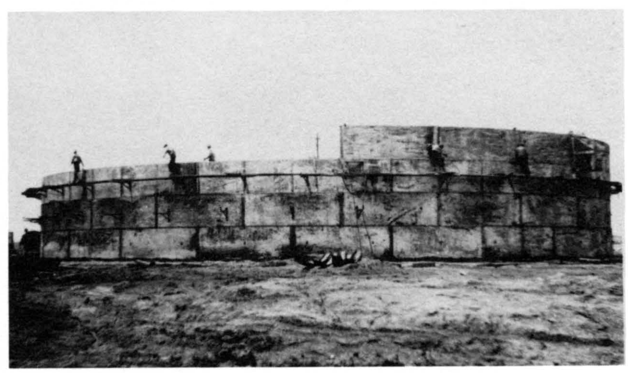
It is recognized that the Topeka oil in the Roubach wells and in other wells as mapped in fig. 12 was produced from a fracture zone about 5 mi (8 km) long, parallel with and under I–70. The Topeka

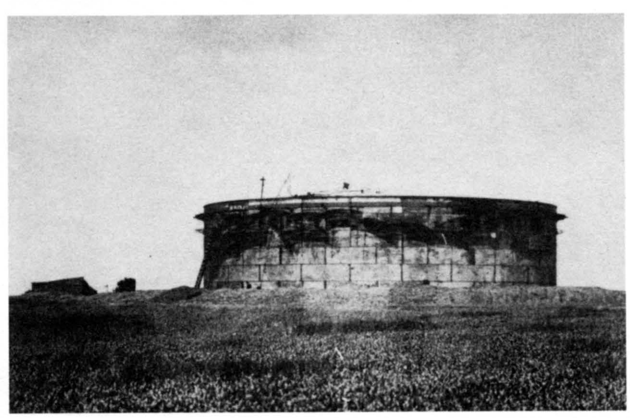
FIGURE 32 (below)—TWO VIEWS OF ROUBACH NO. 1, April 24, 1935, flowing uncontrolled into the pits at the rate of 200 BO per hour. The second view shows a few of the many spectators; both photographs courtesy KIOGA.

FIGURE 33 (right)—THREE VIEWS OF THE CONSTRUCTION OF A 55,000-BBL OIL-STORAGE TANK on the Roubach lease in 1935. The tank was reported as filled in 12 days with oil flowing from the Roubach No. 1, or 4,583 BOPD; photographs courtesy KIOGA.









fracture zone is discussed on p. 28–30. For a discussion of an analogy with similar fracture zones known from lead and zinc mines in Wisconsin, see p. 30–31. Subsidence areas affecting I–70 coincide with and were initally caused by the Topeka fracture zone. Subsidence areas are extensively discussed in the section on environment.

Oil-field development, 1935–1940

Before the excitement of the Roubach Topeka discovery, the Neidenthal oil field (later part of the Gorham oil field) and the Russell oil field at the edge of the city of Russell were discovered in 1934. The year 1935 saw 13 new pool discoveries in Russell County, eight of which—Roubach, Sullivan, Milberger, Cramm, Neidenthal, Neidenthal South, Atherton, and Big Creek—were later combined into the Gorham oil field. Their locations are shown on the historical map (fig. 35) dated April 29, 1935, the day that the Roubach #1 was completed for a flowing potential of 4,760 BOPD. Fourteen new oil fields were found in the banner discovery year of 1936 in Russell County, and it was second only to Rice County in Kansas oil production that year with 7,074,226 BO produced (Landis, 1937). Of the 14 new oil fields, four—Balta, Balta North, Balta Arbuckle, and Harbaugh—were later included in the Gorham oil field. By 1940, many of these new pool discoveries were recognized as part of a major extensive oil field, the 50 mi^2 (130 km^2) Gorham oil field with 37 discovery wells as mapped in fig. 3. The Nomenclature Committee of the Kansas Corporation Commission consolidated many of the former oil fields in 1940 into two "sectors" of the Gorham oil field. The Gorham sector was approximately the northwest diagonal half, and the Big Creek sector was the southeast diagonal half of the present Gorham oil field. Not until after 1950, were the two "sectors" officially combined into one oil field. The "geneaology" or history of the Gorham oil field had to be deciphered to complete the oil-production history graphed in fig. 4 and summarized in the appendix, table 2. This complex history accounts for the discrepancy as to the total and annual oil-production figures among various published records.

Oil production, 1934–1940

Production of oil from the Gorham oil field doubled in 1934 over the prior year. Both oil production and number of oil wells more than doubled again in 1935, then again doubled in 1936. Marketing of Russell County oil from all the newly discovered

FIGURE 34a (below)—Photograph of the Roubach lease, 1935, from the top of the 55,000-bbl storage tank. Shows the Roubach No. 1 derrick and the flat agricultural plains area. 34b (right)—Close-up of Roubach No. 1 pumping oil. Note the steel (not wood) derrick and former cable-tool equipment left on location for production use in pumping oil; courtesy KIOGA.

oil fields was made possible by pipeline extensions and new construction (Landis, 1937). This was the golden era of the discovery of oil fields, later recognized as separate parts of one major oil field. A climax came in 1937 with 4,543,310 BO produced from 339 oil wells. The highest oil production under proration (in terms of average BOPD per well) came in 1936 when the average was 44.90 BOPD per well. In all the years of production from the Gorham oil field (fig. 4), this was only exceeded by the wide-open unprorated oil production in the first four years, 1926–29, when the daily average ranged from 80 BOPD to 47 BOPD per well. Cable-tool drilling was still dominant in 1936 with only a few wells in the older Gorham oil field drilled by rotary tools. All new field exploratory wells ("wildcat wells") were drilled with cable tools.

Oil-field fire, 1936

The pamphlet *Six decades of derricks* (Anonymous, 1983) describes a tragic oil-field fire. That account is here reproduced in full:

Perhaps the most tragic accident occurred on Wednesday night, June 17, 1936, when an untameable fire broke out on the Harbaugh–Marathon well 9 miles southwest of Russell and took the lives of five workers and burned and injured five others.

Those who died were: W. T. Lusher, 61 of McPherson, drilling tool pusher; Earnest Harbaugh, 15; E. O. Wright, 33 of McPherson, a driller; Claude A. Cain, 41, and his son Donald A. Cain, 22, of Galva, drillers. Other workers burned were: Robert Helms–Great Bend, Ernest Bush–Otis, Howard Johnson–Otis, Raymond Roe–Great Bend, and Sam Richardson of Douglas.

The fire was visible for more than 20 miles and flames were said to have shot into the air 300 feet (from the *Russell Record*).

Fig. 36 is a photograph taken after the fire, courtesy of Charles Steincamp (personal communica-

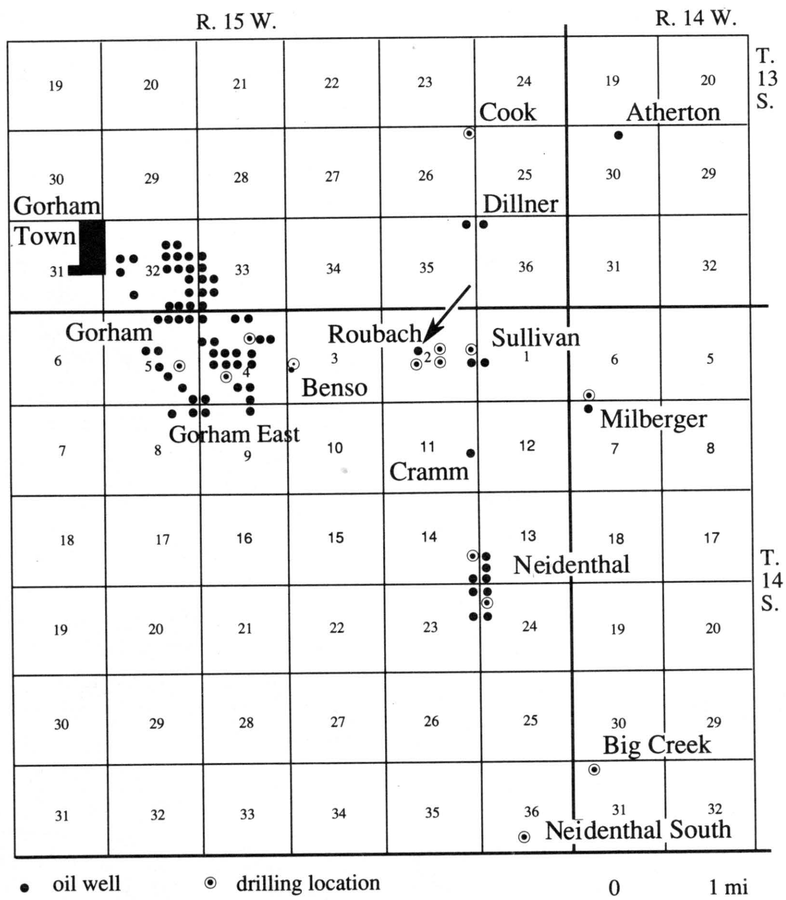


FIGURE 35—Historical map, April 29, 1935, the day that the Roubach No. 1 was completed for a flowing potential of 4,760 BOPD. All the newly discovered oil fields named on the map were later included as part of the Gorham oil field.

tion, June 1989), who remembers accompanying his father who took the photograph. Notice the steel walking-beam supported by a metal "A" frame in place of a wood sampson post. Note also the metal pitman and the metal parts of the band wheel, which survived the fire in this late-model cable-tool rig. This is in contrast to the all-wooden derrick cable tools of 1926 (fig. 23) and the steel derrick with wood walking beam of fig. 34b, used on the Roubach No. 1 in 1935.

The quoted contemporary account credited to the *Russell Record* and the photograph (fig. 36) constitute the factual historical material available to the author. From a general knowledge of oil-field procedures and from dated well-information cards, the author considers that the fire was most likely caused by the accidental ignition of gas and oil from the Kansas City formation while running the 7-inch casing which displaced oil from the hole, releasing gas. Usually only two men are working on a cable-tool rig, the driller and his helper, the tool dresser. At change of tour, four men are on location. When running heavy casing, as was being done at the time of the fire, the crews double up and call out a four- or five-man casing crew. This may account for the unusually high mortality.

Oil-field fire—geological setting

A historical map (fig. 37) shows the oil fields on the date of the fire, June 17, 1936. The arrow points to the location of Ohio Oil Company's J. F. Harbaugh #1 in a meander bend of Big Creek, in the C SE SE NW sec. 25, T. 14 S., R. 15 W., where the fire occurred. The south offset, Hartman and Blair's #1 B. S. Harbaugh, the discovery well of the Harbaugh oil field completed February 17, 1936, was producing oil from the Lansing–Kansas City at 2,950 ft (885 m) TD at the time of the fire. The southeast offset, National Refining Company's 1–C North Reinhardt, was completed on May 4, 1936, as an oil well in the "silicious [sic] lime" (the name formerly used for the Arbuckle dolomite) with a potential of 465 BOPD increased to 692 BOPD after acidizing. The east offset, Skelly Oil Company's #1 Ehrlich, also was a big Arbuckle oil well with a potential of 1,116 BOPD after acidizing, with an estimated 10,000 ft^3 (300 m^3) of gas per day. While the Skelly well was being drilled, it encountered a small show of oil, 250 ft (75 m) of oil in the hole in three hours, and an estimated 1,000 ft^3 (30 m^3) of gas from 2,953 ft (886 m), the same zone that was being produced in the discovery well. We can, therefore, reconstruct a situation where drilling was taking place offsetting two big Arbuckle wells, depth near 3,150 ft (945 m) and offsetting a more shallow Lansing–Kansas City well, depth near 2,950 ft (885 m); it was desired to reach the deeper, more profitable Arbuckle pay. The surviving driller's log from the Harbaugh #1 (although burned and destroyed from 3,095 to 3,140 ft [928–942 m]) shows a fill-up of 800 ft (240 m) of oil in the hole at 2,950 ft (885 m), the producing zone of the south offset. Drilling was continued with oil in the hole to 3,141 ft (942.3 m) in the Arbuckle dolomite. Apparently the 7-inch pipe being run in the hole at 3,141 ft (942.3 m) displaced the high-gravity gassy oil in the hole. This caused oil and gas to flow into the pits where it was somehow accidentally ignited causing a flash fire. The reported great intensity of the fire was probably due to an accumulation of considerable oil in the reserve pit. An accident of this severity is rare, but it also is rare to have a hole full of gassy oil deepened by drilling with cable tools. A few months later the Harbaugh No. 2 was completed for 800 BOPD at a depth of 2,958 ft (887 m) in the Lansing–Kansas City formation at a location only 50 ft (15 m) north of the Harbaugh No. 1. It was a "twin well" to the No.1 Harbaugh, producing from a different oil reservoir.

FIGURE 36 (below)—PHOTOGRAPH OF THE MARATHON (OHIO) OIL COMPANY'S J. G. HARBAUGH NO. 1, JUNE 18, 1936, the morning after the Wednesday night fire of June 17, which took the lives of five workers and burned and injured five others. Courtesy of Charles W. Steincamp who accompanied his father when the photograph was taken.

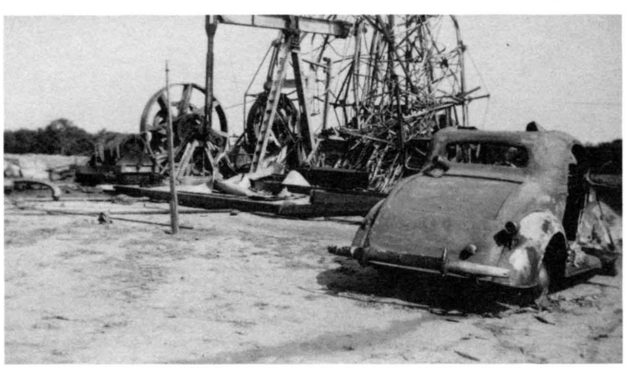
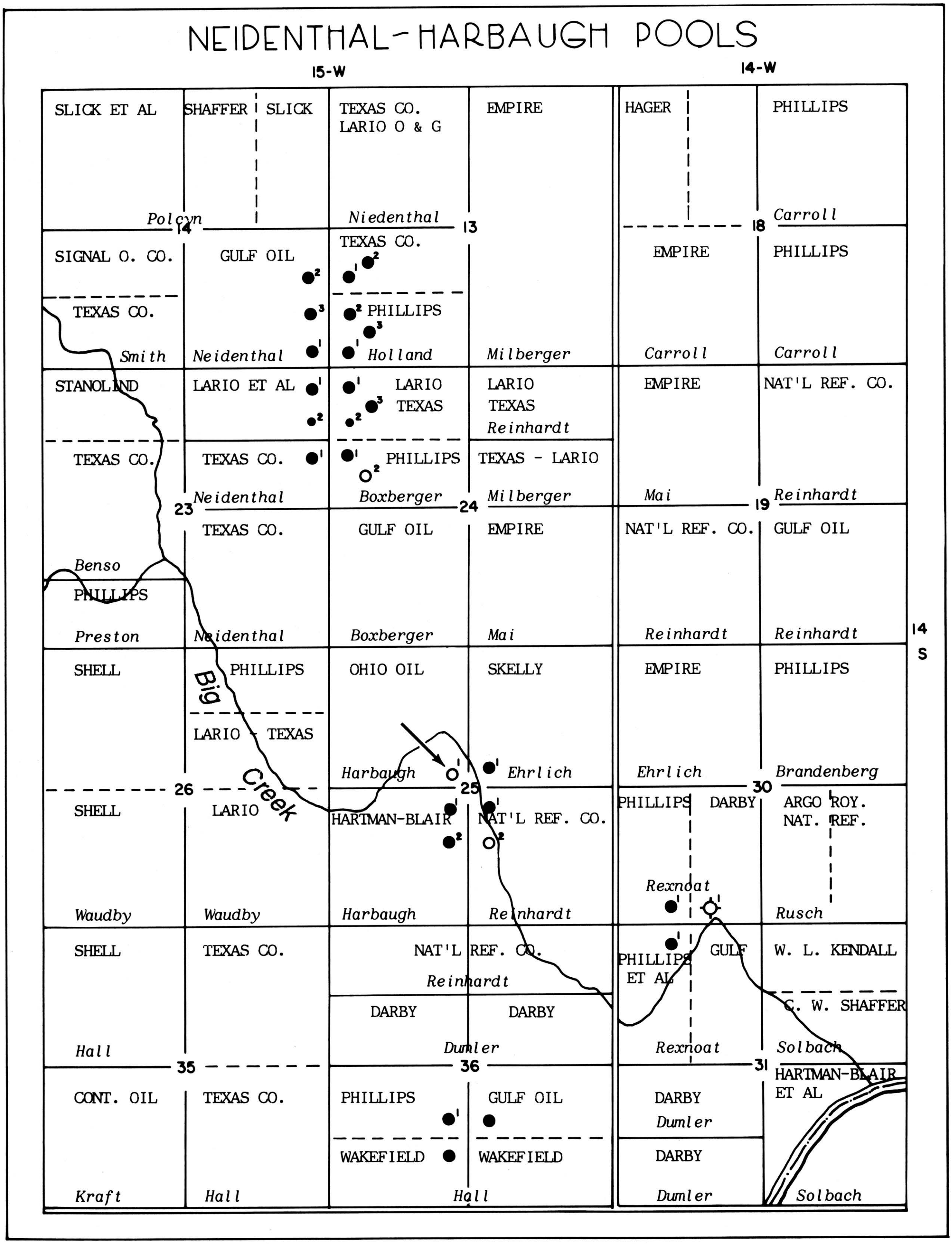


FIGURE 37 (right)—HISTORICAL MAP, GORHAM OIL FIELD, JUNE 17, 1936, showing development on that date of the Neidenthal, Neidenthal South, Harbaugh, and Big Creek oil fields, all of which were later included in the Big Creek sector of the Gorham oil field. Arrow shows location of oil-field fire.



NEIDENTHAL-HARBAUGH POOLS
15-W
14-W
14
S
SLICK ET AL
SHAFFER
SLICK
TEXAS CO.
LARIO O & G
EMPIRE
HAGER
PHILLIPS
Polcyn
14
Niedenthal
13
18
Carroll
SIGNAL O. CO.
GULF OIL
TEXAS CO.
EMPIRE
PHILLIPS
TEXAS CO.
PHILLIPS
Smith
Neidenthal
Holland
Milberger
Carroll
Carroll
STANOLIND
LARIO ET AL
LARIO
TEXAS
LARIO
TEXAS
Reinhardt
EMPIRE
NAT'L REF. CO.
TEXAS CO.
TEXAS CO.
PHILLIPS
TEXAS - LARIO
Neidenthal
Boxberger
Milberger
Mai
Reinhardt
23
24
19
TEXAS CO.
GULF OIL
EMPIRE
NAT'L REF. CO.
GULF OIL
Benso
PHILLIPS
Preston
Neidenthal
Boxberger
Mai
Reinhardt
Reinhardt
SHELL
PHILLIPS
OHIO OIL
SKELLY
EMPIRE
PHILLIPS
Big Creek
LARIO - TEXAS
Harbaugh
Ehrlich
Ehrlich
Brandenberg
26
25
30
SHELL
LARIO
HARTMAN-BLAIR
NAT'L REF. CO.
PHILLIPS
DARBY
ARGO ROY.
NAT. REF.
Rexroat
Waudby
Waudby
Harbaugh
Reinhardt
Rusch
SHELL
TEXAS CO.
NAT'L REF. CO.
Reinhardt
PHILLIPS ET AL
GULF
W. L. KENDALL
DARBY
DARBY
C. W. SHAFFER
Hall
Dumler
Rexroat
Solbach
35
36
31
CONT. OIL
TEXAS CO.
PHILLIPS
GULF OIL
DARBY
Dumler
HARTMAN-BLAIR ET AL
WAKEFIELD
WAKEFIELD
DARBY
Kraft
Hall
Hall
Dumler
Solbach

These 1936 oil wells were treated with acid, the stimulation process first used in 1933 to increase production. The amount of oil that the Kansas Corporation Commission allowed to be produced under proration (the "allowable") was in large part determined by the capacity ("potential") of the well as determined by a witnessed 24-hour physical pumping test. Wells were pumped as fast and hard as possible for 24 hours to obtain the highest potential for allowable purposes. Everything was bolted down and the engine was run wide-open. Sometimes special big equipment was moved in temporarily for the potential completion test. Rod breaks, engine failures, etc. occurred frequently, requiring retesting. Within a few years, it was realized that pumping as hard as possible for a high physical potential was harmful to the wells. Bottom water moved upward in a cone-shaped area, blocking off oil and greatly damaging the well's ultimate production. Amstutz and Stephenson (1944, p. 18) cautiously state "Measurements of fluids produced during and after the physical potential tests also demonstrated to some operators the fact that high pumping rates appeared to jeopardize oil recoveries through premature entrance of water into the wells." For this reason the Kansas Corporation Commission substituted drawdown potential tests. In these, the lowering of fluid level while pumping at various rates was recorded and plotted on a graph. For oil wells with a very high productivity, the plotted graph gave productivity readings approaching infinity. The Kansas Corporation Commission solved this problem by declaring that the maximum a well could be allowed on a drawdown potential test was 3,000 BOPD; hence, the term "maximum well," meaning an oil well capable of producing 3,000 BOPD or more.

The World War II years, December 7, 1941–September 14, 1945

Personnel, materials, and fuel were in short supply during the war years. Government regulations had the effect of curtailing oil-well drilling. Tubular goods were allocated in limited amounts. Gasoline and fuel oil were rationed. Price controls were placed on crude oil. Well spacing was further restricted. Drilling contractors vied with farmers for priority to purchase machinery and gasoline, and with each other for priority to purchase tubular goods. The paperwork to apply for and secure priority rights to purchase these items added to the contractor's burden and cost. The tight economy of the war years prolonged the use of full-hole (top to bottom) cable-tool drilling rigs in the Russell area long after they were obsolete elsewhere in the midcontinent. The two-man crew, the availability of parts from junked rigs, and the supply of older (deferred) skilled drillers made this possible. Oil production was maintained at a high level, 10,000 to 13,000 BOPD, from the Gorham oil field by pumping existing wells at their capacity in these years, as graphed in fig. 4. Although drilling was much curtailed by shortages of casing, tubing, rods, and personnel, most of all it was curtailed by the restriction at the time on well spacing, with only one well allowed for each 40 acres (16 hectares). The number of producing wells remained almost constant at 461, 457, and 458 for three years, then increased to 527 and 523 wells in 1944 and 1945. Most of the increased drilling was 10-acre (4-hectare) infill drilling, which added little to the reserves of oil in the ground and only temporarily stayed the decline in daily oil production. During the year 1945, daily oil production declined 30% to 8,606 BOPD. In post-war 1946, production declined further to 6,922 BOPD; many wells were plugged and abandoned leaving only 449 oil wells. Their average daily production was 15 BOPD per well as compared with a war-year's high of 29 BOPD per well in 1942 and a pre-war average of 20 BOPD per well in 1940. The price paid for 40° crude oil was frozen by government regulations near $1.20 a barrel in 1941–44, but more than doubled when restrictions were removed, reaching $2.60 a barrel in mid-1947 and remaining near $3.00 a barrel through the 1950's and 1960's as illustrated in fig. 17 and by table 5, appendix.

Stripper-production stage, 1955–1986

The Gorham oil field entered the stripper oil-field stage in 1955, defined as production of less than 10 BOPD per well average for the oil field. The field continued its stripper-stage production with gradual but constant decline. By December 31, 1986, 444 wells were averaging only 3.2 BOPD per well.

This unexciting, drab period of the Gorham oil-field history was a caretaker or custodial phase. Wells were handled carefully with a constant eye on cost and a reluctance to spend money. But the old oil field adage prevailed—"take care of your stripper wells and your stripper wells will take care of you." This adage is true because of the flattening of decline curves and the steady but small, long-continued production. In all oil fields, oil wells run out of profit before they run out of oil. In the Gorham oil field, most oil wells are abandoned while still producing 1–3 BOPD. In this connection, the graph of crude-oil posted price (fig. 17), showing the increased crude-oil sale price of the late 1970's and 1980's, explains the prolonged extension of the Gorham oil-field stripper stage.

In the late phase of oil production, where operating costs determine the life of the wells, the highest cost is often the handling and disposing of increased amounts of produced brine associated with the oil. In these stripper years, increased need for deep saltwater-disposal wells provided additional control for the map of the Precambrian basement rocks. A second history of the Gorham oil field is the history of the handling of the produced brines in all stages, not just the terminal stripper stage. A chapter is devoted to this subject under the heading, "Environment."

Drilling with rotary tools in the Gorham oil field

Operators in the Gorham oil field were reluctant to give up the use of cable tools for the more efficient and cost-effective rotary tools. Although rotary tools were common in Oklahoma and Texas in the 1930's, only a few operators in Russell County were experimenting with their use. The earliest rotary rigs used in Kansas were huge machines. They required a 120-ft (36-m) derrick assembled by rig builders, usually two 150-horsepower steam boilers, 6-inch drill pipe, and bits which bored a 9-inch hole. The "fish tail" bits used in the Gulf Coast oil fields were more easily adapted to the predominately shale drilling in Oklahoma than to the harder limestone formations in Kansas. However, by 1940, smaller "portable" rotary rigs with a built-in "jack knife" mast (eliminating the need for services of rig builders) were available. They used a 4-inch drill pipe, roller rock bits, and were powered by internal combustion engines using diesel fuel, gasoline, or even natural gas for fuel. An example of a 1936 hole drilled with rotary tools is the Skelly #1 Ehrlich, sec. 26, T. 14 S., R. 15 W. This well, discussed as an offset to the well with the tragic 1936 fire, was drilled to a depth of 2,927 ft (878 m) with rotary tools that were moved off the hole to allow deepening to 3,157 ft (947 m) TD by cable tools. Rotary drilling was discontinued near the top of the Lansing–Kansas City, encountered at 2,916 ft (875 m), in order to evaluate the known productive zones in the Lansing–Kansas City and Arbuckle by the more familiar open-hole cable-tool method. Operators were afraid of overlooking pay zones in the unfamiliar muddy rotary-drilling fluids with the scrambled well cuttings. William Brunson (personal communication, October 1988) remembers that his father, Howard Brunson, a long time operator of cable tools, leased a new rotary rig in the 1930's, drilled one well with it, got in trouble with lost circulation, and returned to cable-tool drilling.

The years of World War II further retarded the use of rotary tools in 1941–44, but from the late 1940's, the rotary-drilling method became the only method of full-hole top-to-bottom drilling. Cable tools were used only for "drilling in" well-completion work after the oil-string casing was set and cemented in place.

Rotary drilling—role of the geologist

The role of the petroleum geologist again changed with the advent of widespread faster and more cost-efficient rotary drilling. As long as cable-tool drilling prevailed, geologists were not needed at the well site to find oil which, when "struck," was obvious as it came into the empty (air-filled) hole. In rotary drilling, oil shows were not obvious in the constant flow of drilling mud carrying mixed cuttings of the rocks drilled. The drillers operating rotary rigs continued to grab and smell samples and to keep logs but they were usually unsure of what was being drilled and unable to recognize potential oil-producing formations. To evaluate oil shows and to pick the proper place to set packers for drillstem testing or to set oil-string casing, constant day and night around the clock supervision by a geologist at the well site was required. Thus in the post World War II days, in 1945 and later, the flurry of rotary drilling in the Gorham oil field and elsewhere required geologists at the well sites with their binocular microscopes and oil-detecting fluoroscopes. The principal activity of many petroleum geologists became well-site supervision, called "well sitting." Geologists doing well sitting were either employees of major oil companies, or in the 1950's when major oil companies began closing their Kansas offices, self-employed consultants. Among the first of the independent consulting geologists was the firm of Boris Lerke and Raymond Wharton. They provided well-site supervision services to independent oil operators as early as the mid-1930's when only a few rotary rigs operated in Kansas. Well-site geologists, in residence at the drilling well day and night, summer or winter, commonly took naps in their automobiles in the earlier years, but later it became customary to provide a shed or "doghouse" with a stove, then still later to provide a mobile home with a work desk, air conditioning, kitchen facilities, and real bedrooms.

Throughout all these changes the constant role of the petroleum geologist was to find oil. Historically this was done by mapping anticlines with a plane table, by core drilling, by office examination of samples, by "map making" with ideas for new oil fields or oil provinces, or by actually watching the drilling progress of a test hole at the well site.

Rotary drilling—present practices

Drilling with rotary tools is described in some detail in a current Kansas Geological Survey publication by Baars et al. (1989) *Petroleum—a primer for Kansas*. That publication also treats testing and logging in rotary holes. It further treats, in an introductory way, the entire subject of petroleum exploration and production specifically as applied to the state of Kansas. The publication does not, however, include any discussion of the now obsolete method of standard cable-tool drilling which was such a vital part of the Gorham oil field's early history.

Environment

Water

Introduction

The 60-year-old Gorham oil field has affected its environment adversely by leaving a heritage of brine pollution of some freshwater aquifers, an interstate highway subsiding slowly in three areas, and 50 mi^2 (130 km^2) of agricultural lands somewhat impaired. These aspects are summarized briefly. Walters (1959, p. 60–75) has previously discussed the history of brine disposal, oil-well plugging or non-plugging, and highway subsidence in the Gorham oil field.

Freshwater aquifers

In the oil-field areas of Russell County, including the Gorham, Russell, and Hall–Gurney oil fields, two shallow freshwater aquifers became contaminated in some local areas with oil-field brines in the 1930's. Prior to contamination, the first aquifer, the near-surface alluvium present in creek and river valleys, yielded limited amounts of excellent-quality freshwater. For example, Frye and Brazil (1943) state that Victoria, 6 mi (9.6 km) west of the townsite of Gorham, derived its municipal water supply from four dug wells 35 ft (10.5 m) deep in secs. 2 and 12, T. 14 S., R. 17 W., and in sec. 18, T. 14 S., R. 16 W. A composite water sample from the four wells that yield water from the Pleistocene sand contained only 14 parts per million (ppm) chloride and 445 ppm total-dissolved solids (TDS). Almost all the water analyses available in the literature are expressed in the old terminology of parts per million (ppm) as here quoted. When more modern analyses, expressed in milligrams per liter (mg/L) are available, they are so quoted.

A second aquifer is the Dakota Sandstone which contained potable water in limited areas. Frye and Brazil (1943) give the following information: two municipal water wells for the city of Bunker Hill, 24 mi (38 km) east of the Gorham townsite and outside of the oil-field area, yielded water from a depth of 250 ft (75 m) with a chloride concentration of 440 ppm and TDS content of 1,270 ppm. These Dakota sandstone wells are in sec. 6, T. 14 S., R. 12 W. A nearby Dakota well in sec. 12, T. 14 S., R. 13 W., with a total depth of 244.6 ft (73 m), yielded water with only 85 ppm chloride and only 672 ppm TDS. Another Dakota sandstone well nearby in sec. 10, T. 14 S., R. 12 W., depth 183.9 ft (55 m), yielded water with 23 ppm chloride and 466 ppm TDS. In contrast, four Dakota water wells within the Gorham oil field tested by Frye and Brazil in the summer of 1941, averaged 7,655 ppm chlorides and 16,652 ppm TDS. These figures may represent extreme conditions. In the Bunker Hill area, the Dakota formation is shallow and close to the outcrop. It is influenced by percolating rainfall and represents the best of conditions for freshwater in the Dakota sandstones. The most characteristic feature of the Dakota formation is its variability. Sandstones are lenticular, discontinuous, and are inferred to have been deposited mainly by streams and rivers (Bayne et al., 1971). The sandstone lenses act as separate aquifers and are thought to have contained waters of varying salinity prior to oil activity in the area. All studies of the quality of the water in the upper and lower Dakota aquifers are handicapped by the lack of base-line data on the water quality prior to the discovery of the Gorham oil field. Even the early investigators, Frye and Brazil (1943), working in 1941 when the oil field was 15 years old, could not ascertain the pre-oil-field water quality, but could only show that the average analysis of the Dakota water from within the limits of the oil field was notably higher in chlorides and TDS than contemporary analyses of Dakota water from outside the oil-field areas.

The town of Gorham had no municipal water supply in the late 1930's and the early 1940's. In those years, too, the municipal water supply for the city of Russell was changed from water wells to surface water from the Smoky Hill River and Big Creek. The surface water was of poor quality as compared with the prior water supply. Latta (1948) states that "At some periods during the last several years when the stream (Smoky Hill River) was at low stage, the chloride content of the intake has been as high as several thousand parts per million for short periods; and for periods of many days, water in the city mains has averaged 1,100 ppm chlorides. The supply from Big Creek, although of better quality, is not adequate to treat the total needs of the city."

The saline contamination of two freshwater aquifers in local areas was part of the environmental price paid for Russell County oil fields. How did the alluvial and Dakota Sandstone aquifers become contaminated with oil-field brine in some local areas?

Disposal of oil-field brine, 1926–28

For the first two years after the discovery of the Gorham oil field in 1926, the disposal of saltwater was not a problem. All the early wells produced from the Lansing–Kansas City limestones, then termed "Oswald" by correlation with the famous 1923 discovery of the Fairport oil field on land owned by the Oswald family. The Lansing–Kansas City reservoirs are characterized by solution-gas drive. The wells produced but little saltwater along with the oil.

Disposal in surface ponds, 1928–1930's

The discovery on January 28, 1928, of oil in the Gorham sandstone changed the situation. Saltwater production was not yet a problem three months later on April 14, 1928, when the cover photograph was taken but became one soon after. The historical map (fig. 30) shows the intense activity on April 14, 1928, following the discovery of this major prolific oil reservoir with a strong water drive. For a few weeks the Gorham area was a "hot spot" and was perhaps the most exciting place in the U.S. oil business.

The new Gorham sand oil wells, produced at capacity, were soon making large volumes of saltwater along with the oil. For example, the Day #3 in the NE SE NE sec. 32, T. 13 S., R. 15 W., produced 60 BOPD and 50 BWPD initially when completed January 30, 1930.

During the late 1920's and early 1930's, there were no regulations and it was accepted practice to store brine produced with the oil in surface ponds. Ultimately the water may have evaporated but the salt did not. Brine seeped into the soil and eventually made its way into the shallow freshwater aquifers, or else brine washed into the surface stream drainage during storms which eroded out the earthern embankments. Ponds continued to be used into the early 1950's, by which time many of the Reagan Sandstone oil wells were producing 90% saltwater in amounts exceeding 100 barrels of water per day per well. Such ponds are abundantly visible on 1938 and 1951 photographs studied.

Photographs of saltwater ponds in the oil fields of central Kansas were published by Jones (1945, 1950) who discussed the fallacy of considering them "evaporation ponds." Any evaporation of water from brine ponds did not decrease the potential contamination because the residual salts could be redissolved by water from later atmospheric precipitation. Jones (1950) advocated the use of deep disposal-wells in the Arbuckle formation in place of the brine storage ponds and the shallow SWD wells then in common use with depths from 400 to 800 ft (120–240 m).

Fig. 38 is the first of a series of pen and ink drawings by artist Steve Van Buskirk from the vertical air photographs studied. The drawings are drawn from the poor-quality, old photographs supplemented by production records and well-plugging reports. Note that one large pond for storage of produced brine was not sufficient so that a second smaller pond was constructed. These ponds were constructed as evaporation ponds and not as dams in valleys or waterways. At times, the ponds became completely filled, shutting down oil production until additional pond storage was available. A heavy summer storm occasionally over-filled such a pond causing run-off and rapid erosion of the pit wall, dumping the entire brine content into the swollen waterways. Such an "act of God" was welcomed because the pond retaining wall was easily repaired, permitting oil production to be resumed. Virgil B. Cole (personal communication, 1976) stated that old timers in the area suggested that sometimes God was assisted in his "act" by clandestine midnight hand-shoveling of a gap in the pond wall while the storm raged. At any rate, not only were the ponds inadequate to hold the large amounts of oil-field brine, but by the late 1930's, it was recognized that these extensive "evaporation" ponds leaked brine downward, infiltrating and polluting the near-surface alluvial aquifers.

A sad personal story concerning oil-field ponds and the pollution of the Dakota aquifer was related to me by Clarence Keil (personal communication, 1983). It is a representative story for the events of those years. Clarence Keil grew up on a family farm 6 mi (10 km) south of Russell in the Hall–Gurney oil field near the Smoky Hill River. He told me about the big clear cool spring on their family farm, SE sec. 36, T. 14 S., R. 14 W. The spring came out of the Dakota Sandstone on the hillside. As a boy in the 1940's, he remembers going often with his father to take cans of cream to the Dole Creamery in the city of Russell where the water supply had become salty. His father took a dozen gallon jugs of spring water each week for the Dole family who operated the creamery. They were the parents of U.S. Senator Bob Dole. On Sunday afternoons, Keil recounts, as many as 20 automobiles were parked on the road at their farm while the visitors from Russell waited in line to fill water jugs. Later the spring became too salty to drink and the big cottonwood trees surrounding it died. One "evaporation pond" for storage of waste oil-field brine was in use 0.25 mi (0.4 km) west of the spring on the Keil land, another was on the neighbor's land at a higher elevation 0.5 mi (0.8 km) north in the NE sec. 36, and two brine ponds were in use on the NW sec. 36. Officials of a major oil company operating the four oil wells on the Keil land assured the family that their oil wells and others in the Hall–Gurney oil field had nothing to do with the changes in quality of the spring water.

Disposal in shallow SWD wells, 1940's

Beginning in the 1930's, permits were issued for the use of shallow saltwater-disposal wells, defined as wells disposing brine in aquifers (salifers) at depths more shallow than the salt that was encountered from 1,200 to 1,500 ft (360–450 m). Saline contamination of shallow freshwater aquifers by oil-field brines became a problem by 1941. The Kansas Geological Survey conducted a study that year of oil-field brine disposed in the Gorham oil field, and in adjacent parts of Russell and Ellis counties. Test holes were drilled and water samples collected. This study (Frye and Brazil, 1943) was interrupted by World War II before completion, but official approval was given by the Kansas Corporation Commission for disposal of oil-field brines in shallow brine-bearing aquifers, the Cheyenne Sandstone and the Cedar Hills Sandstone, at depths near 400 to 800 ft (120–240 m). Frye and Brazil mapped 22 such shallow SWD wells within the present Gorham oil field of which four affected the Witt and Crawford sinks. Operations were not always discriminating as to the shallow sandstones used, and it was prior to this study that the chloride count in the Dakota aquifer reached 7,655 ppm average of four locations, as compared with 303 ppm chlorides in the non-oil-field areas.

Fig. 39, Roubach lease in 1951, shows the evaporation ponds still holding brine. A shallow SWD well (not visible on the 1951 photograph) near the tank battery was disposing oil-field brine into the Cheyenne Sandstone from 459 ft to 482 ft (138–145 m). There are six remaining oil wells. On the adjacent Crawford lease, left distance, only two of the nine wells shown in 1938 remain. Abandoned are twin wells, Crawford No. 12 and No. 16, at the site of the future Crawford sink affecting I–70. The Crawford lease, too, disposed oil-field brine in a shallow saltwater-disposal well in the Cheyenne Sandstone as did the Witt and Foster B leases comprising the E/2 sec. 3 to the west (right) in fig. 39. Shallow SWD wells for which records survive in the W/2 sec. 2 and the E/2 sec. 3, T. 14 S., R. 15 W. are shown in table 6.

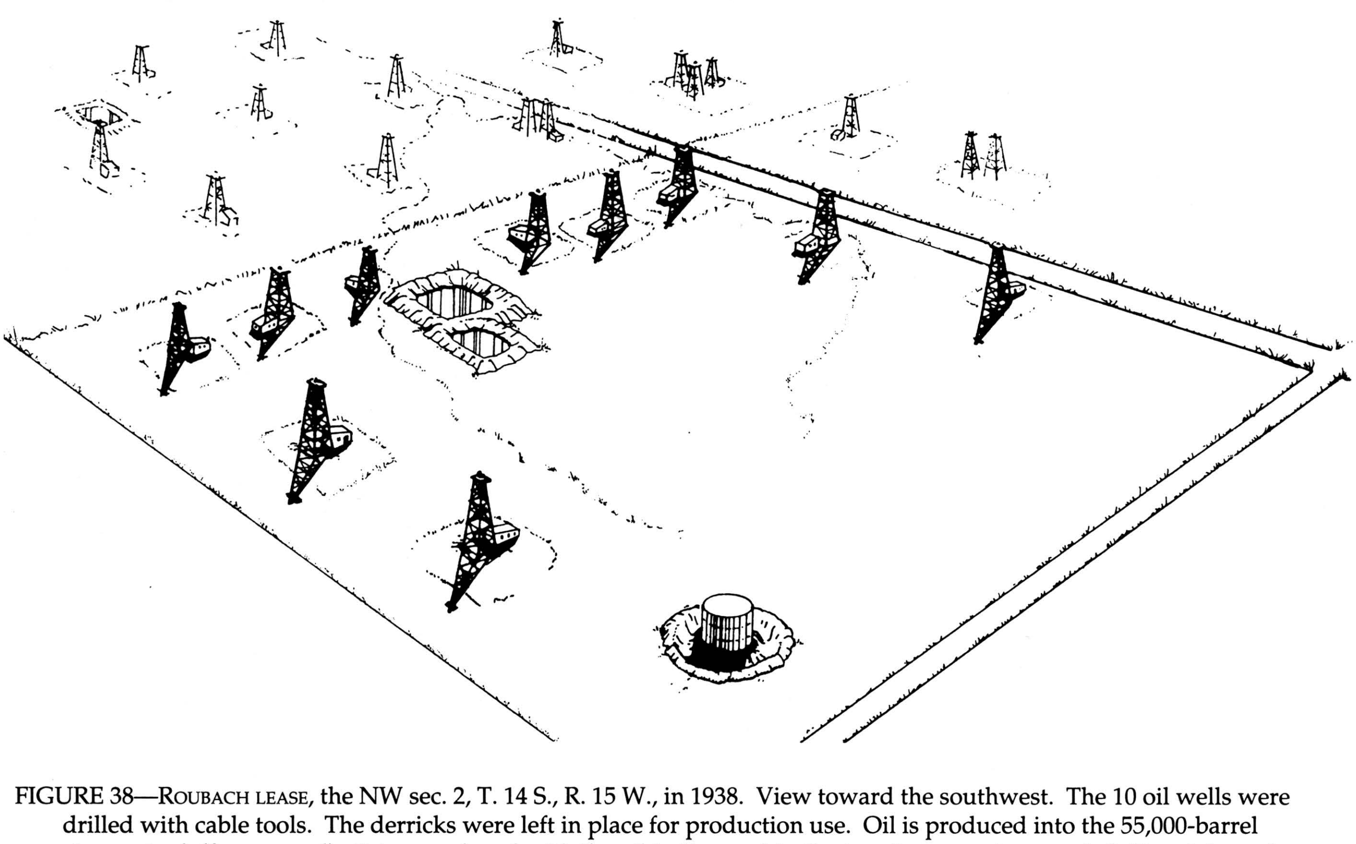


FIGURE 38—ROUBACH LEASE, the NW sec. 2, T. 14 S., R. 15 W., in 1938. View toward the southwest. The 10 oil wells were drilled with cable tools. The derricks were left in place for production use. Oil is produced into the 55,000-barrel storage tank (foreground). Brine produced with the oil is disposed in the two "evaporation ponds." Sketch by artist Steve Van Buskirk from poor-quality vertical aerial photographs supplemented by production records and well-plugging reports. Sketch is repeated as part of a larger area in fig. 47, p. 82.

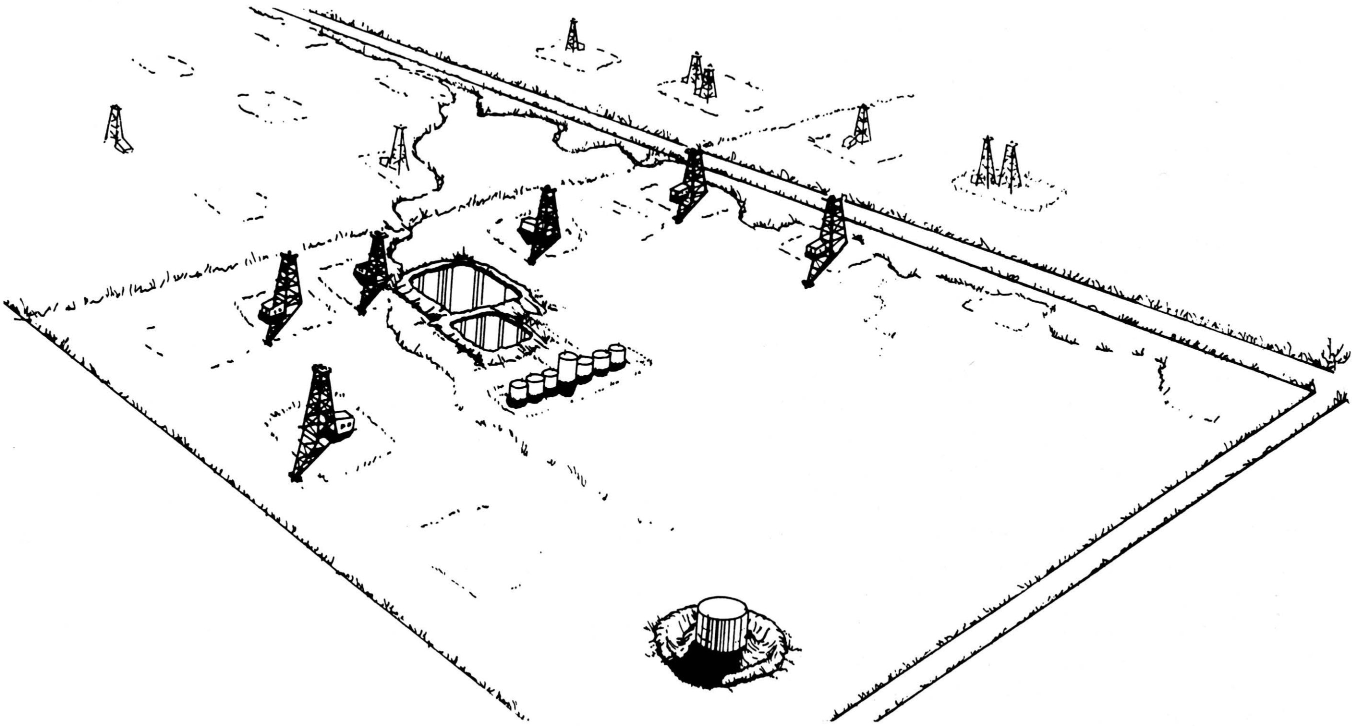


FIGURE 39—ROUBACH LEASE, 1951. The two saltwater "evaporation ponds" are full. Brine pumped from the six remaining oil wells is disposed in a shallow saltwater-disposal (SWD) well 482 ft (145 m) deep (not shown). Oil is being stored in the battery of tanks. Sketch by Steve Van Buskirk.

The disposal formation for depths of 443–500 ft (133–150 m) is the Cretaceous Cheyenne Sandstone; for depths below 500 ft to near 925 ft (150–278 m), it is the Cedar Hills Sandstone. In these SWD wells the white Cheyenne Sandstone directly overlies the red Permian Cedar Hills Sandstone. An early study by Don Butcher (personal communication, January 1990) confirmed that the Cheyenne Sandstone was very friable with only a minor amount of carbonate cement. Acidizing of the formation, along with the surging effect due to releasing pressure when the pump was shut off, caused loose sand to fill the lower part of the bore hole. The Cheyenne disposal wells, therefore, initially took brine by gravity flow but required increasingly higher pressurers with use. Licensing of new Cheyenne SWD wells was discontinued in the 1960's as a result of this study.

Virgil B. Cole (personal communication, 1975), an experienced field geologist, witnessed saltwater springs breaking out on the hillsides in secs. 14 and 23, 2 mi (3.2 km) south of the area under discussion, due to excessive input pressures in shallow saltwater-disposal wells and to the large volume of disposed brine. He related that when injection pressures became too high due to plugging of the SWD well with sand, it was common practice to re-drill shallow saltwater-disposal wells a few feet away from the plugged-off hole so that some locations had two or three shallow SWD wells within a few feet of each other.

Many shallow SWD wells were plugged and abandoned in the 1950's when deep Arbuckle SWD systems were installed. In the course of years of operation of shallow SWD wells, the Dakota sands from the depth of 150 to 350 ft (45–105 m) became contaminated with salty oil-field brines in some areas within the Gorham oil field.

Corrosion caused by brine disposal in shallow SWD wells

The shallow SWD wells licensed by the KCC provided a place to put the produced saltwater when the construction of new surface-evaporation ponds was discouraged in the mid-1940's, then prohibited by legislation passed in 1957. The shallow SWD wells had other unplanned results. Albert Abercrombie (personal communication, August 25, 1988, and other times) was employed by Sohio Petroleum Company as foreman in the Fairport–Gorham district from the spring of 1944 to January 31, 1948. The principal part of his work was the recompletion of oil wells either to put new zones on production or to repair damage due to corrosion. All of the 18 oil wells on the Foster A lease, the NE and N/2 NW sec. 3, T. 14 S., R. 15 W. were drilled with cable tools as were the eight wells on the Witt lease N/2 of SE sec. 3 and the six wells on the Foster B lease, the S/2 NW sec. 3. In producing wells the only

TABLE 6—Shallow SWD wells, W/2 sec. 2 and E/2 sec. 3, T. 14 S., R. 15 W.

Lease	Location	Disposal depth	Years
NW 2 Roubach SWD #1	1,055 FEL) 880 FSL) NW	459– 482	1938 (still in use in 1986)
SW 2 Crawford SWD #1	1,175 N of SL) 1,284 E of WL) C SE	443– 653	9–26–36 9–10–71
NE 3 Foster "B" SWD #1	1,250 FEL) 1,300 FSL) NE	515– 925	8–28–49 1–31–56
SE 3 Witt "A" SWD #1	C S/2 N/2 SE	520– 920	Nov. 1946 4–07–56
V. Witt SWD #1	SE SW SE	483– 880	2–21–45 1–31–56
Witt #8 OWWO SWD	NW SW SE	750– 795	7–24–36 3–26–56

casing left in the holes were short strings of large conductor pipe such as 20 ft (6 m) of 20-inch (50-cm) diameter and oilstrings of 7-inch (17.5-cm) casing (6 5/8 inches [16.5 cm] i.d.) either set in the Kansas City near 3,000 ft (900 m) or set in the Reagan Sandstone near 3,300 ft (990 m). These casing strings were uncemented. This left the annular space outside the 7-inch (17.5-cm) pipe open from the base of the surface pipe to the end of the oil string. Abercrombie even found that the triple wells in the NE NE SE sec. 3 on the Witt lease, adjacent to the Crawford sink, had only oil-string casing, uncemented, with no surface pipe at all left in the hole. In that area, the intermediate strings of casing that shut off water during drilling with cable tools were all pulled out of the hole and reused elsewhere. The casing program of the Tony Witt #4–A, drilled 50 ft (15 m) south of the #4 in the NE NE SW sec. 4, T. 14 S., R. 15 W. near the Witt sink, is typical of the casing program for the oil wells:

Size (inches)	Depth (ft)	Pulled Out (ft)	Left in Hole (ft)
20	20	0	20
15-1/2	389	389	0
12	612	612	0
10	922	922	0
8	2,765	2,765	0
6-5/8 (and later)	3,054	0	3,054
5-liner	3,286	0	232

In the mid 1940's, Abercrombie (personal communication, August 25, 1988) completed shallow SWD wells on the Foster A, Foster B, Witt, and other leases. Within two years casing in many of the oil wells corroded opposite the "Dakota," a field term for the Cedar Hills Sandstone, the Cheyenne Sandstone, and the lower Dakota Sandstone. Production from the 8–10-year-old oil wells had declined to a few barrels of oil a day. In some wells the first indication of casing corrosion due to the brines injected into the nearby shallow SWD wells was an increase in oil production from adjacent oil wells. One of the oil wells on the Foster B lease had declined to 3 BOPD from the Lansing–Kansas City formations but after the "Dakota" water broke in on adjacent wells, production increased to over 100 BOPD due to unplanned water-flooding of the Lansing–Kansas City formation. It was Abercrombie's job for many months to "squeeze-cement" well after well through the corroded casing. Procedure was to set a plug near 800 ft (240 m) inside the 7-inch (17.5 cm) casing, then pump cement down the casing, out the corroded holes, into the annular space outside of the 7-inch (17.5-cm) casing and up the hole inside the surface pipe until cement circulated at the surface. If cementing could not be done in this manner, then 1-inch (2.5-cm) pipe was inserted down the annular space and cement injected through it. While cementing the Witt #1 in the NW NW SW sec. 3, T. 14 S., R. 15 W. (the sinkhole well), the 1-inch

(2.5-cm) pipe could not be pulled out and was left cemented in the annular space. These personal field experiences of Albert Abercrombie between the spring of 1944 and January 31, 1948, are indicative of conditions in the Gorham oil field during those years. Abercrombie's personal knowledge of field conditions in the portion of the Gorham oil field traversed by I–70 through secs. 2 and 3 provides an understanding of the casing programs, of the uncemented condition of cable-tool holes, and of the corrosive effect of disposing oil-field brines in shallow SWD wells.

Butcher (personal communication, January 1990, while conducting a critical peer review) wrote that in his opinion, "All of the sinkholes in this immediate vicinity were caused by 'Dakota' water moving down uncemented annular spaces in producing wells, dissolving salt." The author agrees with this statement with the additional note that the Topeka fracture zone near 2,700 ft (810 m) was a contributing factor in localizing the sinkholes by providing a vertical communication path (originally for the upward movement of petroleum) for the downward movement of disposed oil-field brines, undersaturated as to salt, by gravity flow. For a summary of the pressure relationships of the various aquifers, see Walters (1978, p. 39–45, 63–68).

Shallow SWD wells; map and years licensed

Fig. 40 is a map showing the locations of the 168 shallow SWD wells for which records could be found in the KCC office or elsewhere. None of these shallow SWD wells is shown on other maps of the Gorham oil field in this report. The arrow near the town of Gorham gives the location of the Gorham monitoring site (Macfarlane et al., 1988).

The years in which the shallow SWD wells in the Gorham oil field were licensed by either the KCC or the KDHE, and the number of shallow SWD wells licensed are as follows:

before 1942	22	Frye and Brazil (1944)
1942–July 1944	13	Swineford (1945)
1944–1949	51	
1950–1959	38	
1960–1969	11	
1970–1979	13	
1980–1986	20	
	168	to January 1, 1987

Formation	Depths	Years Licensed
Dakota–Kiowa	250–450	early 1940's Macfarlane et al. (1988)
Cheyenne	450–500	1930's–1960's Butcher (pers. comm., Jan. 1990)
Cedar Hills	500–800	1930's–Jan. 1990 KCC and Butcher (pers. comm., 1990)

Investigation of aquifers affected by shallow SWD wells

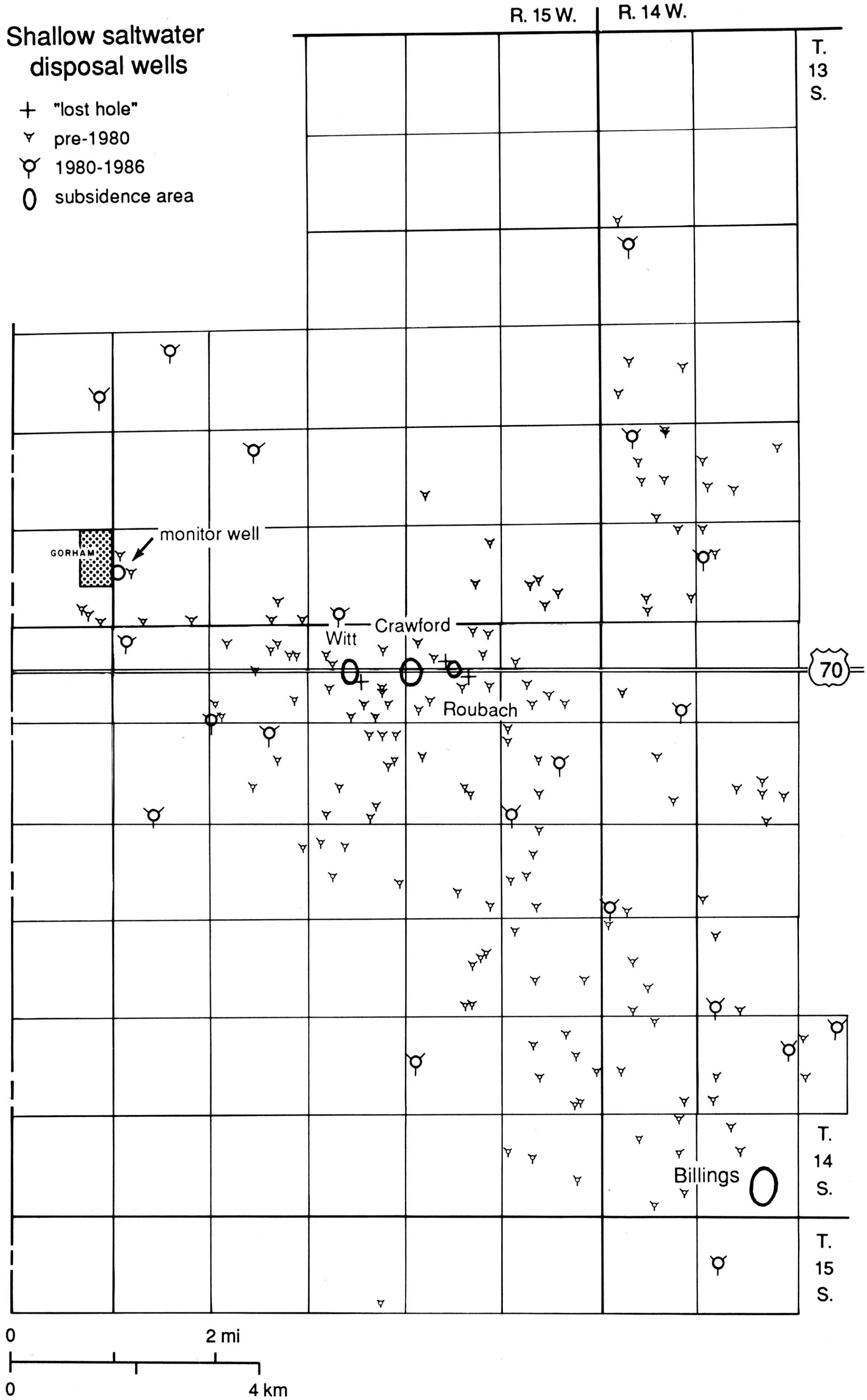
The effect of former and present oil-field SWD wells on the Cedar Hills, Cheyenne, and upper Dakota aquifers was investigated by Macfarlane et al. (1988), at the request of the KCC. Monitor sites were established including one at the east edge of the town of Gorham in the NW SW NW sec. 32, T. 13 S., R. 15 W., as part of the hydrogeologic and water-quality investigation. Measurements of three aquifers at the Gorham monitor site on November 23, 1987, provide the following data:

Aquifer	Depth (ft)	Static Fluid Level A* + B**	TDS, mg/L C***
Pleistocene	0–22	Not measured	—
upper Dakota	148–245	171 + 1,732	3,756
lower Dakota	335–362	Not measured	—
Cheyenne	460–488	197 + 1,706	20,640
Cedar Hills	508–598	158 + 1,745	19,390

*A, In feet below ground level. Assumed elevation, 1,903 ft.
**B, In feet above mean sea level.
***C, Calculated from conductivity measurements.

Static fluid levels at the Gorham monitor site show that the aquifers are separated by confining beds, but if all aquifers were open in an uncased hole, brine from the Cedar Hills Sandstone would flood the Cheyenne aquifer and also would flood the

FIGURE 40(right)—Map showing the location of 168 shallow SWD wells for which records could be found. Also shows Witt, Crawford, Roubach, and Billings subsidence areas. Arrow near town of Gorham indicates KCC 1987 monitor well. Disposal formations were formerly Dakota Sandstone 150–250 ft (45–75 m; early 1940's), Cheyenne Sandstone 440–500 ft (132–150 m; 1930's–1960's) and presently Cedar Hills Sandstone, 500–800 ft (150–240 m; 1930's–1990's). Larger symbols indicate shallow SWD wells licensed 1980–86.


Shallow saltwater disposal wells
+ "lost hole"
pre-1980
1980-1986
subsidence area
R. 15 W.
R. 14 W.
T. 13 S.
T. 14 S.
T. 15 S.
GORHAM
monitor well
Witt
Crawford
Roubach
Billings
70
0
2 mi
0
4 km

upper Dakota aquifer that now carries "usable" water. Complete chemical analyses of water samples, presumably taken November 23, 1987, were published by Macfarlane et al. (1988). The pressure relationships are influenced by a Cedar Hills SWD well completed in June 1986, only a few hundred feet north of the monitor site and by other Cedar Hills SWD wells to the south.

The aquifers measured at the Gorham monitor site are connected hydraulically within the 100-mi^2 (260-km^2) study area. In the western part of the study area, the Cedar Hills aquifer is separated by shale from the overlying Cheyenne Sandstone as described at the Gorham monitor site. Throughout the entire mid-part of the study area, the Cedar Hills Sandstone is directly in contact with the Cheyenne Sandstone. An example is the area of I–70 highway subsidence in secs. 2 and 3, T. 14 S., R. 15 W. In the northeast portion of the study area, the Cedar Hills Sandstone is absent by pre-Cretaceous truncation (Frye and Brazil, 1941). Examples are wells 51 and 52, cross section B–C, fig. 6. The Cheyenne Sandstone is hydraulically connected with the overlying lower Dakota aquifer in that area. The saline aquifer system formed by the merging of these three aquifers has a northeastward flow and discharges into the alluvium in the valleys of Salt Creek and the Saline River, the junction of which, in sec. 33, T. 12 S., R. 14 W., is only 2 mi (3.2 km) northeast of well 53 at the northeastern end of cross section B–C, fig. 6. It is noteworthy that both Salt Creek and the Saline River were named by the Indians as translated by the French fur traders (Rydjord, 1972, p. 110) more than a century before the first oil drilling in Russell County. Whittemore and Pollock (1979) as quoted in Macfarlane et al. (1988), identified the saline seepage into Salt Creek as being predominately derived from a halite-brine (natural) source. They state that the saline seepage had, in 1979, a different salinity identification from that found in Cedar Hills and Cheyenne samples at the Gorham monitor site where the waters are similar to those for oil-field brines in the surrounding area. As of 1979, therefore, oil-field brines were not contributing to the salinity of Salt Creek.

Macfarlane et al. (1988) reached the following preliminary conclusions regarding the Gorham oil-field area:

1) The Cedar Hills aquifer is hydraulically interconnected with the Great Plains aquifer (Cretaceous; Cheyenne, lower Dakota, and upper Dakota aquifers).
2) Saline waters from the Cedar Hills aquifer are moving upward into the Great Plains aquifer.
3) Upward movement of saline waters from the Cedar Hills into the Great Plains aquifer may be accelerated by continued use of the Cedar Hills aquifer for disposal of oil-field brines.

Deep-well disposal systems, 1950's

By the 1950's, oil-field brines produced along with the oil were being disposed in deep SWD wells completed 50 ft (15 m) or more in the Arbuckle dolomite or the underlying Reagan Sandstone. In 1950, Sunray DX completed a 3-mi (4.8-km)-long pipeline system in secs. 11, 12, and 14, T. 14 S., R. 15 W., to gather oil-field brines from 20 wells connected to the deep Furthmeyer SWD well in the NE NE SE sec. 22. In 1955 Sohio Petroleum Company installed a 54-well saltwater-gathering system nearly 4 mi (6.4-km) long leading to its No. 1 Minnie Preston SWD well in the NW SW NW sec. 22, T. 14 S., R. 15 W. Arbuckle dolomite was drilled into at 3,273 ft (982 m), 7-inch (17.5-cm) casing was set at 3,300 ft (990 m), and the total depth was 3,430 ft (1,029 m). The well was in use for 20 years until it was replaced by another SWD well in the same section in 1975. When licensed in April 1955, by the Kansas Corporation Commission, the planned maximum capacity was 18,220 barrels of water per day (BWPD). This is the equivalent of an anticipated average of 337 BWPD for each of the 54 wells connected to the system. The daily amount of saltwater introduced is the equivalent 12-1/2 barrels or 530 gallons (2,014 L) of water per minute, illustrating the ability of the Arbuckle dolomite to take large amounts of saltwater by gravity flow. The reason for transporting the produced saltwater nearly 4 mi (6.4 km) was that under the leases served in secs. 2, 3, 10, and 15, T. 14 S., R. 15 W., the Arbuckle dolomite is either thin (under 50 ft [15 m]) or not present. The Reagan Sandstone is thin or absent. In the downfaulted area of sec. 22, T. 14 S., R. 15 W. (fig. 9), where the deep saltwater-disposal wells were located, as much as 400 ft (120 m) of Arbuckle–Reagan sandstone section is present.

The 1957 perspective drawing of the Roubach lease (fig. 41) shows only two wells remaining on that lease. Most of the wells are abandoned on the adjacent Crawford lease, background left. The 17 oil wells remaining in the E/2 sec. 3 (only three are shown in fig. 41) were connected to Sohio's SWD deep-well saltwater-disposal system. The five shallow SWD wells replaced by the system were plugged in 1956. Roubach and Crawford leases were not connected to the saltwater-gathering system.

Fig. 41 shows the presence of the saltwater-evaporating ponds (visible in the 1957 photo), presumably not in use but drying out for future land restoration. All derricks are removed either by wind and weather or in order to make room for the more efficient truck-mounted mobile pulling units to change bottom-hole pumps. The freshwater pond present (center of sketch) at the former location of the twin wells, Crawford No. 12 and Crawford No. 16, is a subsidence feature that later caused problems during the construction of I–70 in 1965–66.

Saltwater disposal, 1960's–1980's

Deep disposal wells continue to be the preferred means of disposing the large volume of saltwater produced from the 550 to 450 stripper oil wells active during these years. Fig. 42 is a photograph of a typical deep saltwater-disposal well installation. The only visible evidence of the presence of a deep SWD well is the large receiving and settling tank often made of redwood and partly buried below ground level to permit gravity flow into the tank. A float valve releases the saltwater that flows by gravity into the well, requiring no pump or other equipment.

With the increase in the price of crude oil in the 1970's and 1980's (fig. 17), there was considerable activity in drilling infill wells on old leases, deepening or re-completing old oil wells, and the increased need for SWD facilities. Some of the 49 additional deep disposal wells were completed by reentry of abandoned oil wells or dry holes and deepening if the old holes had sufficient surface pipe left in place. Cost factors, demand by operators, and expediency caused the licensing of 33 additional shallow Cedar Hills Sandstone SWD wells in these years, bringing the total to 168 shallow SWD wells within the Gorham oil field. The policy of the regulatory agencies is to continue issuing permits for shallow wells disposing oil-field brines in the Cedar Hills Sandstone (except near the sinks affecting I–70), but to encourage operators to use deep Arbuckle SWD wells.

The sketch diagram (fig. 43) illustrates the 1986 situation in the Gorham oil field, where most of the oil wells are plugged and abandoned and the land restored to agriculture. I–70 from east to west across the sketch passes through the Crawford sink area, the subsidence of which is discussed in detail in the following section.

Subsidence

Introduction

I–70 has been subsiding in two areas, 0.5 mi (0.8 km) apart, within the Gorham oil field since construction of the highway in 1965 and 1966. Sinking

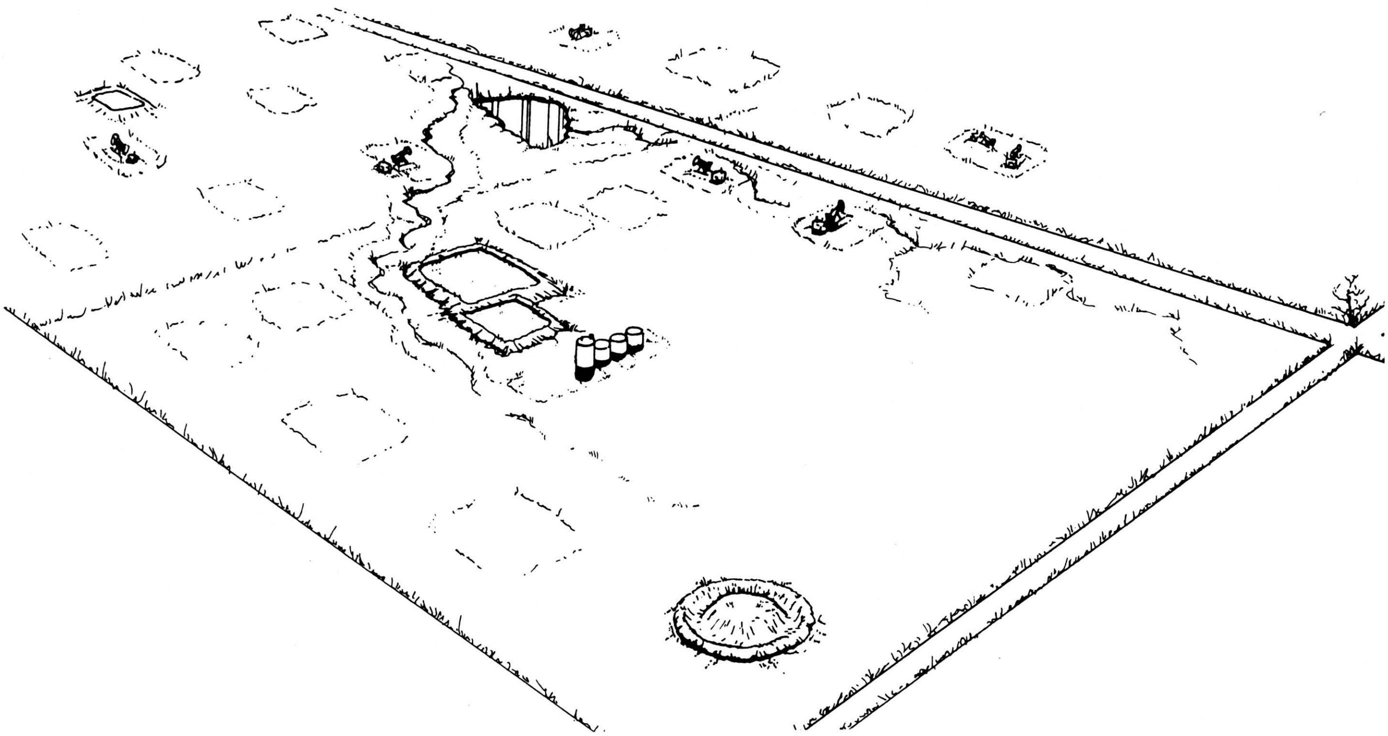


FIGURE 41—ROUBACH LEASE, 1957. The derricks have been removed from the two remaining oil wells. Visible on the aerial photographs and in the sketch are the former brine-evaporation ponds, now dried out, and a new freshwater pond adjacent to the section-line road in the middle distance. The pond, at the site of the former twin oil wells, Crawford No. 12 and Crawford No. 16 (figs. 38 and 45), is the first indication of the "Crawford sink" affecting the future I–70. Sketch by Steve Van Buskirk.

has been slow (less than one foot per year) and is continuing (January 1, 1987). Subsidence to a level dangerous to traffic caused the rebuilding of I–70 in 1971 in both areas and again in 1986 in the west area. A third area is developing 0.5 mi (0.8) further east. It is anticipated that other subsidence areas will develop. The subsidence areas affecting I–70 are located exactly above the Topeka fracture zone described on p. 28–32 and illustrated in fig. 12. The subsidence areas are related to the fracture zone (Walters, 1978, p. 68–73).

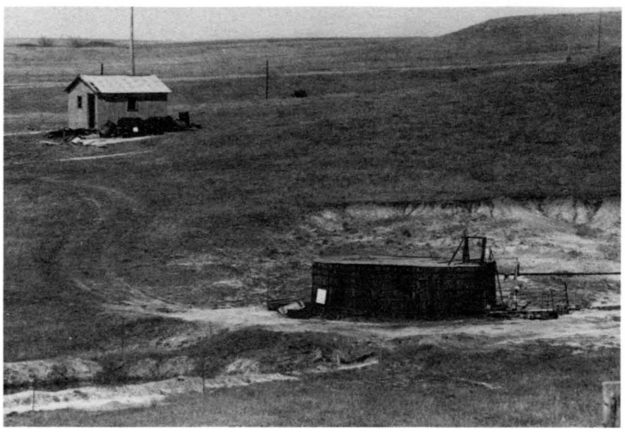


FIGURE 42—Photograph of a deep saltwater-disposal (SWD) installation. Disposal of brine into the Arbuckle formation, depth near 3,400 ft (102 m), is by gravity flow from the brine-storage tank. Courtesy Russell County Historical Society.

History

Burgat and Taylor (1972), geologists with the Kansas Highway Commission during the construction of I–70, published an abstract, "Highway subsidence caused by salt solutioning." They named the subsidence areas "Witt" (west) and "Crawford" (east) after the names used on the adjacent oil leases which in turn were named from the landowners in the 1930's. Fader (1975) and Walters (1978) described the subsidence areas or "sinks." Steeples et al. (1986) published the results of their innovative shallow seismic programs. They employed a "CDP" or common depth point procedure through the subsidence areas in the Gorham oil field by shooting a continuous line along the ditch on the north side of the westbound lane of I–70 through the area pictured in fig. 43. A second seismic line, next described, was recorded south to north along the section-line road with a bridge over I–70, also shown in fig. 43.

North-south seismic section

Fig. 44 is a seismic section furnished by Steeples et al. (1986) from their 1981 CDP seismic work. It is

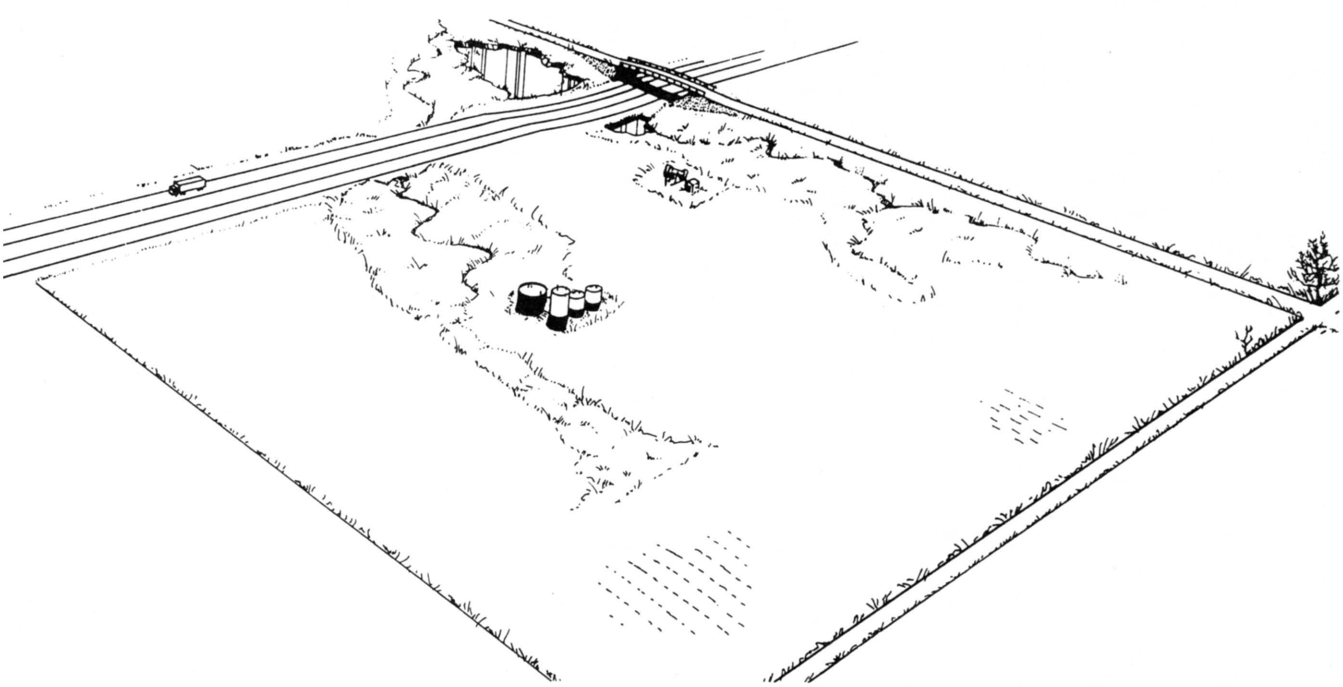


FIGURE 43—Roubach lease, 1986, with one remaining oil well. I–70, constructed in 1965–66, passes through the "Crawford sink." Subsidence affecting both the eastbound and the westbound lanes of I–70 and the bridge have been continuous since construction but at rates declining to 0.5 ft (15 cm) per year in 1986. Sketch by Steve Van Buskirk.

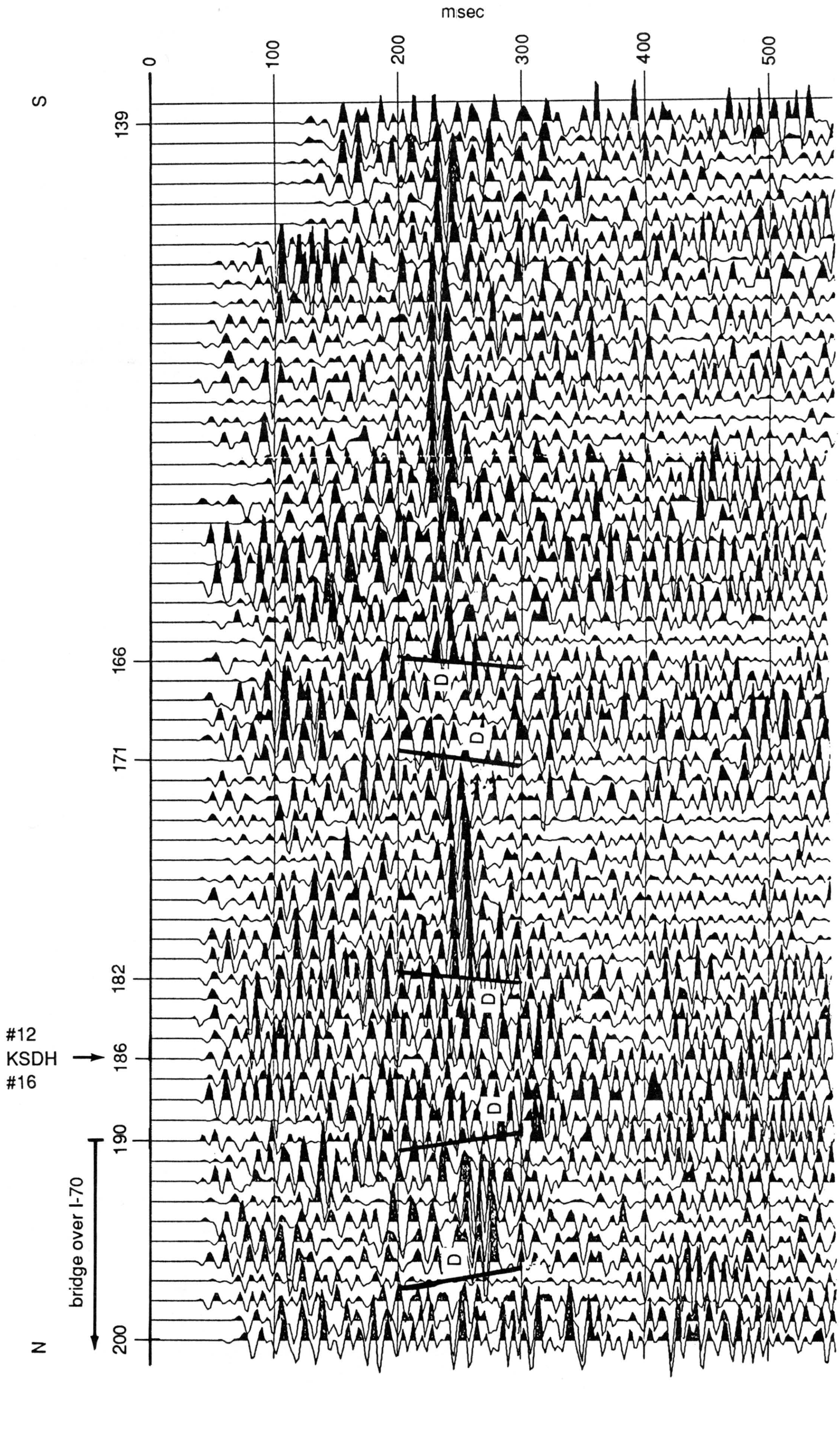


FIGURE 44—NORTH-SOUTH SEISMIC SECTION ALONG THE SECTION-LINE ROAD, south from the bridge shown in fig. 43. The Stone Corral anhydrite (the reflection below the 200 msec travel-time mark) is faulted and downdropped through the Crawford sink. This previously unpublished seismic section was furnished by Steeples et al. (1986).

the south half of their unpublished north-south section. It extends from the north lane of I–70 south for 0.48 km (about 1,600 ft) along the section-line road west of the Crawford sink. Shotpoints, which are numbered from 139 to 200, are spaced at 8-m intervals (about 26 ft). The prominent reflecting bed between 200 and 300 milliseconds, two-way travel time, is the Stone Corral anhydrite. At the south end of the section, shotpoints 139–166, the Stone Corral is undisturbed except for a slight tilt to the north. At shotpoints 166 to 171, the Stone Corral is downfaulted. It is fragmented between the faults. From shotpoint 171 to 182, the Stone Corral anhydrite is downfaulted as a solid unit. In the interval from shotpoints 182 to 190, the Stone Corral is fragmented and dropped. The twin Crawford sinkhole wells, Numbers 16 and 12, with the Kansas State Department of Transportation's test hole between them are projected into the cross section from 330 ft (99 m) east as shown near shotpoint 186. From shotpoint 190 to 200 at the north end of the cross section, two faults, down to the south, have lowered blocks of Stone Corral anhydrite. The 225-ft (67.5-m)-long bridge over highway is built over these fault blocks. The bridge is under torque stress because it has subsided unequally, with the southeast corner lowered the most.

Cross section, I–70

Fig. 45 is a west-to-east cross section along I–70, just over 1 mi (1.6 km) long. It shows what is known about sub-highway conditions for 2,000 ft (600 m) below the pavement. The cross section is based on the CDP seismic work of Steeples et al. (1986) recorded in 1980 as a continuous seismic-reflection survey performed along the north shoulder (westbound) of I–70. Their published seismic sections and their interpretations provide the basis for sketching the position and condition of the Permian Stone Corral anhydrite reflector, usually encountered near a depth of 900 ft unless downdropped by subsidence due to the removal of part of the underlying 300-ft (90-m)-thick Permian salt section present from 1,280 ft to 1,580 ft (384–474 m) where undissolved. Much dissolution of salt has occurred but this is usually not determinable from data recorded on the seismic sections. The partly dissolved salt section in fig. 45 is sketched diagrammatically by Walters. Steeples et al. (1986) were able to delineate the top and bottom of the Hutchinson salt only along that part of the line through the Crawford sink.

Across the top of the diagram are the interpretations of the sub-highway conditions by Steeples et al. (1986). These include 1) currently subsiding areas, the Witt sink, the Crawford sink, and the Roubach sink; 2) stable or competent areas not expected to subside; 3) an extensive broken area that is expected to subside in the future; and 4) an area at the east end of the cross section where subsurface seismic information suggests a future sinkhole not now manifest on the I–70 highway surface. The extensive area that is expected to subside in the future is east of the Witt sink and may become a portion of the Witt subsidence area.

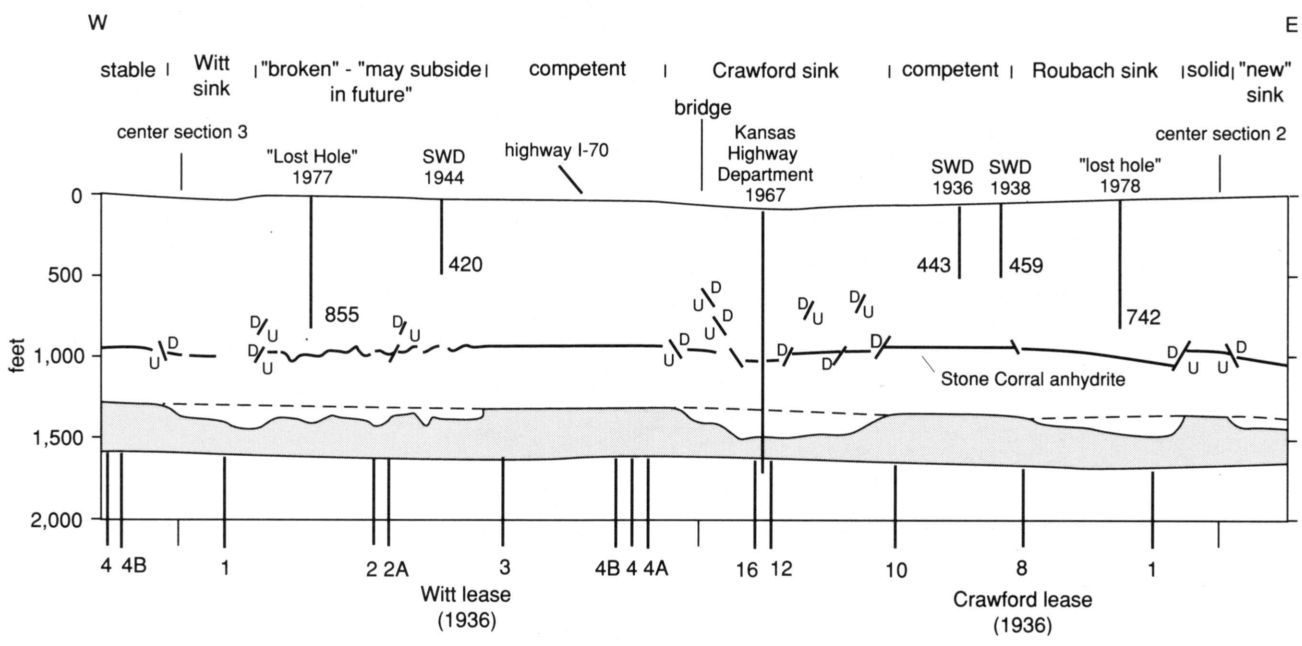


FIGURE 45—Cross section, 1981, along I–70 from west to east through the centers of secs. 3 and 2, T. 14 S., R. 15 W., showing subsurface conditions under I–70. The faulting is based on seismic work by Steeples et al. (1986). Their appraisal of future highway safety is summarized by words across the top of the cross section.

In the upper portion of the cross section above the salt, three post-subsidence test holes and three early shallow SWD wells are projected into the cross section. For clarity none of the many former oil wells is shown in the area above the salt. The positions of the former oil wells adjacent to the south side of I–70 (eastbound) are shown below the salt by well numbers. The faulted condition of the Stone Corral anhydrite is based on the seismic survey. Downfaulted segments overlie areas from which salt has been dissolved by downward-flowing water or undersaturated oil-field brine. Surface subsidence at the Witt, Crawford, and Roubach localities is caused by subsidence of the anhydrite and other underlying rock layers due to the removal of salt by dissolution.

Fig. 46, a restored cross section through the same area as fig. 45, shows subsurface conditions in 1938 before dissolution of the salt section. Land surface on which the highway was built 20 years later in 1956 and 1957 is nearly flat. The Stone Corral anhydrite is unbroken, and the salt section is present in its full thickness of 300 ft (90 m). Surface conditions in 1938 are sketched in fig. 38 and in fig. 47.

Former oil wells; brine conduits or "sewers"

All the subsidence is salt-related and occurs above the salt. There is no disturbance of beds below the salt. The former oil wells were drilled in 1936 and 1937 with cable tools on 10-acre (4-hectare) locations, 660 ft (198 m) apart, with additional twin wells in the Crawford sink, near the Witt sink, and (not shown) within the Roubach sink. Most of these former oil wells are now plugged and abandoned, and often have corroded casing left above, within, and below the salt section. In most bore holes there is no cement or other plugging materials in the interval from the base of the salt to about 3,000 ft (900 m). The uncemented annular spaces outside of the oil-string casings provide conduits for downward-moving water. These former oil wells were the initial brine outlet or "sewer" needed for discharge of the long continued downward flow of freshwater or unsaturated brine across the salt section, thereby causing salt solution and resulting in subsidence. Fader (1975) calculated that an average rate of flow of only 15 gallons per minute (0.95 L/s) for the 30-year period from 1941 to 1970 would account for the salt dissolution causing the surface subsidence at the Crawford sink. He made similar computations for the Witt sink showing that only 5 gallons per minute (0.3 L/s) of water would be needed for 30 years to dissolve the amount of salt equivalent to the volume of the surface subsidence. In making these calculations he assumed that the volume of salt removed is equal to the volume of the subsidence and that the concentration of chloride in the downward-moving water changed from 3,000 to 150,000 ppm as the fluid circulated through the salt at a constant rate for the years 1941–1970.

Fig. 47, by artist Steven Van Buskirk, visualizes the dense drilling in 1 mi^2 (2.6 km^2) of the area. It was drawn from a 1938 vertical air photograph. The view is toward the southwest. The 53 oil wells are marked by 53 derricks; they were erected on the spot in 1935–37 for drilling with cable tools. They were

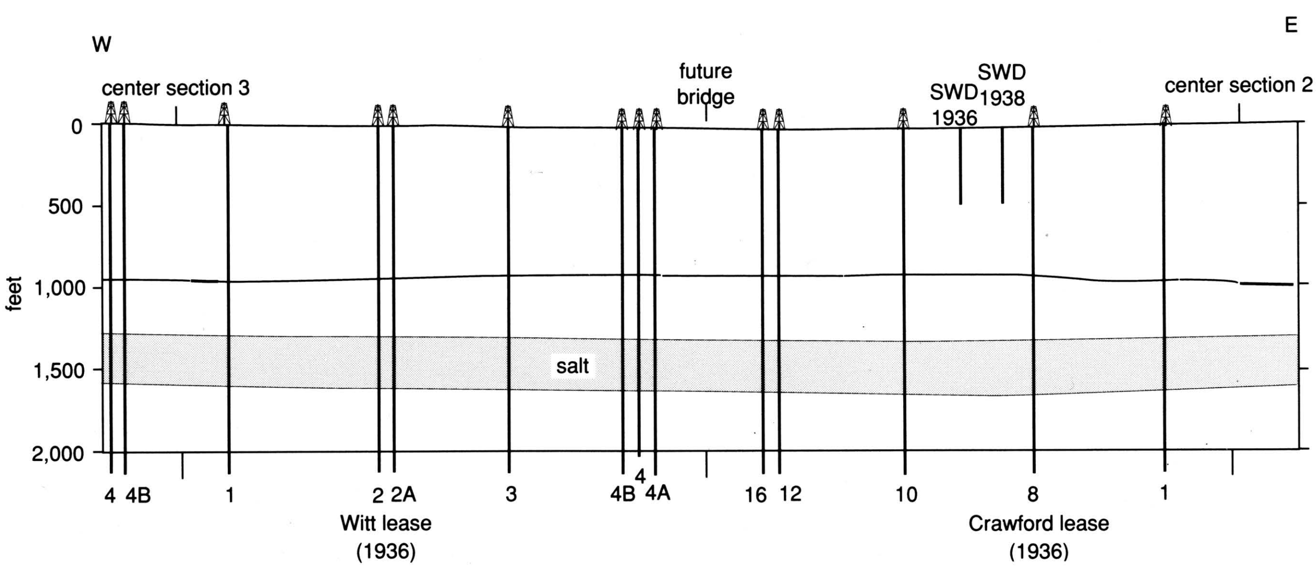


FIGURE 46—Cross section, 1938, along the course of future I–70 as shown in fig. 45. The salt section is undissolved and the overlying rocks are intact and unfaulted. Surface conditions in 1938 are sketched in fig. 38.

then left erect through the years for use as production derricks for pulling rods, tubing, and bottom-hole pumps. The drawing includes the northwest quarter of sec. 2 (nearest), the southwest quarter of sec. 2 (left), the northwest quarter of sec. 3 (right), and the southwest quarter of sec. 3, T. 14 S., R. 15 W. (most distant). I–70 now passes from left to right through the center of the drawing. The future Roubach subsidence area is at the left edge of the drawing; the Crawford in the center (twin oil wells in the northwest quarter of southwest quarter of sec. 2), and the Witt at the extreme right edge of the drawing. Each of these 53 cable-tool-drilled oil wells had oil-string casing originally uncemented for 2,700 ft (810 m) or more from the surface of the ground to the oil pay. Each was a potential conduit for the downward transport of freshwater or unsaturated brine across the face of the 300-ft (90-m) salt section from 1,200 to 1,500 ft (360–450 m) depth. Note the presence of six brine-storage "evaporation" ponds.

Present shallow fracturing or brecciation

Evidence that the rocks in the sinkhole areas of Gorham are extensively fractured is also provided by three unsuccessful oil test holes drilled in or near sink areas in 1977, 1978, and 1981. All three resulted in "lost holes" and had to be abandoned at shallow depths. Two are shown on the cross section (fig. 45) and all three were mapped in fig. 40:

In Witt sink, south of I–70	**In Roubach sink, north of I–70**
H & H Production Inc.	Richard L. Mai
Witt No. 9	Roubach No. 14
70 ft (21 m) south of C N NW SE	C W SE SE NW
sec. 3, T. 14 S., R. 15 W.	sec. 2, T. 14 S., R. 15 W.
Lost circulation @ 400 ft (120 m)	Lost circulation
Lost hole @ 855 TD	Lost hole @ 742 TD
December 1977	November 25, 1978

The third is located a few feet east of the cross section and 330 ft (99 m) south of I–70. It is James A. Bolton Pierce No. 4 in the C N/2 NW SE sec. 2, T. 14 S., R. 15 W. Lost circulation resulted in a lost hole July 7, 1981.

The significance of complete and irrecoverable "lost circulation" in the three recent "lost holes," all close to I–70, is that they indicate that a major fracture system or brecciated area has formed where previously the rocks were solid. This means that for a stretch of about 1,200 ft (360 m) of I–70, between the Witt and Crawford sinkholes, settling and brecciation have occurred below the area of visible subsidence. Near the Roubach sink, which is barely visible on the highway surface, about 850 ft (255 m) of I–70 is similarly underlain by brecciated rock slumped into void space caused by dissolution of salt.

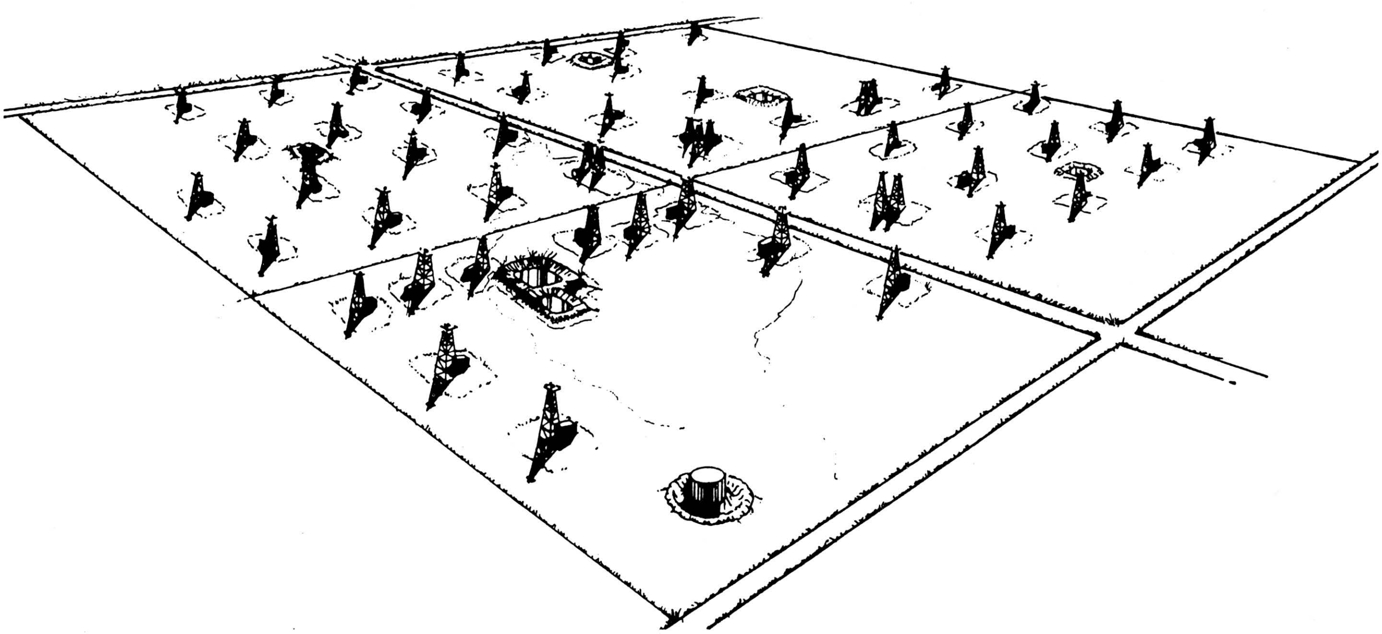


FIGURE 47—Sketch, 1938, W/2 sec. 2 and E/2 sec. 3, T. 14 S., R. 15 W. The Roubach lease is in the foreground. The future I–70 passes from left (east) to right (west) through the center of the drawing. The sketch shows the dense drilling in 1 mi^2 (2.6 km^2) with 53 oil wells marked by production derricks left in place after drilling with cable tools. The future Roubach sink is at the extreme left edge of the drawing, the future Crawford sink is in the center, and the future Witt subsidence area is at the right edge of the drawing. Each quarter section has one or more "evaporation ponds." Sketch by Steve Van Buskirk. View is toward the southwest.

Drilling with rotary tools in highly fractured rocks

When circulation is lost while drilling with rotary tools, it may become difficult, dangerous, or sometimes impossible to continue drilling. The latter condition is cryptically designated as "lost hole," meaning abandonment of the hole. To support the significance of lost circulation and "lost hole" reports for test holes drilled in recent years near the Witt and Crawford sinks, rotary-drilling practices are briefly reviewed.

In rotary drilling, fluid is pumped down the inside of the rotated drill pipe through openings or nozzles in the bit, cooling the bit and flushing cuttings. The fluid, loaded with cuttings, is forced up the annular space between the drill pipe and the wall of the hole. This process is called "circulation." The drilling fluid, called "mud," then flows into a settling pit where the cuttings drop out due to slower velocity through the pit area. Drilling mud consists essentially of freshwater or saltwater with additives to control viscosity, gel strength, weight, and water loss. During routine drilling, the mud is recirculated without appreciable volume loss. Water and additional mudmaking materials are added as the hole depth increases. When circulation is "lost," fluid pumped down the hole does not return to the surface. Usually circulation is regained in a few hours by an addition of fibrous or platy "lost circulation" additives that form a wall cake, plugging off the pore space into which the fluid portion of the mud was infiltrating. This is not effective when systems of larger voids or fractures are encountered.

Large open voids capable of causing a hole to be lost include 1) fracture systems, which are defined as connected cracks of any kind, large or small; 2) faults, which are fractures with movement of one wall relative to the other; and 3) cavernous porosity such as caves in limestone. Drilling into fracture or cavernous porosity can cause immediate and drastic loss of circulation. If the fractures are sufficiently wide and interconnected, called a "reticulated fracture system" or "brecciated area," or if cavernous porosity of large volume is encountered, it may become impossible to stop the loss of circulation. All manner of particulate or fibrous material, including entire hay stacks, have been used in unsuccessful attempts to control this class of lost circulation. With no returns at the surface, the bit may become improperly cooled, cuttings are not flushed away from the drilling surface, and the hole walls may collapse or cave in. Some combination of these factors at times causes stuck drill pipe. These are the conditions described as dangerous to impossible, resulting in the "lost hole" notation on well cards. The presence of three such lost holes along I–70 (and their absence or scarcity elsewhere) is evidence of the collapsed and broken conditions underlying the portions of I–70 that are subsiding or will be subsiding in the future.

Volume of salt dissolved

A 1957 photo shows a pond at the location of the abandoned twin wells, Crawford No. 12 and Crawford No. 16, indicating subsidence. These twin wells encountered the Stone Corral anhydrite at depths of 904 and 901 ft (271 and 270 m) when drilled in 1937. Thirty years later, in August 1967, the Highway Department well drilled between them encountered the anhydrite at 938 ft (281 m) or a drop of 34 ft (10 m). The 1980 seismic work (Steeples et al., 1986) north of the twin well locations at the center of the sinkhole indicates that "approximately 50% of the salt has been dissolved beneath the highway at the point of maximum drop in the Stone Corral. This compares favorably with a 40% dissolution estimate obtained by drilling done by the Highway Department in 1967." One-half of the 280 ft (84 m) of salt drilled in the Crawford No. 16 borehole from 1,265 to 1,545 ft (380–464 m) equals 140 ft (42 m) of salt removed.

At the Witt sink, downdropping of the Stone Corral anhydrite was confirmed on January 12, 1986, on the log of the Witt 1–A drilled by the Kansas Department of Transportation 4 ft (1 m) west of the original Witt No. 1. In the 1986 hole, the Stone Corral was encountered at a depth of 946 ft (284 m), or an elevation of 928.5 ft (279 m) above sea level, compared to its position in the original Witt oil well at an elevation of +969.0 ft (291 m) in 1936. This is a drop of 40.5 ft (12 m). Steeples et al. (1986) comment on the conditions in and adjacent to the Witt subsidence area: "The area to the west of the Witt sink contains competent rock at all depths to well below the salt." To the east, however, for a distance of 400 m (1,320 ft), "The Stone Corral reflections exhibit incoherent or broken-up characteristics," and "may subside in the future." In the Witt sink area, the position and thickness of the salt section cannot be interpreted from the seismic information. However, Don Butcher (personal communication, December 26, 1989), who supervised the 1985–86 drilling of the Witt A–1, stated that "solid salt" was drilled at 1,387 ft (416 m). This is 95 ft (29 m) lower than its position in the original hole. Above the "solid salt" the interval from 1,320 to 1,387 ft (396–416 m) drilled rapidly, is shaly on the gamma log, and was called "washed salt" by Butcher. The author interprets that section as collapsed rubble including some residual partly dissolved salt.

As shown in fig. 45, the Stone Corral is downfaulted under all four sink areas on the east-west cross section (fig. 45) as compared with its original undisturbed position prior to the salt dissolution (fig. 46), but the volume of salt dissolved cannot be measured from the seismic work.

Highway subsidence—amount, rate, trend, and cost

In 1966 the Kansas State Highway Commission initiated a program of regular, precise elevation surveys to the nearest one-hundredth of a foot along the midline of both the eastbound and the westbound lanes of I–70. The successor agency, the Kansas Department of Transportation, continued surveys and furnished data to April 26, 1983. Table 7 in the appendix summarizes subsidence data in the three sinking areas: Witt sink, Crawford sink, and Roubach sink.

Highway subsidence in the Witt sink is shown diagrammatically in fig. 48 with a vertical exaggeration ×100. The time period involved extends from the rebuilding of the highway in the summer of 1971 (after sinking 4 ft [1.2 m]) until April 26, 1983. The sinking of the highway, as shown, created a sag causing a car or truck to suddenly disappear from view of the following vehicle, a hazardous condition. Rain water collected in the sag. Runoff eroded a gulley in the south shoulder. The gulley led directly to the sunken casing of the abandoned oil well Witt #1, where the rain water disappeared down the outside of the casing, presumably causing additional salt dissolution and subsidence. Because of these conditions, it was necessary to rebuild I–70 in 1985 in the vicinity of the Witt sink. During 1985 and continuing into 1986, the Kansas Department of Transportation with the support and advice of the Kansas Corporation Commission and the Kansas Geological Survey undertook a remedial operation to plug off the "sewer," or brine outlet, as a means to prevent future subsidence. A newspaper article from the Wichita *Eagle–Beacon*, January 12, 1986, is reproduced as fig. 49. Don Butcher, geologist with the KCC who was in charge of the drilling project, furnished his final report (personal communication, September 1988). In it he states that the rate of subsidence affecting I–70 in the Witt sink after repair was 0.50 ft (12.5 cm) in 1986 and 0.40 ft (10 cm) in 1987. The cumulative subsidence affecting the eastbound lane at the Witt sink is about 13 ft (3.9 m);

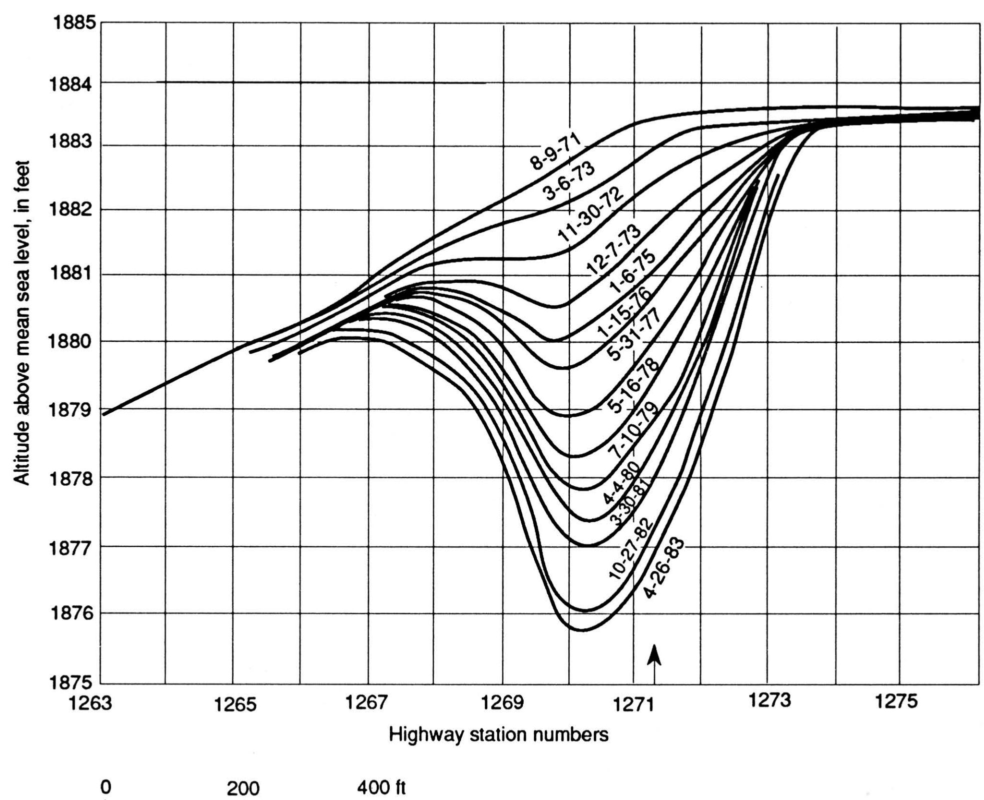


FIGURE 48—Graph of the subsidence at Witt sink, eastbound lane, 1971–1983. Vertical exaggeration ×100. Subsidence measurements are recorded in the appendix, table 7, p. 102. This portion of I–70 was rebuilt in 1985 to the 1971 grade. Data courtesy of the former Kansas State Highway Commission. Arrow shows projected location of twin oil wells.

THE WICHITA EAGLE-BEACON Sunday, January 12, 1986 7B

Sinkhole Solution Proposed

By John Jenks
Staff Writer

Three state agencies are getting ready to pump wet cement 1,800 feet into the ground of north central Kansas to stop the earth from swallowing a 750-foot stretch of I-70.

Without that, the highway, built in 1965 over a sinkhole in western Russell County, will continue dropping about 6 inches a year, said Larry Rockers, chief geologist for the state Department of Transportation.

The highway has sunk about 13 feet since it was built and will sink another 13 feet if nothing is done, Rockers said. That stretch of highway — over the Witt sinkhole — has been regraded twice at a cost of about $650,000 and and is now almost level.

THE STATE also regraded another stretch of I-70 over the Crawford sinkhole — a half mile away — in 1971. The road there has sunk 7 feet since.

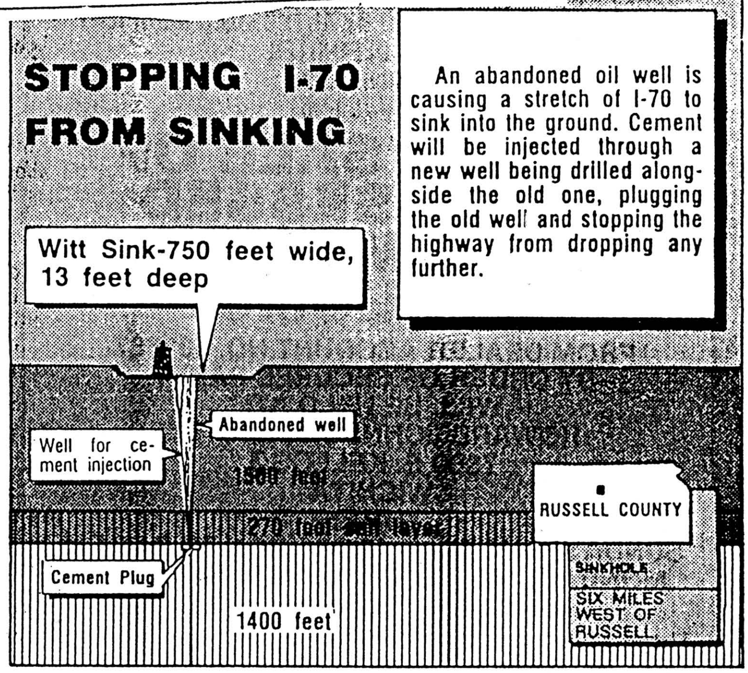
Until now nothing has been done about the root of the problem — abandoned oil well holes near the highway.

Water has been seeping into the well holes since the late 1950s and dissolving chunks of a 270-foot-thick salt bed lying 1,500 feet below the highway, Rockers said. The salt-laden water escapes through the well holes into rock farther below, leaving empty space.

The ground above the salt bed settles, leaving sinkholes on the surface.

WHEN OFFICIALS building the interstate in the 1960s discovered the problems the sinkholes would cause, the highway had already been mapped out and work had begun, Rockers said.

● SINKHOLE, 7B, Col. 1



Alison Kuhn/Staff Artist

Seepage Dissolving Salt Bed Under Road

● SINKHOLE, From 1B

"I think after we got into it we realized that we had gotten into a problem, but we were under construction from both ends," he said. "We just had to go on."

In 1985, the Kansas Corporation Commission, the Kansas Department of Health and Environment and the Kansas Department of Transportation got together and decided to attack the root of the problem for the first time — plugging a well hole that caused the Witt sink.

Don Butcher, who is in charge of the project, said the plug should stop the salt bed from dissolving by blocking the water's escape route. And that should stop the road from sinking any further, he said.

"IF WE get the exit shut off ... we would expect all measureable growth at the surface to stop within the year," Butcher said.

Early last week a crew started drilling a new well about four feet from the abandoned well hole, which is 80 feet away from the highway. When they get to the bottom of the salt layer, they'll pump wet cement through the new well — and into the old well hole — until it's plugged, Butcher said.

Drilling will take at least five more days, Butcher said. He wasn't sure when the cement would be pumped.

He declined to say how much the operation would cost.

HE WON'T know for at least two years whether the project worked, he said. Two similar plugging operations he has done have stopped sinkholes from growing, he said.

The two abandoned wells that caused the nearby Crawford sinkhole — 1,000 feet wide and 13 feet deep — might be candidates for a similar operation if this one works, he said.

"I would hope we would try it on the other one if we were successful," Butcher said.

FIGURE 49—Facsimile of a news item in Wichita *Eagle–Beacon*, Sunday, January 12, 1986, describing remedial work in the Witt subsidence area. Reprinted with permission of the Wichita *Eagle–Beacon*. Copyright January 12, 1986, The Wichita Eagle and Beacon Publishing Company.

at the Crawford sink, about the same amount; at the Roubach less than 1 ft (0.3 m); and at the new sink none.

It is significant that the rate of subsidence is diminishing over the 21-year period for which measurements are available. The average rate of subsidence in the two major sinking areas has declined to less than 0.4/ft per year (or about 5 inches [12.5 cm]). Subsidence rates have declined nearly 50%. This is an encouraging trend.

These seemingly minor amounts of subsidence, measuring only a few inches per year, have cost nearly one million dollars in highway repair, including about $650,000 at the Witt sink in 1985, and $250,000 at the Crawford and Witt sinks in 1971.

While subsidence is continuing (January 1, 1988), there is less cause for concern about safe use of the highway than in the past because the elevation surveys confirm a diminishing rate of subsidence, table 7, p. 102. It is anticipated that slow but not catastrophic subsidence will continue.

Future subsidence along I–70

Future slow subsidence is anticipated along I–70, particularly in the area east of the Witt sink labeled in fig. 45 as "broken—may subside in future." The broken, fragmented condition of the Stone Corral as recorded in the seismic work is similar to the fragmented condition of the Stone Corral beneath the present Witt and Crawford sinks. It is different from the competent areas where the seismic work shows solid, unbroken Stone Corral anhydrite. The presence of a lost hole, depth near 885 ft (266 m), confirms the fractured or brecciated subsurface condition. A second factor contributing to slow subsidence in the future is the continued compaction of the fractured and brecciated rock above and below the Stone Corral anhydrite. A third factor contributing to future slow subsidence of I–70 concerns the Cedar Hills–Cheyenne common aquifer, depths 341 ft to about 600 ft (102–180 m). That common aquifer is over-pressured due to recharge from shallow SWD wells disposing oil-field brines into it in the past and continuing to the present. One shallow SWD well in the future subsidence area, completed in 1944 at a depth of 420 ft (126 m), is shown in fig. 45. The recharged common aquifer is expected to continue discharging downward through the previously used channels, fractures, or improperly plugged well bores, dissolving more salt, causing more slumping, and causing continued slow surface subsidence of I–70 in the area marked "may subside in the future." It is expected that the subsidence will continue to be less than 0.40 ft (10 cm) per year. The salt section is being dissolved from the top, according to drilling evidence and seismic evidence, and not from the bottom or from the mid-part of the salt section as is the case during commercial solution mining of salt. Over a broad area beneath I–70, the resulting void space has spans exceeding the beam strength of the weak shale roof rock that sags into the void almost simultaneously with its formation. The sagging and fallen roof rock, by its own bulking, provides partial roof support limiting upward subsidence to bedding-plane separations in decreasing amounts upward, resulting in surface subsidence measured in inches per year.

Research drilling and coring in other salt-related subsidence areas in Kansas

In 1977 through 1980, research drilling and coring programs were conducted at three salt-related subsidence areas in Hutchinson, Kansas, by the Solution Mining Research Institute, an international organization supported by companies engaged in the commercial mining of salt by solution. The principal investigator was Dr. Alfred J. Hendron, Jr.

The first area in which research test holes, both vertical and inclined, were cored, drilled, and logged was at Cargill, Inc., south of the plant, in a large, 90,000-yd^3 (68,400-m^3) subsidence area. The surface expression formed in three days in October 1974 (Hendron et al., 1977) and (Walters, 1978). The second area of research coring was also at Cargill Inc., but north of the plant where 26 years of slow subsidence at a rate of a few inches a year involved the driveway, parking area, loading dock, and plant warehouse (Hendron et al., 1979a). The third area of vertical and inclined drilling and coring was at the Carey Salt Co. brine field, where two small related subsidence areas 700 ft (210 m) apart formed in three days in June 1978 (Hendron et al., 1980, 1983) and (Walters, 1979). From these field investigations, Hendron et al. (1979b) reached general conclusions that rock mechanisms resulting in surface sinkholes involved 1) broad unsupported spans, 2) a large salt cavity, 3) a trigger mechanism such as brine-pressure change or removal of critical roof support by continuing salt dissolution, and 4) in situ stress conditions in the roof rocks. They concluded that where all four conditions are present in proper proportions, deep sinkholes are likely to develop at the surface in very short periods of time (8–20 hours). If only the first and third conditions are present, shallow sinkholes are likely to develop slowly on the ground surface. Their depth and lateral extent tend to increase in a time span of years. The situation at I–70 in the Gorham oil field fits well with their criteria for slow shallow, long-continued surface subsidence.

Subsidence at a deep saltwater-disposal well

Subsidence in another portion of the Gorham oil field occurred around a deep SWD well in 1982. The area around the well was lowered 9 ft (2.7 m). A large saltwater settling tank was tilted inward toward the well. The location, in the NE SW SE sec. 32, T. 14 S., R. 14 W., is in a flat field sloping slightly to the north. The field is underlain by alluvium deposited on the Pleistocene floodplain of the Smoky Hill River, 0.5 mi (0.8 km) northwest. The subsidence area, centered around the former SWD well, was 600 ft (180 m) in diameter and circular. Because the SWD well was located 1,650 ft (495 m) west and 990 ft (297 m) north of roads along the east and south sides of sec. 32, there is no surface damage other than to the SWD well itself and to the tilted tank.

The SWD well, the Billings No. 1, drilled into Arbuckle dolomite at 3,180 (-1,453) ft (954 m) in 1953 with 5-1/2-inch (13.75-cm) casing set at 3,235 ft (971 m). Under a permit from KCC, oil-field brines were disposed into the Arbuckle and Reagan sand from 3,235 to 3,370 ft TD (970–1,011 m). Precambrian basement is estimated to be near 3,405 ft (1,022 m).

The Kansas Geological Survey surveyed a west-to-east surface-elevation profile (Don Steeples, personal communication, 1982) on September 15, 1982, as part of a gravity survey. The survey stakes were still in place October 1, 1982, when the author visited the location. The results of the limited gravity survey were inconclusive. In order to properly plug the well to protect the freshwater aquifer in the alluvium, it was necessary to construct a ramp into the sink area and to drill a hole close to the slumped 5-1/2-inch (13.75-cm) casing of the SWD well. Don Butcher, who supervised the plugging (personal communication, 1988), stated that coarse alluvial sand which downdropped as a result of the subsidence was still being encountered at 300 ft (90 m), the total depth of the relief hole into which cement was pumped. The saltwater-disposal well has been plugged, the location leveled, and the field restored to agriculture.

Although there are 49 deep SWD wells in the Gorham oil field (fig. 2), no other subsidence areas were reported as of January 1, 1987.

Conclusion—subsidence areas

The subsidence around the Billings No. 1 SWD well and the subsidence areas described as affecting I–70 are adverse environmental consequences of the development of the 60-year-old Gorham oil field.

Agriculture

Impact of the Gorham oil field on agriculture

Much of the 50 mi^2 (130 km^2) within the official boundary of the Gorham oil field is agricultural land largely devoted to growing wheat. The oil-field boundaries are defined in the index map (fig. 3) and in fig. 50, the map of active oil wells as of October 1986. No map is included specifically showing agricultural lands, but fig. 16, the map of the Fence-post limestone, provides an approximation. In the northern part of that map, heavy outcrop lines in a continuous crinkled pattern mark the change from canyon country, largely pasture, on the north to fairly flat farmland on the south. In the extreme southwest portion of the map, the Fence-post limestone crops out in an area of gentle hills. Much of the farmland within the Gorham oil field is a fairly flat but dissected plain or is part of the valleys of Big Creek and the Smoky Hill River.

During the many years of drilling, completion, redrilling, and production of oil there was considerable interference with normal farming operations. With the plugging of many old holes, the area is being restored to agriculture. A person driving along I–70 or on any of the section-line roads sees but infrequent reminders of the once-extensive oil field. Even though 444 oil wells were still active in October 1986, as mapped in fig. 50, there are large areas where a tourist would not know there had been oil production. Gone are the derricks, once the symbols of an oil field. Gone too, are most of the tank batteries and the roads leading to them and to the many now-abandoned oil wells.

When the land is viewed on a more detailed scale, many areas of an acre or two are damaged. Land on which tank batteries were formerly located may have an accumulation of oily bottom sediment dumped when cleaning oil-storage tanks. Former lease roads, even after they are ripped up, may be more compacted than the surrounding field. Metallic junk left in weed patches or buried under a shallow cover of soil is a hazard for farm equipment. In a few areas of remote pasture, the four cement derrick foundation blocks have been left in place since the wells were abandoned 30 years ago. Examples of unremoved derrick foundation blocks occur along the south line of sec. 10 and the north line of the adjacent sec. 15, T. 14 S., R. 15 W., where the road between the two sections is closed and there is access only by private road.

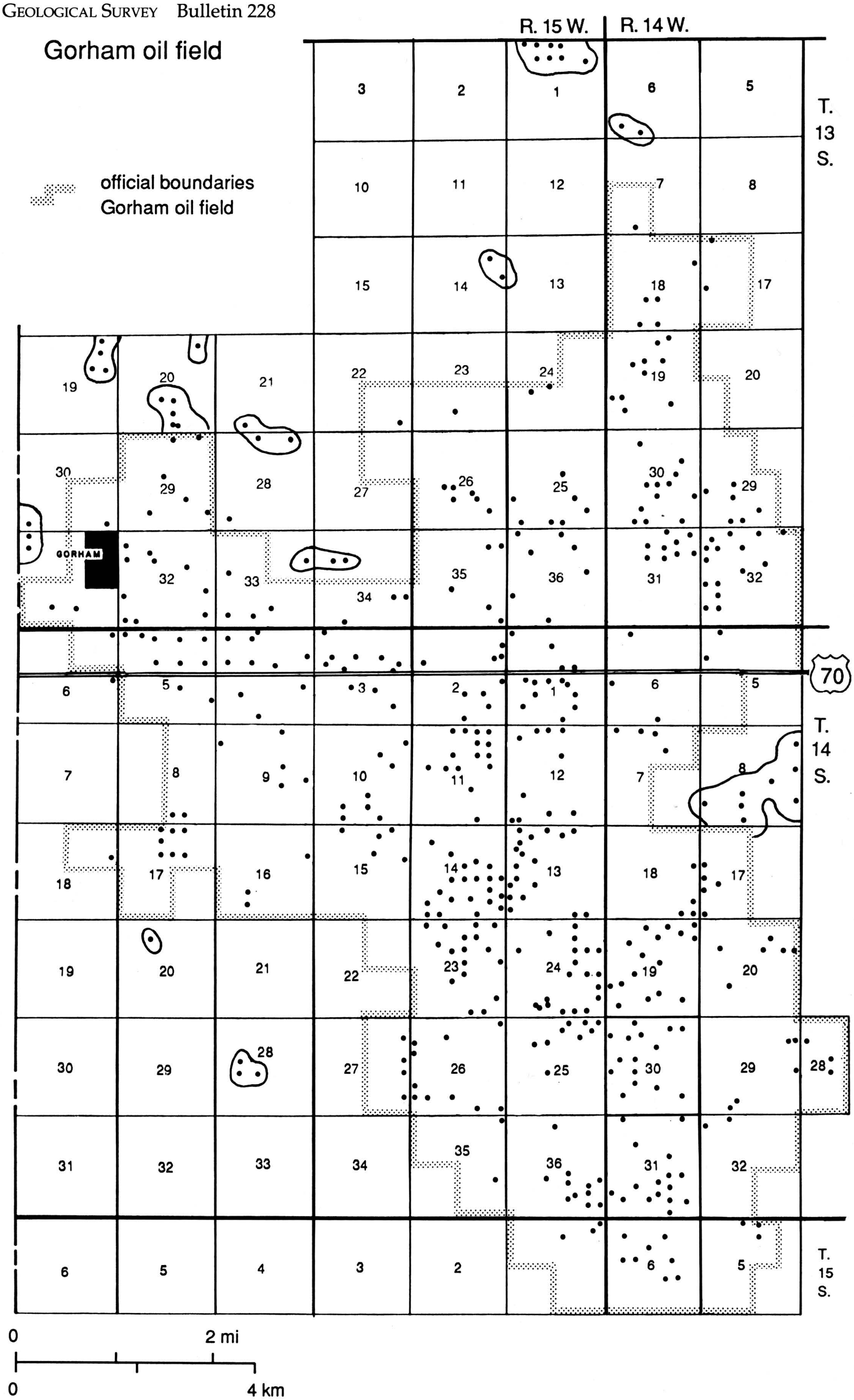


FIGURE 50—Map of the Gorham oil field, 1986, showing the location of the 444 remaining active oil wells as of December 31, 1986. Compare with oil-field map, fig. 2, p. 3.

The quantitative impact of the formerly more extensive Gorham oil field on agriculture has not been investigated as a part of this study. Four U.S. Geological Survey 7-1/2-minute topographic maps surveyed in 1961, contour interval 10 ft, scale 1:24,000, are available. They are the Gorham, Russell Northwest, Walker, and Russell Southwest quadrangles. Detailed large-scale air photographs which are used by government agencies in quantitative assessment work, were reviewed. These detailed maps or photomosaics are available as blueline prints, scale 1 inch = 400 ft. Each section (square mile) is a little more than 13 inches square. They show each building, road, trail, oil well, pit, etc. The date of the photography is February 1986. Also available are soil-survey maps, scale 1:20,000, compiled from 1981 photographs (Jantz et al., 1982).

One concern regarding agriculture was the extensive use of unlined earthen pits during drilling operations through the 60 years of the Gorham oil field. In this connection, the 1,827 deep test holes drilled for oil and gas and the 168 shallow SWD wells had one or more pits for water storage during drilling and for accumulation of well cuttings. These were unlined earthen pits, filled only once for time periods of days or weeks, causing minimal salt contamination. No steel tanks were used for pits as is required in some urban areas. Almost all these former pits were filled in order to not interfere with later farming operations. To be properly filled, a pit needs to be left until absolutely dry, which may take half a year, then filled with dry material. Oil-field operators know this and follow this procedure. Occasionally landowners become impatient and demand immediate filling of pits. When such pits are filled while still wet, they can remain a hazard for years with tractors used in farming operations sinking into them.

The extensive shallow saltwater-evaporation ponds in use in the 1930's and 1940's have been filled and leveled. They have more impact on agriculture than the pits used for drilling with rotary tools or the single pit into which cable-tool well cuttings were dumped. Evaporation ponds were filled and then refilled over periods of months to years and decades, accumulating concentrations of residual salts. Evaporation of water from those extensive evaporation ponds did not decrease the potential contamination of aquifers or soils because the dissolved salts remained after evaporation of water, either dissolved in more concentrated brines, or, with complete evaporation, as salt crusts. In addition, from time to time rain water redissolved the salts. The resulting brine either ran off or infiltrated as ground water. Where the now-filled abandoned ponds have residual salts buried within reach of plant root systems, crop production is impaired. The residual salts are drawn to the surface in drought years or flushed deeper in wet years. They adversely affect growing crops for long time periods. For example, the area of the former twin saltwater ponds on the much cited Roubach lease, the NW sec. 2, T. 14 S., R. 15 W., is now a salty waste land.

Summary—environmental impact of the Gorham oil field

The environmental impact of the Gorham oil field was not measured quantitatively. The area is being restored to agriculture with pits filled, tank battery dikes leveled, and lease roads ripped up, but areas of one acre or more that were sites of former "evaporation ponds" are damaged by increased salinity of the soil. In addition there is some local saline pollution of former freshwater aquifers and continued costly slow subsidence of I–70. Less environmental damage was due to the mishandling of crude oil, a valued product, than was due to mishandling of saltwater, a waste product. The production of almost 100 million barrels of crude oil, and perhaps 10 times that volume of associated brine, has unfavorably affected the 50-mi^2 (150-km^2) area of the Gorham oil field. Rigorous regulation by the Kansas Corporation Commission is being directed toward minimizing future adverse environmental impact on the area due to oil-field operations in the nearly depleted Gorham oil field.

Summary

The Gorham oil field from which nearly 100 million barrels of oil have been produced, is representative of central Kansas giant oil fields in Russell, Barton, and Rice counties. All produce oil prolifically from the Arbuckle and Lansing–Kansas City carbonate rocks at the relatively shallow depths of 3,000–3,300 ft (900–990 m) from closely spaced oil wells, 660 ft (198 m) apart, on a regular spacing pattern of 10 acres (4 hectares) per well. In the Gorham oil field, an estimated 66% of the cumulative oil production came from the Arbuckle dolomite or related Cambrian Reagan Sandstone. The unconformity surface at the top of the Arbuckle reservoir, depth near 3,300 ft (990 m), is a buried paleo-land surface characterized by paleo-karst topography with solution moats around three buried Precambrian hills, with solution-enhanced porosity on a scalped paleo-karst plain, but with only a few residuum-filled sinkholes. About 25% of the oil was produced from limestones of the Pennsylvanian Lansing–Kansas City group, depths just below 3,000 ft (900 m). An estimated 7% of the oil was produced from 30 Pennsylvanian Shawnee "Topeka" wells of large capacity, depths near 2,750 ft (825 m), that flowed spectacularly in 1935 from an intermittent fracture zone 5 mi (8 km) long. Analogous fracture zones are present in Ordovician rocks in the upper Mississippi Valley lead and zinc district, Wisconsin. About 100 oil wells produced shallow, stratigraphically trapped oil from "Tarkio" silty sandstones of Pennsylvanian age, depth near 2,500 ft (750 m). A minor amount of oil was produced from fractures in Precambrian quartzite in nine wells and from fractures in fresh granite in six wells.

The Gorham oil field is localized by a 10-mi (16-km)-long northwest-southeast-trending anticline structurally controlled by block faulting in the Precambrian basement rocks. A prominent fault zone on the southwest flank of the Gorham anticline is downthrown over 400 ft (120 m) to the southwest on the Precambrian rocks. There is structural relief of 150 ft (45 m) on the pre-Pennsylvanian unconformity or buried land surface, 75 ft (22.5 m) of relief on the Lansing–Kansas City limestones that are draped over the major anticline and over local highs, and 50 ft (15 m) of relief on the Permian Stone Corral anhydrite, depth near 1,000 ft (300 m). The near-surface Cretaceous Fence-post limestone is folded in an anticline with 30 ft (9 m) of closure directly over the position of the fault zone in the Precambrian rocks. This demonstrates the structural control of the Gorham anticline due to episodic block faulting in the Precambrian granite basement rocks. In one well the granite was dated as 1,505 million years old.

Within the trap formed by the broad Gorham anticline, the Arbuckle dolomite and Reagan Sandstone were a single oil reservoir over a 50-mi^2 (130-km^2) area with a strong water drive and an original oil-water contact near subsea –1,440 ft (–432 m), now much distorted by fluid withdrawal. Oil production from the 829 Arbuckle oil wells averaged 55,000 barrels of oil (BO) per well. The 215 Reagan Sandstone wells averaged 88,000 BO per well. The overlying Lansing–Kansas City limestones provide oil reservoirs in several separate local closures, each an individual oil accumulation with a dissolved gas drive for energy. The 477 Lansing–Kansas City oil wells recovered an estimated average of 50,000 BO per well of which one-third is attributed to secondary recovery by water flooding. Wells producing from the Topeka fracture zone averaged over 200,000 BO per well. Two giant Topeka fracture-zone oil wells are known to have produced over one-half million barrels of oil each, from depths near 2,750 ft (825 m). Shallow Tarkio oil wells from depths near 2,500 ft (750 m) are considered as averaging about 8,000 BO per well. Production figures are for a 60-year period from October 15, 1926, to December 31, 1986.

The petroleum geology of the Gorham oil field was investigated by the author's examination of well cuttings from more than 300 bore holes, many of which were drilled with cable tools in the 1920's and the 1930's, providing samples from which acid insoluble residues could be prepared. Examination of the original well-cutting samples and of their insoluble residues permitted the recognition of six mappable units within the Arbuckle–Reagan section, 400 ft (120 m) thick. Sample examination also permitted subdividing the unconformity-related sandstone, called "Gorham sand" locally, into five recognizable mappable units of differing ages and reservoir characteristics.

The oil produced from the unconformity-related Cambrian and Ordovician Arbuckle–Reagan Sandstone reservoir migrated long distances from Oklahoma into central Kansas in mid-Permian time and filled that unit reservoir to its spillpoint. The Gorham anticline trapped hydrocarbons in all porous formations and fractures below the Permian Wellington salt encountered from 1,300 to 1,600 ft (390–480 m). The salt, together with the shales below and above it, served as a seal preventing further upward movement of hydrocarbons or downward movement of brines until the salt section was pen-

etrated by the 2,168 oil and gas test holes within the 100-mi^2 (260-km^2) study area.

The Gorham oil field, discovered in 1926, is the second oldest oil field in the west ranges of Kansas, and was then 120 mi (192 km) west of the nearest oil production except for the Fairport oil field, 10 mi (16 km) north, discovered in 1923. The drilling and development history of the Gorham oil field is described at length with illustrations of cable-tool drilling rigs, derricks, and early automobiles. The obsolete method of full-hole cable-tool drilling was used exclusively in the Gorham oil field during development in the 1920's and into the 1930's, and was still used for part of the drilling during World War II years of the early 1940's. Cable-tool drilling is done by suspending a heavy bit from a cable and drilling the rock by pounding on it. An advantage of cable-tool drilling is that when oil is "struck," it enters the air-filled hole and is immediately detected and measured by the drillers. Geologists were not needed at drilling locations but were involved in surface mapping of anticlines or working with "core drilling machines" such as that used by Tom Allan to discover the Gorham oil field in 1923–25, probably the first such application in the midcontinent United States. Disadvantages of cable tools include the fact that when flowing gas and oil are encountered, an uncontrolled blowout may occur as illustrated by the much-photographed early "gushers." A second disadvantage was that when oil was "struck" (found), drilling had to be discontinued without knowledge of deeper, more prolific pay zones.

After the 1940's, all drilling was done with the faster and cost-efficient "mobile" rotary-drilling tools with a folding "jack-knife" mast in place of a derrick. In rotary drilling, a bit on the end of the drill pipe is rotated, chipping the rocks. The cuttings are removed by circulating drilling fluid or "mud" through the bit. This completely changed the role of geologists who became indispensable at well sites to detect oil shows in samples of well cuttings and to determine the depth at which the production casing should be set.

Another aspect of the Gorham oil-field history is the handling or mishandling of increasingly large volumes of brine produced along with the oil, principally from the Arbuckle reservoir. In the 1920's, the produced brine was dumped into the waterways. In the 1930's, brine was required to be stored in "evaporation ponds" throughout the oil field. In 1957, this practice was no longer allowed. In the 1940's, shallow saltwater-disposal wells, depths near 500 ft (150 m) in the Cretaceous Cheyenne Sandstone or near 800 ft (240 m) in the Permian Cedar Hills Sandstone were licensed. During the 1950's, in the stripper stage of the oil-field's production history, the wells pumped 90% or more of saltwater. The shallow saltwater-disposal wells and the evaporation ponds could not dispose all the produced brine. Systems of gathering lines were built and brine was transported 4 mi (6.4 km) south, where it was disposed in deep saltwater-disposal wells utilizing the full downfaulted 400-ft (120-m) thickness of the Arbuckle dolomite for brine disposal.

On January 1, 1987, there were 444 producing oil wells in the Gorham oil field, but production had declined to an average of 3.21 BO per day per well. The 60 years of continuous production of nearly 100 million barrels of oil and perhaps nine times that amount of saltwater adversely affected the environment in three ways.

1) Near-surface freshwater aquifers, the alluvium and the Dakota sandstones, have in some parts of the Gorham oil field become unusable because of contamination by saline oil-field brines. This saline pollution was caused by downward seepage of brine from the formerly used surface-evaporation ponds and by the upward movement of disposed brine from the shallow saltwater-disposal wells, many of which were still in use in 1986.

2) Subsidence of three areas along 1 mi (1.6 km) of I–70 within the Gorham oil field has entailed repair expenses of about one million dollars. Subsidence, beginning at the time of construction of the highway in 1965–66 and continuing through 1986 is caused by the dissolving of large volumes of salt due to inadvertent downward movement of undersaturated oil-field brines being disposed in saltwater-disposal wells, some with unknown corroded leaky casing. Subsidence is expected to continue in the future, but the rate of subsidence is declining and was a maximum of only 0.5 ft (0.15 m) per year in 1986.

3) Within the Gorham oil field, agricultural land has been damaged by increased salinity of the soil in areas of one acre or more that were sites of former "evaporation ponds."

Land is being restored to agriculture with pits properly filled, tank battery dikes levelled, and with lease roads ripped up. There are large areas within the Gorham oil field where a person driving along I–70 or on any of the section-line roads will see but infrequent reminders of the once-extensive oil field. Rigorous regulation by the Kansas Corporation Commission of waste oil-field brine disposal, of plugging abandoned wells, and of protection of fresh or usable water is minimizing future adverse environmental impact due to oil-field operations in the nearly depleted Gorham oil field.

Acknowledgments

The author accepts full responsibility for the investigations and conclusions of this report but acknowledges the indispensable help of the following, whom he thanks.

Pieter Berendsen, Don W. Steeples, W. Lynn Watney, and Don Whittemore each critically reviewed that portion of the text within his own field of specialty and expertise. Each contributed helpful and constructive criticism regarding respectively, Precambrian rocks, seismic and subsidence, stratigraphy, and hydrology.

Rex Buchanan, Don Butcher, William W. Hambleton, W. Lynn Watney, and Frank Wilson helpfully reviewed the entire text. In addition, Rex Buchanan suggested improved captions for the 50 illustrations.

Ralph W. Knapp, Don W. Steeples, Richard D. Miller, and Carl D. McElwee contributed their unpublished seismic cross section (1986) reproduced as fig. 44.

The Russell County Historical Society furnished photographs used in the history section, as individually acknowledged. These include the cover photograph and figs. 19, 20, 22, 23, 28, 29, and 31.

Craig Miner made available the Hartman family scrapbooks containing contemporary newspaper accounts of the spectacular Hartman and Blair Roubach No. 1 that "struck oil" in 1935.

The Kansas Independent Oil and Gas Association (KIOGA) allowed reproduction of photographs from their 1987 publication *Discovery* (Miner, 1987), here reproduced as figs. 21, 24, 28 (the inset of the collapsed derrick), 32, 33, 34, and 42.

Charles Steincamp furnished the photograph of the oil-field fire (fig. 36). He also contributed information concerning the Topeka fracture zone from his well-site experience.

Albert Abercrombie talked freely, vividly, and often with the author concerning his years of work in 1944–48 in the Gorham oil field as assistant field foreman repairing casing leaks and reworking wells on the Nate Appleman's Central Petroleum Company properties and the Anthony Witt properties after they were purchased by Standard Oil Company of Ohio.

Tom Allan (deceased 1985), a resident of Russell, Kansas, from 1923 to 1933, furnished the original core-drill map used in the discovery of the Gorham oil field (redrafted as fig. 16). He verified the identification of photographs of his "core-drilling machine" (fig. 22).

Jene C. Darmstetter furnished oil-field maps of historical interest from his personal file. These showed early development drilling within the Gorham oil field.

Larry H. Skelton furnished the 1936 historical map (fig. 37) and made helpful suggestions regarding history, oil production, and records of secondary recovery.

Robert Frensley furnished information on secondary recovery by waterflooding in the Gorham oil field, based on his personal experience as a consultant when waterflood projects were in the planning stage.

Virgil B. Cole (deceased 1984), an expert on mapping Cretaceous beds, shared his knowledge of the development of the Gorham oil field in the 1930's, during the time that he and the author worked in the same office in 1940–41. In the 1970's, he provided first-hand knowledge of past events such as the drilling of carefully watched holes (dry in Topeka zone) offsetting the spectacular Roubach No. 1 in 1935. He had a vivid memory for field developments, with almost total recall of location by section, township, and range, and of formation depths and dates. He shared his experiences through frequent conversations. In addition, he was an expert on wells drilled to the Precambrian basement rocks (Cole, 1962, 1976).

Don Butcher, who was in charge of the 1985–86 repair work at the Witt sink under I–70, furnished a copy of his January 1986 final report on the project. In addition, his concise comments as a peer reviewer, based on his years of practical field experience supervising the plugging of dry holes and oil wells, were most helpful. For example, in reviewing the original brief section concerning future subsidence affecting I–70, he made a cryptic marginal comment, "You should describe why you think this will subside." His comment led to a restatement and expansion of that section and to the addition of the section "Research drilling and coring in other salt-related subsidence areas in Kansas."

Jack H. Heathman, my long-term business associate, provided enthusiastic encouragement over the years. Moreover, in 1955 he financed and drilled two unsuccessful holes in the Gorham oil field based on my effort to extend the Reagan Sandstone oil production. We drilled the wrong spot (by 660 feet) and were 10 years too late for primary production from the then-depleted Lansing–Kansas City formation and 10 years too early for the successful waterflood (Bass, 1966) on our formerly owned leases.

Heber–Beardmore furnished historical lease ownership maps for the Gorham area and shared some of his experiences with the cable tools owned by the former Beardmore Drilling Company.

Steve Van Buskirk, artist and geologist, used the available poor-quality old photographs as a basis for his sketches, figs. 38, 39, 41, 43, and 53. He also assisted in compiling the geological maps, figs. 7, 9, 10, 11, and 12 which required careful distinction among the five various oil-production zones.

Jim Harden, consulting geologist, Hays, Kansas, provided blueline prints of the land in the Gorham oil field, scale 1 inch equals 400 ft, or 1 mile equals 13.2 inches. He also provided helpful information on local developments.

The Kansas Geological Society Library, Wichita, Kansas, loaned the material photographed in figs. 26 a and b, and loaned the four original plotted drillers' logs from which fig. 27 was constructed.

As background concerning the "personal communication" items dating back to the 1970's, it was then that the author completed investigations of human-induced land subsidence in central Kansas related to salt dissolution (Walters, 1978). To understand the cause of subsidence affecting I–70, it was necessary to understand not only the geology but also the oil-field history of the Gorham oil field; short excerpts of both, as they directly affected subsidence, were summarized in that report. Dr. William W. Hambleton, then Director of the Kansas Geological Survey, encouraged the preservation of my accumulated data and knowledge by the inclusion in this publication of historical and environmental chapters not usually part of oil-field geological reports. Without Dr. Hambleton's persistent, patient, long-continued support, this report would not have been completed. His successor, Dr. Lee C. Gerhard, gave added impetus during 1989, the year of centennial celebration for the Kansas Geological Survey, by approving publication of the illustrations of oil derricks, cable-tool drilling rigs, old automobiles, and historic maps included in the section "Oil-field history."

Appendix

Tables 1–5, 7, and 8

(follows)

TABLE 1—List of discovery wells; oil fields now merged into Gorham oil field. Locations are mapped in fig. 3.

Field and discovery date	Discovery well and producing horizon (italic)	Location
Atherton July 21, 1935	McMorrow et al., Atherton #1 *Arbuckle*	30–13S–14W NW NW NE
Atherton North May 27, 1939	Cities Service Oil Co. Dutt #1 *Arbuckle*	18–13S–14W NW NW SE
Atherton Oswald October 10, 1935	Phillips Petroleum Downing #1 *"Oswald"*	19–13S–14W SE SE SW
Atherton South June 25, 1936	Shell Petroleum Brown #1 *Arbuckle*	31–13S–14W NE NE SE
Atherton West December 28, 1945	Coralena Olson #1 *Arbuckle*	23–13S–15W C S/2 SE SE
Balta February 18, 1936	Hartman and Blair Boxberger #1 *"Oswald"; later August 12, 1936, deepened to Arbuckle*	32–13S–14W NW NW SW
Balta Arbuckle June 11, 1936	Empire Oil and Refining Co. Boxberger #1 *Arbuckle*	32–13S–14W SW SW NW
Balta North July 27, 1938	Phillips Petroleum Co. Miller #1 *Arbuckle*	29–13S–14W C NW SW
Benso January 25, 1936	Central Petroleum Co. Benso #1 *Lansing–Kansas City*	9–14S–15W SE SE SW
Big Creek July 6, 1935	Hartman and Blair Rexroat #1 *Arbuckle*	31–14S–14W NE NW NW
Big Creek East July 12, 1938	Aylward Productin Co. Solbach #1 *Arbuckle*	31–14S–14W SE SE NE
Big Creek Oswald December 31, 1935	Phillips Petroleum Co. Hall #1 *"Oswald"*	36–14S–15W SE NE SW
Cook June 23, 1950	H. H. Blair Cook #2 *Lansing–Kansas City*	26–13S–15W NW NW SE
Cook Arbuckle January 31, 1951	H. H. Blair Cook #3 *Arbuckle*	26–13S–15W SW NW SE
Cramm July 31, 1935	J. C. Shaffer Cramm #1 *Arbuckle*	11–14S–15W NE NE SE
Dillner May 5, 1930	Empire Oil and Refining Co. Dillner #1 *Arbuckle*	36–13S–15W NW NW NW
Dillner Northwest December 16, 1947	Kissinger Billings #C–1 *Arbuckle*	27–13S–15W NE NE NE
Foster March 3, 1936	Central Petroleum Co. Foster #B–1 *"Oswald"*	3–14S–15W SW SW NE

TABLE 1 (continued)—LIST OF DISCOVERY WELLS.

Field and discovery date	Discovery well and producing horizon (italic)	Location
Gorham October 15, 1926	Mid–West Refining Co. Dortland #36 *"Oswald"*	5–14S–15W SE SE NW
Gorham Council Grove November 5, 1935	Hartman–Blair et al. Roubach #3 *Neva*	2–14S–15W NE SE NW
Gorham East September 18, 1935	Bridgeport Machine Co. Polson #1 *Lansing–Kansas City*	10–14S–15W NW NW NE
Gorham–Gorham Sand January 28, 1928	Stearns and Streeter Mermis #1 *Gorham sand*	33–13S–15W SW NW SW
Gorham Pool #2 December 12, 1985	Shields Oil Producers Inc. #1 Crawford "A" *Lansing–Kansas City*	16–14S–15W NW SE SW
Gorham Reagan January 12, 1984	Ladd Petroleum Reinhardt "A"–4 *"Reagan sand"*	19–14S–14W C W/2 NE NW NE
Gorham Shawnee April 23, 1935	Hartman–Blair Roubach #1 *Shawnee, Topeka*	2–14S–15W SE SE NW
Gorham Wabaunsee July 10, 1935	Gypsy Oil Co. Ehrlich #1 *Tarkio*	1–14S–15W SW SW NW
Harbaugh February 17, 1936	Hartman and Blair Harbaugh #1 *"Oswald"*	25–14S–15W NE NE SW
Harbaugh Arbuckle May 15, 1936	National Refining Co. Reinhardt "C"–1 *"siliceous lime"*	25–14S–15W NW NW SE
Milberger April 29, 1935	Kirk and Jones Milberger #1 *"siliceous lime"*	7–14S–14W NE NW NW
Neidenthal August 28, 1934	Lario Oil and Gas Co. Niedenthal #1 *Arbuckle ("siliceous")*	23–14S–15W NE NE NE
Neidenthal LKC February 2, 1940	Phillips Petroleum Co. #1 Boxberger *Lansing–Kansas City*	24–14S–15W NW SW NW
Neidenthal South June 13, 1935	Wakefield–Armer Hall #1 *Arbuckle*	36–14S–15W NE SE SW
Rusch Arbuckle May 28, 1941	Westgate Greenland Oil Co. Rusch #1 *Arbuckle*	29–14S–14W CE/2 SE NE
Sullivan February 8, 1935	Hartman and Blair #1 Sullivan *"Oswald"*	2–14S–15W NE NE SE
Vaughn March 15, 1937	Empire Oil & Refining Co. Vaughn #1 *Lansing–Kansas City*	17–14S–14W SW SW SW
Vaughn PBC May 4, 1938	National Refining Co. #5–D Reinhardt *Penn. basal conglomerate*	19–14S–14W SE SE NE
Vaughn Arbuckle December 25, 1937	Philhan Oil Co.–GW Hinkle #1 Reinhardt *Arbuckle*	19–14S–14W SE SE SW

TABLE 2—Annual oil production, Gorham oil field, Russell County, Kansas; data graphed in fig. 4.

Year	Annual oil production (bbls)	Number of wells	Barrels of oil per day per well
1926	6,206	1	77.60
1927	69,020	4	47.30
1928	587,110	20	80.20
1929	476,511	26	50.02
1930	399,692	33	33.20
1931	331,144	34	26.70
1932	249,428	30	22.70
1933	220,246	32	18.90
1934	555,655	47	32.40
1935	1,377,313	111	34.00
1936	3,500,294	213	44.90
1937	4,543,310	339	36.70
1938	3,449,373	381	24.80
1939	2,941,831	402	20.00
1940	3,129,355	425	20.10
1941	3,483,624	461	20.70
1942	4,824,139	457	28.90
1943	3,876,295	458	23.20
1944	4,488,525	527	23.30
1945	3,141,280	523	16.50
1946	2,526,745	449	15.40
1947	2,757,600	445	17.00
1948	2,639,139	447	16.10
1949	2,395,967	460	14.30
1950	2,649,023	506	14.30
1951	2,617,395	517	13.90
1952	2,201,767	516	11.70
1953	2,105,119	512	11.30
1954	1,760,547	454	10.60
1955	1,582,918	457	9.50
1956	1,530,570	436	9.60
1957	1,500,710	503	8.20

TABLE 2 (continued)—Annual oil production, Gorham oil field, Russell County, Kansas.

Year	Annual oil production (bbls)	Number of wells	Barrels of oil per day per well
1958	1,498,922	496	8.30
1959	1,420,889	494	7.90
1960	1,310,776	485	7.40
1961	1,237,771	484	7.00
1962	1,195,630	491	6.70
1963	1,385,752	514	7.40
1964	1,479,822	—	—
1965	1,446,078	533	7.40
1966	1,349,529	548	6.70
1967	1,259,957	537	6.40
1968	1,166,607	512	6.20
1969	947,621	498	5.20
1970	821,268	488	4.60
1971	708,587	488	4.00
1972	646,430	491	3.60
1973	560,242	442	3.50
1974	565,991	448 (341) RFW	3.46 (4.55) RFW
1975	552,037	456	3.31
1976	604,152	477	3.47
1977	621,334	500	3.40
1978	583,600	510	3.13
1979	544,065	511	2.92
1980	521,873	528	2.70
1981	598,480	486	3.37
1982	611,212	510	3.28
1983	584,073	516	3.10
1984	598,891	532	3.08
1985	600,279	525	3.13
1986	520,292	531 (444) RFW	2.68 (3.21) RFW
	93,860,001		

TABLE 3—Oil and gas test holes, cross sections A–B and B–C, figs. 5 and 6 (p. 8–9), and map (fig. 3, p. 5).

Test hole number	Company/ Elevation (ft)	Well, total depth (ft), year drilled	Location
1	Clinton Oil Co. 1881 KB	#1 V. Jann 3426 TD 1973	19–14S–15W NW SW NW
2	Hanhoff Oil Co. 1897 KB	#2 Frank Schmale 3758 TD 1982	18–14S–15W 330 FSL NE/4 835 FEL
3	Hanhoff Oil Co. 1896 KB	#1 Frank Schmale 3762 TD 1982	18–14S–15W C E/2 SE NE
4	Brown et al. 1877	#1 Baumrucker 3439 TD 1930	18–14S–15W NE NE NE
5	Aylward Drilling Co. 1841 KB	#1 Jacobs 3340 TD 1963	8–14S–15W NE NE SW
6	Bridgeport Machine Co. 1843	#1 Black 3332 TD 1935	8–14S–15W NW NW SE
7	Bridgeport Machine Co. 1871	#3 Dortland 3306 TD 1937	8–14S–15W C NE/4
8	shallow SWD well —	Bulletin 50* 700 TD±	4–14S–15W projected from SE SW SW
9	Day and Keys 1880	#2 Dortland 3340 TD 1930	8–14S–15W NE NE NE
10	Homestake Prod. Co. 1886 KB	W–26 Witt "F" 3280 TD 1962	4–14S–15W SW SW SW SW
11	Mid West 1886	#31 Benso 3086 TD 1929	4–14S–15W SW SW SW
12	Stanolind Oil & Gas 1888	#21 Benso 3072 TD 1936	4–14S–15W NE SW SW
13	Stanolind Oil & Gas 1893	#6 W. E. Benso 3400 TD 1937	4–14S–15W NW NW SW
14	Homestake Prod. Co. 1886 KB	W–18 Witt "F" 3290 TD 1962	4–14S–15W C SW/4
15	Central Petroleum 1887	3–A Benso 3073 TD 1935	4–14S–15W SW NE SW
16	Coop Refining Assoc. 1883 KB	#1 Witt "F" 3275 TD 1958	4–14S–15W C NE SW
17	Central Petroleum 1873	2–A Benso 3081 TD 1935	4–14S–15W NE NE SW
18a	Homestake 1876	0–56–B Mills 3279 TD 1964	4–14S–15W SW SW NE
18b	Aylward Petroleum 1871	#3 Mills 3085 TD 1935	4–14S–15W SW SW NE
19	Aylward Production 1887	#2 Mills 3090 TD 1935	4–14S–15W NE SW NE
20	shallow SWD well	Bulletin 50* 700' TD±	4–14S–15W approx C NE/4
21	Bridgeport Machine Co. 1896	#2 John Mills "A" 3072 TD 1940	4–14S–15W C S/2 NE NE
22	Bridgeport Machine Co. 1898	#1 John Mills "A" 3300 TD 1940	4–14S–15W C N/2 NE NE
23	Bridgeport Machine Co. 1901	#3 Mills "B" 3330 1937	33–13S–15W SW SE SE

TABLE 3 (continued)—OIL AND GAS TEST HOLES.

Test hole number	Company/ Elevation (ft)	Well, total depth (ft), year drilled	Location
24	shallow SWD well	Bulletin 50*	33–13S–15W
	—	700± TD	SE SE SE SE
25	Central Petroleum	#1 Mills	34–13S–15W
	1895	3319 TD 1938	SW SW SW
26	Central Petroleum	#2 Mills	34–13S–15W
	1891	3314 TD 1940	C S/2 SW
27	Brougher Oil Inc.	#8 Mills "B"	33–13S–15W
	1914 KB	3572 TD 1985	projected from NE NE SE
28	Barnett Oil Co.	#1 Coady	34–13S–15W
	1918 KB	3377 TD 1959	NE NE SW
29	Hartman–Blair et al.	#1 Mills	27–13S–15W
	1921	3387 TD 1935	SE SE SW
30	Texas Co.	#1 Cook "D"	26–13S–15W
	1896	3371 TD 1952	SE NW SW
31	water well	Bulletin 50*	22–13S–15W
	1885	223.5 TD	projected from NW NW SE
32	H. H. Blair	#2 Cook	26–13S–15W
	1890	3052 1950	NW NW SE
33	H. H. Blair	#1 Cook "C"	26–13S–15W
	1891	3356 TD 1950	SW SW NE
34	Jolly J. Inc.	#2 Neal	26–13S–15W
	1896 KB	3344 TD 1978	NW SW NE
35	Wakefield	#1 Cook	26–13S–15W
	1891	3344 TD 1941	C E/2 NE SE
36	Wakefield	#2 Cook	26–13S–15W
	1890	3322 1955	C W/2 NE NE
37	Wakefield	#1 Cook	26–13S–15W
	1892	3326 TD 1954	NE NE NE
38	water well	Bulletin 50	30–13S–14W
	1870	184 ft	projected from SE NW
39	Great Lakes Carbon Co.	#1 Anna Bicker	24–13S–15W
	1877	3331 TD 1950	NE SW SW
40	Great Lakes Carbon Co.	#2 F. Bicker	24–13S–15W
	1843	3317 TD 1949	SW NE SW
41	Great Lakes Carbon Co.	#1 F. Bicker	24–13S–15W
	1844	3326 TD 1949	NE NE SW
42	Great Lakes Carbon Co.	#1 McAllister	24–13S–15W
	1846	3284 TD 1948	SW SW NE
43	Great Lakes Carbon Co.	#5 McAllister	24–13S–15W
	1831	3287 TD 1956	NW SE NE
44	W. C. McBride Inc.	#A. D. Jellison	19–13S–14W
	1762	3575 TD 1937	NE NE SW
45	B and R Drilling Co.	#1 New Estate	18–13S–14W
	1810	3279 TD 1947	C S/2 SW SW
46	Wilhelm	#3 Olson	18–13S–14W
	1745 KB	3188 1967	SE NE SW
47	Cities Service Oil Co.	#1 Dutt	18–13S–14W
	1686	3134 TD 1939	NW NW SE
48	Jay–Bee Oil Co.	#1 Krug A	18–13S–14W
	1782	3226 TD 1966	NE SE NE

TABLE 3 (continued)—OIL AND GAS TEST HOLES.

Test hole number	Company/ Elevation (ft)	Well, total depth (ft), year drilled	Location
49	Morgenstern Oil 1661 KB	#4 Krug 3481 TD 1968	17–13S–14W C N/2 NW NW
50	Cities Service Oil Co. 1648	#1 Sutton 3118 TD 1940	7–13S–14W SE SE SE
51	Jay–Bee Oil Co. 1641	#2 Rogg 3100 TD 1966	7–13S–14W NW NE SE
52	Jay–Bee Oil Co. 1699	#1 Rogg 3175 1965	7–13S–14W SE SE NE
53	Shields Oil Producers 1806	#1 Mollinger 3297 TD 1955	8–13S–14W SW SW NE

*Bulletin 50—Frye and Brazil (1943)

TABLE 4—GORHAM OIL FIELD oil production 1926–1986, by formations.

Number of oil wells	Formation	Barrels in 1000's	% of total	Gravity degrees	Average BOPW
100±	SHALLOW PRODUCTION Chase, Council Grove, Wabaunsee (Tarkio) Shawnee (Plattsmouth)	800	1.3	40°	8,000
30	TOPEKA Fracture zone only	6,500	7.0	39°	217,000
477	LANSING–KANSAS CITY	24,000	25.0	37°	50,000
607	**SUB-TOTALS**	**31,300**	**33.3**		
28	ARBUCKLE, E MEMBER	1,000)			35,000
324	ARBUCKLE, D MEMBER	14,500)			45,000
229	ARBUCKLE, C MEMBER	16,000)	= 46.4	35°	70,000
248	ARBUCKLE, B MEMBER	12,000)			48,000
215	REAGAN SANDSTONE "Gorham sand"	19,000	20.2	35°	88,000
14	PRECAMBRIAN	60	0.1		4,000
1,058	**SUB-TOTALS**	**62,560**	**66.7**		
1,665*	**TOTALS**	**93,860**	**100.0**		

*A total of 1,397 oil wells were mapped within the 50 mi^2 (130 km^2) Gorham oil field (fig. 2). Many wells are counted twice or more in table 4 because they produced from more than one formation, most commonly from both the Arbuckle and the Lansing–Kansas City.

TABLE 5—WELL-HEAD PRICE KANSAS CRUDE OIL, 40° gravity; price at mid-year in dollars.

Year	Mid-year price	Year	Mid-year price
1910	—	1950	2.57
1911	.50	1951	2.57
1912	.70	1952	2.56
1913	.86	1953	2.69
1914	.75	1954	2.81
1915	.40	1955	2.80
1916	1.55	1956	2.79
1917	1.70	1957	3.15
1918	2.25	1958	3.15
1919	2.25	1959	3.15
1920	3.50	1960	2.90
1921	1.00	1961	2.84
1922	2.00	1962	2.91
1923	1.60	1963	2.85
1924	1.75	1964	2.98
1925	1.80	1965	2.98
1926	2.29	1966	3.05
1927	1.28	1967	3.15
1928	1.28	1968	3.20
1929	1.45	1969	3.35
1930	1.29	1970	3.60
1931	.22*	1971	3.52
1932	.92	1972	3.52
1933	.44	1973	4.20
1934	1.00	1974	10.70
1935	1.00	1975	12.75
1936	1.10	1976	12.10
1937	1.22	1977	14.15
1938	1.22	1978	13.20
1939	1.02	1979	22.00
1940	1.02	1980	34.21
1941	1.17	1981	35.00
1942	1.20	1982	28.00
1943	1.20	1983	29.00
1944	1.22	1984	27.00
1945	1.42	1985	26.50
1946	1.93	1986	10.50**
1947	2.60	1987	18.50
1948	2.58	1988	14.75
1949	2.57	1989	19.25

* July 3, 1931 Koester (1933)
** August 1, 1986

TABLE 7—Subsidence in feet per year at Witt, Crawford, and Roubach sinks, affecting I–70; subsidence at Witt sink is graphed in fig. 48.

Date	Days	Maximum subsidence in feet	Rate of subsidence in feet per year
		SUBSIDENCE, CRAWFORD SINK—WESTBOUND	
Built 1965–66			
01–26–70		1.85	
05–15–71	476	0.75	Average 0.575 ft
	5±years	2.60	per year 5±yrs
Rebuilt 8–9–71			
12–20–73	863	1.20	
01–15–76	756	0.85	Average 0.462 ft
	1,619	2.05	per year 4.44 yrs
05–16–76	851	1.10	
03–30–81	1,089	0.85	
07–26–83	817	0.80	Average 0.3640 ft
	2,757	2.75	per year 7.55 yrs
		SUBSIDENCE, CRAWFORD SINK—EASTBOUND	
Built 1965–66			
01–26-70		2.40	
05–17-71	476	1.10	Average 0.844 ft
	5±years	3.50	per year 5±yrs
Rebuilt 8–9–71			
12–07–73	850	1.60	
01–15–76	769	1.25	Average 0.643 ft
	1,619	2.85	per year 4.44 yrs
05–16–78	851	1.15	
04–14–80	698	0.60	
07–06–83	1,198	1.10	Average 0.379 ft
	2,748	2.85	per year 7.53 yrs
		SUBSIDENCE, ROUBACH SINK—WESTBOUND	
12–31–78			
04–26–83	1,577	0.70	Average 0.162 ft
		0.70	per year 4.32 yrs
		SUBSIDENCE, ROUBACH SINK—EASTBOUND	
12–31–78			
04–26–83	1,577	0.60	Average 0.139 ft
		0.60	per year 4.32 yrs

TABLE 7 (continued)—Subsidence in feet per year at Witt, Crawford, and Roubach sinks, affecting I–70.

Date	Days	Maximum subsidence in feet	Rate of subsidence in feet per year
		SUBSIDENCE, WITT SINK—WESTBOUND	
Built 1965–66			
10–20–66		0.90	
05–17–71	1,670	3.15	Average 0.688 ft
	5±years	4.05	per year 4.58 yrs
Rebuilt 8–9–71			
12–07–73	850	2.00	
01–15–76	769	0.80	Average 0.631 ft
	1,619	2.80	per year 4.44 yrs
05–16–76	844	0.95	
03–30–81	1,055	0.85	
07–26–83	757	0.95	Average 0.378 ft
	2,656	2.75	per year 7.28 yrs
		SUBSIDENCE, WITT SINK—EASTBOUND*	
Built 1965–66			
10–20–66		1.35	
05–17-71	1,670	4.00	Average 0.874 ft
		5.35	per year 4.58 yrs
Rebuilt 7–9–71			
12–07–73	850	2.30	
01–15–76	769	1.05	Average 0.755 ft
	1,619	3.35	per year 4.40 yrs
05–16–78	844	1.40	
03–30–81	1,055	1.55	
04–26–83	757	1.25	Average 0.577 ft
	2,656	4.20	per year 7.28 yrs
Rebuilt 1985			
1986		0.50**	Average 0.50 ft
1987		0.40**	Average 0.40 ft

* see graph, fig. 48, p. 84
**personal communication, Don Butcher, 1989

TABLE 8—Petroleum production statistics for the state of Kansas (Kansas Geological Survey; listed by year of statistical data, not by year of publication which was from one to five years later.)

Mineral Resources Circular 1	1927
Mineral Resources Circular 2	1928–1930
Mineral Resources Circular 3	1931–32
Mineral Resources Circular 6	1937
Mineral Resources Circular 10	1933–37
Mineral Resources Circular 13	1938

Bulletin 28	1938
Bulletin 36	1940
Bulletin 42	1941
Bulletin 48	1942
Bulletin 54	1943
Bulletin 56	1944
Bulletin 62	1945
Bulletin 68	1946
Bulletin 75	1947
Bulletin 78	1948
Bulletin 87	1949
Bulletin 92	1950
Bulletin 97	1951
Bulletin103	1952
Bulletin 107	1953
Bulletin 112	1954
Bulletin 122	1955
Bulletin 128	1956
Bulletin 133	1957
Bulletin 138	1958
Bulletin 147	1959
Bulletin 155	1960
Bulletin 160	1961
Bulletin 166	1962
Bulletin 172	1963
Bulletin 179	1964
Bulletin 185	1965
Bulletin 190	1966

Special Distribution Publication 41	1967
Special Distribution Publication 50	1968
Special Distribution Publication 54	1969
Special Distribution Publication 59	1970
Special Distribution Publication 64	1971

Energy Resources Series No. 2	1972
Energy Resources Series No. 4	1973
Energy Resources Series No. 6	1974
Energy Resources Series No. 8	1975
Energy Resources Series No. 10	1976
Energy Resources Series No. 12	1977
Energy Resources Series No. 14	1978
Energy Resources Series No. 16	1979
Energy Resources Series No. 18	1980
Energy Resources Series No. 20	1981
Energy Resources Series No. 23	1982
Energy Resources Series No. 24	1983
Energy Resources Series No. 25	1984

Data Base Series No. 1*	1985
Annual oil and gas production	1986
reports 1985, 1986, 1987, 1988, 1989	1987
	1988
	1989

Data Base Series No. 2*	1989
Cumulative oil field production histories 1965–1989	

Secondary Recovery Operations in Kansas

Oil and Gas Investigations No. 20	1959
Oil and Gas Investigations No. 24	1960
None	1961
Special Distribution Publication No. 6	1962
Special Distribution Publication No. 16	1963
Special Distribution Publication No. 21	1964
Special Distribution Publication No. 30	1965
Special Distribution Publication No. 32	1966
Special Distribution Publication No. 36	1967
Special Distribution Publication No. 46	1968
Special Distribution Publication No. 49	1969
Special Distribution Publication No. 57	1970
Special Distribution Publication No. 62	1971

Enhanced Oil Operations in Kansas

Energy-Resource Series No. 1	1972
Energy-Resource Series No. 3	1973
Energy-Resource Series No. 5	1974
Energy-Resource Series No. 7	1975
Energy-Resource Series No. 9	1976
Energy-Resource Series No. 11	1977
Energy-Resource Series No. 15	1978
Energy-Resource Series No. 17	1979
Energy-Resource Series No. 19	1980
(None compiled)	1981
Energy-Resource Series —	1982*
(Series discontinued after 1982)	

*Compiled and published as a computer printout only.

Oil-field abbreviations

Oil-field abbreviations used in this report for convenience include the following:

BO Barrels of oil. An oil-field barrel contains 42 U.S. gallons.

BOPD Barrels of oil per day.

BOPW Barrels of oil per well.

BOPDPW Barrels of oil per day per well.

sec. Section. A unit of land survey, one mile square, containing 640 acres.

Twp or **T** Township. A unit of land survey six miles square containing 36 sections. In Kansas, townships are numbered consecutively southward (S) from the Kansas–Nebraska border. The Gorham oil field is in Townships 13 and 14 South.

R Range. A measure of longitude, usually six miles. In Kansas, ranges are measured east (E) or west (W) of the 6th Principal Meridian which passes through Wichita. The Gorham oil field is in Ranges 14 and 15 West.

Section numbers Within a township, sections are numbered sequentially, 1 to 36, in the following order:

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Section numbers are omitted from most maps because of space limitations.

sec. 6, T. 13 S., R. 15 W. Section 6 of Township 13 South, Range 15 West.

NW sec. 6 The northwest quarter of section 6; 160 acres square, measuring one-half mile (2,640 ft) on each side.

NW NW sec. 6 The northwest quarter of the northwest quarter of section 6; 40 acres square, measuring one-fourth mile (1,320 ft) on each side.

NW NW NW sec. 6 The northwest quarter of the northwest quarter of the northwest quarter; 10 acres square, measuring one-eighth mile (660 ft) on each side. If describing the location of an oil-test hole, the location is inferred as being in the center of the described unit. Wells located on regular 10-acre spacing (such as NW NW NW) are spaced 660 ft apart and 330 ft from the unit line or lease boundary.

HFW Hole full of water, meaning filled with water or brine to the static fill-up level which may be some distance below the surface of the ground. In the Gorham oil field, wells do not fill with water completely to the top of the hole. There are no artesian flowing water or brine wells.

SWD Saltwater-disposal well. Waste oil-field brine produced along with the oil was disposed in deep SWD wells (depths commonly below 3,500 ft) or formerly was disposed of in shallow SWD wells at depths above the salt section encountered near 1,300 ft.

SWI Saltwater-injection well. A well in which water or brine is injected, usually under pressure, into an oil-producing formation as a method of secondary recovery by waterflooding, displacing oil toward nearby oil wells.

KCC Kansas Corporation Commission, the State regulatory body for drilling permits, licensing of SWD and SWI wells, allowed oil production, and plugging of abandoned holes.

KDHE Kansas Department of Health and Environment, the State regulatory body concerned with pollution, contamination, and oil spills, brine spills, and general environmental matters such as surface pits or ponds, migratory birds, etc.

Abbreviations for depth-of-hole measurements:

DF derrick floor
KB kelly bushing
GD ground level
TD total depth

References

Allan, T. H., and Valerius, M. M., 1929, Fairport oil field, Russell County, Kansas; *in*, Structure of Typical American Oil Fields v. 1: American Association of Petroleum Geologists, Tulsa, Oklahoma, p. 35–48

Amstutz, P. T., Jr., and Stephenson, E. A., 1944, Optimum producing rates for Arbuckle limestone wells: University of Kansas Research Foundation, Bulletin 1, University of Kansas Publications (publication sponsored by Kansas State Board of Health), 148 p.

Anonymous, 1983, Six decades of derricks: Russell County Historical Society and Oil Patch Museum, 36 p.

Baars, D. L., Watney, W. L., Steeples, D. W., and Brostuen, E. A., 1989, Petroleum—a primer for Kansas: Kansas Geological Survey, Educational Series 7, 40 p.

Bailey, E. H. S., 1902, Special report on mineral waters; The University Geological Survey of Kansas, Vol VII, p. 138

Bass, R. O., 1966, How one company makes an old oil field pay off: World Oil, v. 162, no. 6, p. 115–118

Bayne, C. K., Franks, P. C., and Ives, W., Jr., 1971, Geology and ground-water resources of Ellsworth County, central Kansas: State Geological Survey of Kansas, Bulletin 201, 84 p. and maps

Berendsen, P., and Blair, K. P., 1986, Subsurface structural maps over the Central North American rift system (CNARS), central Kansas, with discussion: Kansas Geological Survey, Subsurface Geology Series 8, 16 p., 6 figs., 7 maps, scale 1:250,000

Bickford, M. E., Harrower, K. L., Hoppe, W. J., Nelson, B. K., Nusbaum, R. L., and Thomas, J. J., 1981, Rb-Sr and U-Pb geochronology and distribution of rock types in the Precambrian basement of Missouri and Kansas: Geological Society of America, Bulletin, v. 92, p. 323–341

Bickford, M. E., Van Schmus, W. R., and Zietz, I., 1986, Proterozoic history of the midcontinent region of North America: Geology, v. 14, p. 492–496

Buchanan, R. (ed.), 1984, Kansas geology—an introduction to landscapes, rocks, minerals, and fossils: University Press of Kansas, Lawrence, Kansas, 212 p.

Burgat, V. A., and Taylor, W. K., 1972, Highway subsidence caused by salt solutioning (abs.): Association of Engineering Geologists, 15th annual meeting, Kansas City, Missouri, p. 20

Burrus, R. C., and Hatch, J. R., 1987, Regional variations in crude oil geochemistry, Anadarko basin, Oklahoma, Texas, and Kansas—evidence for multiple sources, mixing, and migration distances (abs.): American Association of Petroleum Geologists, Bulletin 71, p. 535

________, 1989, Geochemistry of oils and hydrocarbon source rocks, greater Anadarko basin—evidence for multiple sources of oils and long-distance oil migration: Anadarko Basin Symposium, 1988, Oklahoma Geological Survey, Circular 90, p. 53–64

Chenoweth, P. A., 1967, Southern midcontinent; past, present, and future—A reconstruction of the Late Cambrian and Early Ordovician history of the southern midcontinent: Oil and Gas Journal, p. 130–135

Cole, V. B., 1962, Configuration of top of Precambrian basement rocks in Kansas: University of Kansas Publications, State Geological Survey of Kansas, Oil and Gas Investigations No. 26, map

________, 1976, Configuration of the top of Precambrian rocks in Kansas: Kansas Geological Survey, Map M–7, scale 1:500,000

Cole, V. B., and Ebanks, W. J., Jr., 1974, List of Kansas wells drilled into Precambrian rocks: Kansas Geological Survey, Subsurface Geology Series 1, 101 p.

Cole, V. B., Merriam, D. F., and Hambleton, W. W., 1965, Final report of the Kansas Geological Society Basement Rock Committee and list of Kansas wells drilled into Precambrian rocks: State Geological Survey, The University Kansas, Special Distribution Publication 25

Cole, V. B., and Watney W. L., 1985, List of Kansas wells drilled into Precambrian rocks: Kansas Geological Survey, Subsurface Geology Series 7, 139 p.

Denison, R. E., Lidiak, E. G., Bickford, M. E., and Kisvarsanyi, E. B., 1984, Geology and geochronology of Precambrian rocks in the central interior region of the United States: U.S. Geological Survey, Professional Paper 1241–C

Fader, S. W., 1975, Land subsidence caused by dissolution of salt near four oil and gas wells in central Kansas: U.S. Geological Survey, Water-Resources Investigations 27–75, 28 p.

Farquhar, O. C., 1957, The Precambrian rocks of Kansas: Kansas Geological Survey, Bulletin 127, pt. 3, 132 p., 1 plate

Folger, A., and Hall, R. H., 1933, Part I, Development of the oil and gas resources of Kansas in 1928 and 1929; Part II, Development of the oil and gas resources of Kansas in 1930: Kansas Geological Survey, Mineral Resources Circular 2, 174 p.

Frye, J. C., and Brazil, J. J., 1943, Ground water in the oil-field areas of Ellis and Russell counties, Kansas: State Geological Survey of Kansas, Bulletin 50, 104 p., map

Gore, C. E., 1954, Cave sandstones in Cotter Dolomite, northeastern Oklahoma: Tulsa Geological Society Digest, v. 20, p. 144–179

Gussow, W. C., 1954, Differential entrapment of oil and gas—a fundamental principle: American Association of Petroleum Geologists, Bulletin, v. 38, p. 816–853

Hendron, A. J., Jr., Heuer, R. E., Fernandez–Delagado, G., 1977, Preliminary report on field investigations at Cargill sinkhole, Kansas: Solution Mining Research Institute, Inc.

Hendron, A. J., Jr., Fernandez, G., Lenzini, P. A., 1979a, Field investigations of north subsidence area at Cargill, Kansas: Solution Mining Research Institute, Inc., 32 p., appendix, logs

________, 1979b, Study of sinkhole-formation mechanisms in the area of Hutchinson, Kansas: Solution Mining Research Institute, Inc., 17 p., 10 figs., appendix

________, 1980, Field investigations of subsidence areas at Carey Salt brine field, Hutchinson, Kansas: Solution Mining Research Institute, Inc., 46 p., 10 figs., 14 plates

________, 1983, Subsurface investigations at well 56 Carey Salt brine field, Hutchinson, Ks.: Solution Mining Institute, Inc., 40 p., 8 figs., appendix, logs

Heyl, A. V., Jr., Agnew, A. F., Lyons, E. J., and Behre, C. H., Jr., 1959, The geology of the upper Mississippi Valley zinc-lead district: U.S. Geological Survey, Professional Paper 309, p. 1–310, plus map case with 24 plates

Hintze, F. F., 1928, Discoverer of Gorham oil district, Kansas: American Association of Petroleum Geologists, Bulletin, v. XII, p. 443

Jantz, D. R., Wehmueller, W. A., and Owens, H. D., 1982, Soil survey of Russell County, Kansas: U.S. Department of Agriculture, Soil Conservation Service, in cooperation with the Kansas Agricultural Experiment Station, p. 103, plus maps, scale 1:20,000

Jewett, J. M., and Butcher, D., 1957, Disposal of oil-field brines in Kansas: Kansas Geological Survey, Open-file Report 57–2, 22 p.

Jones, O. S., 1945, Disposition of oil-field brines: University of Kansas Publications, Lawrence, Kansas, 192 p.

________, 1950, Freshwater protection from pollution arising in the oil fields: University of Kansas Publications, Lawrence, Kansas, 129 p.

Kansas Geological Survey, 1973, Kansas brine: Kansas Geological Survey, computer data file

Kerans, C., 1988, Karst-controlled reservoir heterogeneity in Ellenburger Group carbonates of west Texas: American Association of Petroleum Geologists, Bulletin, v. 72, no. 10, p. 1,160–1,183

Keroher, R. P., and Kirby, J. J., 1948, Upper Cambrian and Lower Ordovician rocks in Kansas: State Geological Survey of Kansas, Bulletin 72, 140 p.

Kesler, L. W., 1928, Oil and gas resources of Kansas in 1927: Kansas Geological Survey, Mineral Resources Circular 1, 60 p.

Kisvarsanyi, G., Grant, S. K., Pratt, W. P., Koening, J. W. (eds.), 1983, International Conference on Mississippi Valley Type Lead-Zinc Deposits: Rolla, Missouri, University of Missouri (Rolla), 603 p.

Knapp, R. W., Steeples, D. W., Miller, R. D., and McElwee, C. D., 1989, Seismic reflection surveys at sinkholes in central Kansas; *in*, Geophysics in Kansas, D. W. Steeples (ed.): Kansas Geological Survey, Bulletin 226, p. 99–120

Koester, E. A., 1934, Development of the oil and gas resources of Kansas: Kansas Geological Survey, Mineral Resource Circular 3, 76 p.

Latta, B. F., 1948, Ground-water supplies at Hays, Victoria, Walker, Gorham, and Russell, Kansas, with special reference to future needs: Kansas Geological Survey, Bulletin 76, pt. 6, 196 p., illustrations (includes geological map)

Macfarlane, P. A., Townsend, M. A., Whittemore, D. O., Doveton, J., and Staton, M., 1988, Hydrogeology and water chemistry of the Great Plains (Dakota, Kiowa, and Cheyenne) and Cedar Hills aquifers in central Kansas, end of contract report: Kansas Geological Survey, Open-file Report 88–39, 184 p.

Martin, R. B., 1968, Relationship between quality of water in the Arbuckle Group and major structural features in central and eastern Kansas: M.S. thesis, University of Kansas, Lawrence, Kansas, p. 1–79, 4 plates

McCracken, E., 1955, Correlation of insoluble residue zones of upper Arbuckle of Missouri and southern Kansas: American Association of Petroleum Geologists, Bulletin, v. 39, p. 47–59

Merriam, D. F., 1963, The geologic history of Kansas: Kansas Geological Survey, Bulletin 162, 317 p.

Merriam, D. F., and Atkinson, W. R., 1956, Simpson-filled sinkholes in eastern Kansas: Kansas Geological Survey, Bulletin 119, p. 61–80

Miner, C., 1987, Discovery! Cycles of change in the Kansas oil and gas industry 1860–1987: Kansas Independent Oil and Gas Association (KIOGA), Wichita, Kansas, 239 p.

Moore, R. C., 1917, Oil and gas resources of Kansas: State Geological Survey of Kansas, Bulletin 3, 391 p.

Muehlberger, W. R., Hedge, C. E., Denison, R. E., and Marvin, R. F., 1966, Geochronology of the midcontinent region, United States—Part 3, Southern area: Journal of Geophysical Research, v. 72, p. 5,409–5,426

Ohle, Ernest L., 1985, Breccias in Mississippi Valley type deposits: Economic Geology, v. 80, p. 1,736–1,752

Oringderff, B., 1984, The competitive edge: Kansas Territorial, v. IV, no. V, September–October, 6 p. (unnumbered)

Poyser, L., 1988, Performance of water flooding and the potential for the carbon dioxide process miscible in the Lansing–Kansas City formation: M.S. thesis, University of Kansas, quoted in Tertiary Oil Recovery Project, Newsletter, v. 4, no. 1, March 1988, p. 1–2

Rall, C. G., and Wright, J., 1953, Analyses of formation brines in Kansas: U.S. Bureau of Mines Bulletin, Report of Investigations, no. 4974, p. 1–40

Rich, J. L., 1931a, Function of carrier beds in long-distance migration of oil: American Association of Petroleum Geologists, Bulletin 15, p. 911–924

________, 1931b, Source and data of accumulation of oil in granite ridge pools of Kansas and Oklahoma: American Association of Petroleum Geologists, Bulletin 15, p. 1,431–1,452

________, 1933, Distribution of oil pools in Kansas in relation to Mississippian structure and areal geology: American Association of Petroleum Geologists, Bulletin 17, p. 793–815

Rubey, W. W., and Bass, N. W., 1925, The geology of Russell County, Kansas: Kansas Geological Survey, Bulletin 10, pt. 1, p. 1–86

Rydjord, John, 1972, Kansas place names: University of Oklahoma Press, 613 p.

Steeples, D. W., Knapp, R. W., and McElwee, C. D., 1986, Seismic reflection investigations of sinkholes beneath Interstate Highway 70 in Kansas: Geophysics, v. 51, no. 2, p. 295–301, 7 figs.

Steeples, D. W. (ed.), 1989, Geophysics in Kansas: Kansas Geological Survey, Bulletin 226, 212 p.

Swineford, A., and Williams, H., 1945, The Cheyenne sandstone and adjacent formations of a part of Russell County, Kansas: Kansas Geological Survey, Bulletin 60, pt. 4, p. 101–168, illustrations (incl. sketch maps); analyses of ground waters by Howard A. Stollenberg

Van Schmus, W. R., and Bickford, M. E., 1988, Project Upper Crust—a program to sample the Precambrian basement of the midcontinent region of North America using industrial drill holes: University of Kansas, Department of Geology, unpublished, includes comprehensive summary of U-Pb zircon dates from the Kansas basement

Van Schmus, W. R., Bickford, M. E., and Zietz, I., 1987, Early and middle Proterozoic provinces in the central United States; *in*, Proterozoic Lithospheric Evolution, A. Kroner (ed.): American Geophysical Union, Geodynamics Series, v. 17, p. 43–68

Ver Wiebe, W. A., 1938, Oil and gas resources of western Kansas: State Geological Survey of Kansas, Mineral Resources Circular 10, 179 p.

Ver Wiebe, W. A., Goebel, E. D., Jewett, J. M., and Hornbaker, A. G., 1953, Oil and gas developments in Kansas during 1952: Kansas Geological Survey, Bulletin 103, 201 p.

Walters, R. F., 1946, Buried Precambrian hills in northeastern Barton County, central Kansas: American Association of Petroleum Geologists, Bulletin, v. 30, p. 660–710, 8 figs. and 1 folded plate with 8 cross sections

________, 1953, Oil production from fractured Precambrian basement rocks in central Kansas: American Association of Petroleum Geologists, Bulletin, v. 37, p. 300–313, 6 figs.

________, 1958, Differential entrapment of oil and gas in the Arbuckle dolomite of central Kansas: American Association of Petroleum Geologists, Bulletin, v. 42, p. 2,133–2,173, 21 figs.

________, 1976, Land subsidence in central Kansas related to salt dissolution: Solution Mining Research Institute, Inc., 144 p., 37 figs., cover photograph

________, 1978, Land subsidence in central Kansas related to salt dissolution: Kansas Geological Survey, Bulletin 214, 82 p., 39 figs.

________, 1979, Surface subsidence related to salt well operation, Hutchinson, Kansas: Solution Mining Research Institute, Inc., 31 p., 15 figs.

________, 1987, Differential entrapment of oil and gas in the Arbuckle dolomite of central Kansas; in, Petroleum Geology of the Midcontinent, Bailey Rascoe, Jr., and Norman J. Hyne, eds.: Tulsa Geological Society, Special Publication No. 3; reprinted in full from American Association of Petroleum Geologists, Bulletin 42, no. 9, p. 2,133–2,173 (September 1958)

Walters, R. F., and Price, A. S., 1948, Kraft–Prusa oil field, Barton County, Kansas; *in*, Structure of Typical American Oil Fields: American Association of Petroleum Geologists, v. III, p. 249–280, 7 figs.

Watney, W. L., 1980a, Cyclic sedimentation of the Lansing–Kansas City Groups in northwestern Kansas and southwestern Nebraska, a guide for petroleum exploration: Kansas Geological Survey, Bulletin 220, 72 p.

________, 1980b, Subsurface geologic study of the Hutchinson salt: Kansas Geological Survey, Open-file Report 80–16, 6 p., 37 figs.

Watney, W. L., and Paul, S., 1980, Maps and cross sections of the lower Permian Hutchinson salt in Kansas: Kansas Geological Survey, Open-file Report 80–7, 10 p., 6 plates

Whittemore, D. O., and Pollock, L. M., 1979, Determination of salinity source in water resources of Kansas by minor alkali and halide chemistry: Kansas Water Resource Research Institute, Contribution No. 208, Manhattan, Kansas, 28 p.

Zeller, D. E. (ed.), 1968, The stratigraphic succession of Kansas: Kansas Geological Survey, Bulletin 189, 81 p., chart

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