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OIL WELLS IN A KENTUCKY KARST REGION

by

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(7 figures)

RESUME. - Puits de pétrole dans une région karstique du Kentucky.
La récente reprise de l'activité pétrolière dans le terrain karstique de Warren County (Kentucky) a provoqué divers problèmes. Certains de ceux-ci sont essentiellement les mêmes que ceux qui surgirent lors de la première période d'exploitation, dans les années 20; d'autres sont typiques des problèmes d'environnement de la société des années 80.

Une introduction à la stratigraphie, à la lithologie, à la structure et à la spéléologie du karst de Warren County sert de base pour une discussion de ces problèmes et de leurs solutions possibles.

La difficulté fondamentale que rencontre l'exploitation du pétrole à faible profondeur, résulte de l'abondance des cavités souterraines. Elles ont souvent les dimensions de grottes et beaucoup sont remplies d'eau. Les problèmes de la prospection géophysique, du forage, de la production et des déchets sont illustrés. Les solutions déjà trouvées par les exploitants sont discutées, ainsi que des solutions possibles aux questions toujours pendantes, spécialement celles qui concernent l'environnement.

ABSTRACT. - The recent resurgence of the oil industry in the karst terrain of Warren County (Kentucky) has resulted in a variety of problems. Some of the problems are essentially the same as those engendered in the first period of oil exploitation in the 1920's; others typify the environmental concerns of society in the 1980's.

An introduction to the stratigraphy, lithology, structure, and speleology of the Warren County karst provides a background for a discussion of problems and possible solutions.

The fundamental difficulty of petroleum exploitation in the region's shallow productive zone lies with the abundance of subterranean cavities. Voids in the rock are often cavernous in size, and many are water-filled. Problems in geophysical exploration, drilling, production and waste disposal are illustrated. Solutions for some of the problems already solved by the oil industry are discussed along with some possible solutions to unsolved problems, especially those of an environmental nature.

I.- INTRODUCTION

The mixture of oil wells and karst presents the potential for a variety of unusual problems. Difficulties in exploration, drilling, production and waste disposal may be quite different from those in nonkarst terrain. Kentucky's Warren County (fig. 1) is an area of modest oil production, and situated in the Southwestern Pennyroyal Karst region near Mammoth Cave. It therefore offers an opportunity to identify some problems with oil wells located in a karst region.

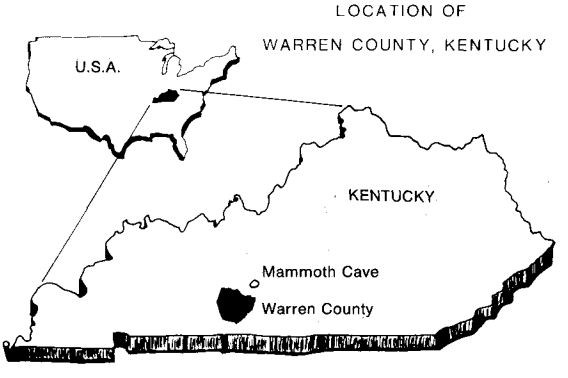

Figure 1. - Location of Warren County, Kentucky, U.S.A.

II. - WARREN COUNTY OIL PRODUCTION

Historically, Warren County's major oil period was in the early 1920's when production exceeded one million barrels per year (fig. 2). A decline then occurred over several decades, reaching a low in 1975 (Kentucky Department of Mines and Minerals). Commonly the early wells began producing 1500-2500 barrels per day

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(bpd) for the first few days or weeks, then declined to a steady 5 to 15 bpd (St. Clair, 1921). Hundreds of wells have been drilled through the years. Many have

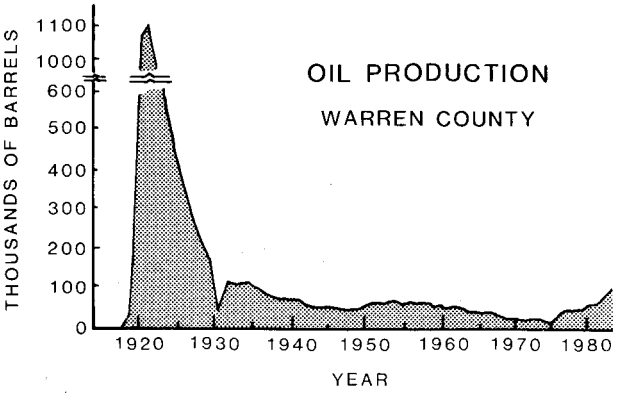

Figure 2. - Oil production of Warren County, 1918-1983.

been abandoned; others remain with very low production.

Beginning in 1976 the county experienced a resurgence of the oil industry. Issuance of drilling permits rose sharply from a previous ten-year average of 7 per year to a recent average of 51 per year. In 1982 alone, 103 drilling permits were issued. Oil production also began to rise in 1976 (fig. 2), and in 1983 was in the vicinity of 100,000 bpd- the highest in almost half a century.

The modern exploitation of the old oil fields is occurring because of newly profitable economic conditions. The Warren County oil rests in several shallow zones ranging from about 100 m to 400 m beneath the surface. The shallow occurrence yields an economic advantage because : 1) overall cost is less than for deep wells; 2) promotion for investment capital is easier; 3) there is an abundance of drilling equipment and operators with local experience; and 4) relatively inexpensive portable cable tool drilling is possible, and fast, economical air rotary drilling is a more modern alternative.

III. - GEOLOGIC SETTING

The oil pools of Warren County (fig. 3) are essentially the same ones known in the early decades. With more intense modern exploitation, the pools may be extended and new pools discovered (McGrain & Sutton, 1973).

Oil production from Warren County pools occurs in two terrain types (fig. 3). In the north and northwest, some of the oil pools lie beneath the Chester Upland, a dissected plateau with moderate relief, ap-

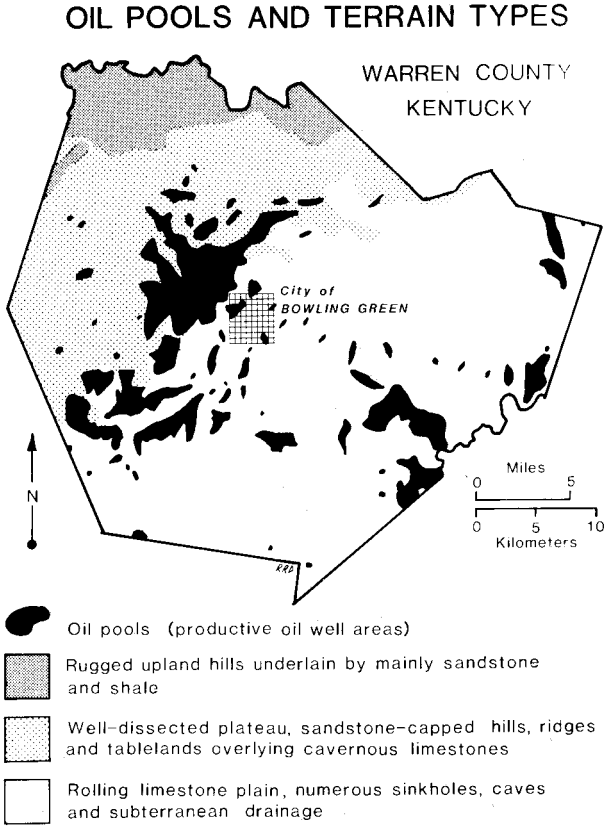

Figure 3. - Oil-productive areas and terrain types, Warren County.

proaching 100 m in places. The surface is capped by Mississippian sandstones that are underlain by cavernous limestones, somewhat similar to the Mammoth Cave region immediately to the northeast (fig. 4). In Warren County, however, the caves are fewer and smaller.

The other terrain type overlying Warren County oil pools is the rolling Pennyroyal limestone plain (Sauer, 1927), mostly to the south and east of Bowling Green (figs. 3 and 4). Local relief is commonly 5 m to 15 m, locally greater. In the Pennyroyal Sinkhole Plain there are thousands of small shallow sinkholes (dolines), few surface streams, several subterranean stream networks, and numerous shallow, wet caves. On its southeastern fringe, the Pennyroyal Marginal Plain (fig. 4) is a narrow, discontinuous zone of less soluble rock with small surface streams that sink at the edge of the sinkhole plain.

Lithology and structure are dominated by a series of sedimentary strata dipping gently to the northwest (fig. 5). The oil pools lie under the dissected Chester Upland (lithologic zone 2) and under the Pennyroyal Plain (lithologic zones 3, 4 and 5). Local interruptions in the regional dip, and unconformities, have allowed oil to accumulate in small anticlines, domes, and various stratigraphic traps. A variety of physical factors help control oil production : structure, porosity, stratigraphic pinchouts, gas expansion and water drives (McGrain & Sutton, 1973).

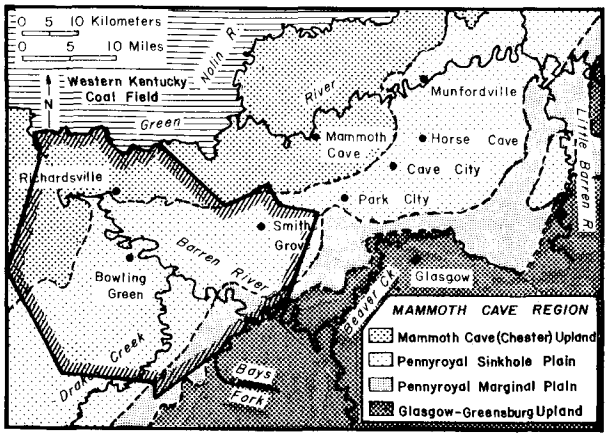

Figure 4
Warren County and physiographic divisions of part of the Western Pennyroyal district. Boundaries adapted from Sauer (1927) and Quinlan & Rowe (1977).

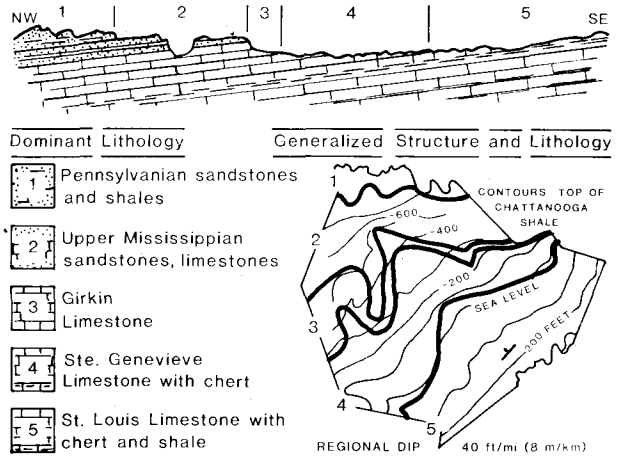

Figure 5
Lithology and structure of Warren County. Oil zones are in several strata beneath St. Louis Limestone.

From the surface, oil wells must extend down through several rock units to reach productive strata. Located beneath the St. Louis Limestone, the Mississippian Warsaw and Devonian "Corniferous" zones are the most productive in Warren County. Before encountering oil, drilling is likely to penetrate shallow cavernous zones, depending on well location, in the Haney, Girkin, Ste. Genevieve and St. Louis limestones.

IV. - OIL WELL PROBLEMS

A.- INTRODUCTION

The major natural cause of unusual problems of oil exploitation in the karst areas of Warren County probably is rock voids. Cavities in the subsurface produce one set of problems; other difficulties arise from karstic surface expression. The very wide range of methods of subsurface cavity detection (Butler, 1977) is not fully utilized in Warren County. Shallow cavernous zones must, in any event, be penetrated in order to reach the oil. Thus cavity detection is more a chance encounter than a planned rendezvous.

Increased costs and physical difficulties due to unusual field conditions historically have been expected by the oil industry (see for example, Day, 1922; Uren, 1946; Hyne, 1984). A karst setting not only may present unique difficulties, but can magnify problems common to other geologic settings. The following overview briefly considers problems of drillers, producers, and the environment.

B.- PROBLEMS FOR DRILLERS

An objective of oil well drillers is to penetrate smoothly downward into rock. Cavities in the rock hinder this goal. First, the pounding, crushing motion of a cable tool is very effective in drilling until a large dry or water-filled cavity is met. Then diversion of the cutting tool may occur, even to the extent that drilling must be discontinued and the well abandoned.

Second, in rotary drilling it is essential that the air or mud pumped down the center of the drill pipe be recirculated upward, along with cuttings, through the annular space between the drill pipe and the rock wall. If the deepening drill hole suddenly breaks out into a large cavity, loss of circulation occurs. If the void is too large to be sealed off with mud or other sealant, the well may have to be abandoned.

A third problem, encountered in cable tool drilling, is that numerous small cavities can cause the rock cuttings to disperse in the subsurface. Samples may be impossible to retrieve with a bailer for large vertical distances, often 30 m to 100 m, with resultant loss of geologic information.

A fourth problem for drillers may arise with the task of setting the tubular casing in a well. Casing protects fresh groundwater from oil, brine and other pollutants, and at the same time seals the oil from external contamination. Cementation of casing also permits the containment of undesired vertical migration of fluids through the annulus between casing and rock. Various seals and plugs to isolate strata are used in the oil industry in a large variety of geologic settings. In cavernous strata the problems can be greatly magnified. Often enormous quantities of cement are used to set casing and seal strata from subjacent and superjacent beds (fig. 6). The fifth problem, the possibility of encountering pressurized gas, also is common to other geologic settings. In karst, unpredictability may pose special problems in drilling with regard to pressure, explosion and fire.

C.- PROBLEMS FOR PRODUCERS

Producers are responsible for maintaining a smooth flow of oil upward out of the rock. Maintenance of well, pump and storage facilities, re-exploitation of old wells,

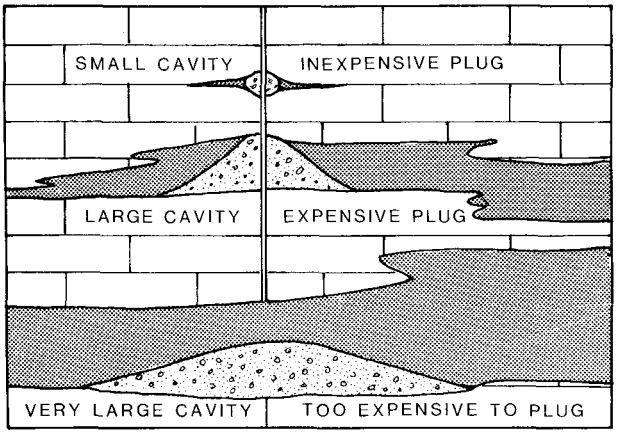

Figure 6. - Schematic representation of attempts to plug cavities.

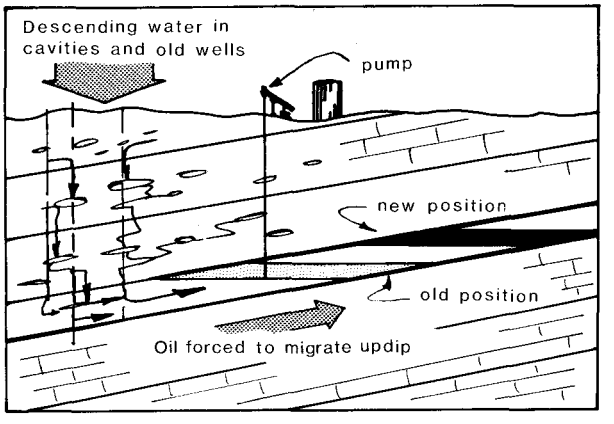

Figure 7
Migration of oil pool leaves well dry or pumping water, not oil.

and storage and disposal of waste are among their tasks. Improperly maintained well operations, or the presence of old abandoned wells, unplugged or with corroded, leaky casing, create problems made worse by cavernous limestone. First, migration of a reservoir may occur, the oil being forced updip by descending water (fig. 7). The well will pump water, not oil. Second, large amounts of karst water freely circulating between formerly sealed aquifers may create drilling, production, and contamination problems. Third, when old, rotten casings collapse into voids, re-exploitation of the well may be difficult or impossible. Fourth, the combination of voids and leaky casing may allow fresh water to come in contact with swelling clay in the Corniferous pay zones. Production may diminish from 5 barrels to one-half a barrel per day. Finally, although present laws allow excess water from oil production to be stored in surface ponds, future regulations may stipulate that injection wells be used. Disposal by injection into and through cavernous rocks will present another series of problems for the producers.

D.- PROBLEMS FOR THE ENVIRONMENT

Environmental pollution, largely through improper practices, may easily occur at an oil field in karst terrain. Old unplugged or leaky wells may cause pollution of fresh groundwater by oil or by salt water. At the surface, oil leaks, spills and vandalism at the well, pump and storage facilities can result in surface and subsurface pollution. Waste water stored in ponds can slowly leak directly into enlarged joints through thin regolith. Sinkhole collapse can occur suddenly when storage ponds occupy dolines in thick regolith.

Oil field brines may be an especially serious problem to the environment. A nearby oil field in the past created severe salt water pollution in wells and regional streams, including some in Mammoth Cave (Krieger & Hendrickson, 1960). Warren County, however, has remained relatively free of serious contamination. Finally, the odor and hazard of oil well gas may be exacerbated in a karst region by poor maintenance or abandonment.

V. - CONCLUSION

The literature of karst studies appears to be somewhat lacking in references to technical problems of the oil industry. Undoubtedly many scattered accounts occur in the literature of petroleum geology; petroleum engineering, oil industry trade journals, hydrogeology, and environmental issues. Some of the solutions to problems are "trade secrets", not discussed openly by oil industry representatives. The present paper is by no means a comprehensive treatment, but rather an initial attempt to illustrate a topic that may not be familiar to many karst scholars. The problems of well drillers, oil producers, and environmental protection in karst terrain can certainly provide a wealth of ideas for future karst studies, both pure and applied.

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