KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 81-14

Exploration for Petroleum in Cyclic Sediments of
Late Pennsylvanian Age in Central and Western Kansas:
A Closer Look at a Mature Province

by

W. Lynn Watney

Disclaimer
The Kansas Geological Survey does not guarantee this document to be free from errors or inaccuracies and disclaims any responsibility or liability for interpretations based on data used in the production of this document or decisions based thereon. This report is intended to make results of research available at the earliest possible date, but is not intended to constitute final or formal publications.

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

OF 81-14

EXPLORATION FOR PETROLEUM IN CYCLIC SEDIMENTS OF LATE PENNSYLVANIAN AGE IN CENTRAL AND WESTERN KANSAS-- A CLOSER LOOK AT A MATURE PROVINCE

by

W. Lynn Watney

Kansas Geological Survey

University of Kansas

Lawrence, Kansas 66044

ABSTRACT

Upper Pennsylvanian, Lansing and Kansas City Groups of western and central Kansas offer continued opportunity for new oil discoveries. Selective isopachs construction and facies mapping keyed with core descriptions of individual Lansing and Kansas City cycles provides the necessary information to interpret general environmental conditions active during the deposition of a cycle across the shelf. Quality of potential reservoir carbonates varies in response to the duration and extent of: 1) energy levels in the water column affecting deposition of regressive carbonate and 2) early diagenesis responsible for the formation of secondary porosity.

The western Kansas shelf is divided into several settings of carbonate reservoir types distinguished on the basis of the mapping results. A relative risk factor for exporation success is assigned to each area.

ACKNOWLEDGEMENTS

Talat Abdullah and Rita Sooby assisted in the compilation of the well log data. Richard Brownrigg, Joe Brentano, and Charles Ross contributed to the computer graphics. Nancy Christensen and John Doveton reviewed the manuscript, and Lea Ann Shreve typed the manuscript. Renate Hensiek and Jorgina Aspiazu, also members of the Kansas Geological Survey, were instrumental in the final preparation of the graphics.

Cities Service Company, Conoco, Amoco, and Texaco are thanked for the opportunity to examine cores in their possession. This paper is published with the permission of the Director of Kansas Geological Survey.

EXPLORATION FOR PETROLEUM IN CYCLIC SEDIMENTS OF LATE PENNSYLVANIAN AGE IN CENTRAL AND WESTERN KANSAS--A CLOSER LOOK AT A MATURE PROVINCE

INTRODUCTION

The Upper Pennsylvanian Lansing and Kansas City Groups in Kansas are a succession of thin widespread cyclic carbonates and clastic units whose rythmic nature has been attributed to fluctuations in sea level (Wanless and Shephard, 1936; Moore, 1979; Heckel, 1977; Watney, 1980). While global plate tectonics can only explain changes in sea level (Rona, 1973) slower than required in the formation of these cycles (30,000 to 300,000 years, Duff, et al., 1967), evidence for concurrent continental glaciation in Gondwanaland has rekindled support for this mechanism as the cause of rapid and significant changes in sea level (Crowell, 1978). Changes in sea level of only a few tens of feet could have significantly altered the conditions across a stable, low-relief, shallow epicontinental sea.

At least 12 cycles are developed in the Lansing and Kansas City Groups in western Kansas. Each cycle typically begins with a thin transgressive unit followed by a thin marine shale. The marine shale is overlain by a thicker regressive carbonate, the primary petroleum reservoir, which is in turn overlain by a generally unfossiliferous, occasionally oxidized, regressive shale at the top of the cycle (Watney, 1980).

Early eogenetic (Choquette and Pray, 1970) diagenesis resulting from fresh and undersaturated water percolation enhanced this primary porosity and redistributed porosity by differential solution and precipitation of cement. All rocks examined across the shelf area were affected by these processes; only the intensity and duration of this early diagenesis vary. Intuitively, it may be expected that eogenetic diagenesis would be more active over the more positive areas of the paleo-shelf, areas such as those demonstrated along the upper (northern) shelf in northern Kansas and southern Nebraska (Watney and Ebanks, 1978; DuBois, 1979; Watney, 1980). Here near the strandline subaerial exposure and meteoric, fresh-water diagenesis is pervasive. The results presented in this paper extend this work southward in the basinward direction.

A major study by Brown (1963) of the Lansing-Kansas City Groups in southwestern Kansas borders this present study area on the southwest. His work on documenting the cyclic nature and petrographic character of these rocks complement the results of this study. Work by Morrison (1979) in an M.S. thesis describes the structure and cyclic nature of the Lansing Group in Gove and Trego counties and provides an insight as to reservoir quality and economic evaluation of these cyclic units. Rascoe (1962) and recently Moore (1979) interpret the generalized lithofacies across the midcontinent during the Late Paleozoic, including the Missourian (Late Pennsylvanian). Heckel (1980) interprets the evolution of the paleography across the midcontinent during the development of Late Pennsylvanian age cyclothems.

1,825 well logs comprise the network of control in the 30.5 thousand square mile study area where well spacing averages one well per 12 square miles (Fig. 1). The Central Kansas Uplift (CKU) and the Cambridge Arch (CA) occupy the eastern area of the map, while the western Kansas shelf, the northern extension of the Hugoton Embayment, lies to the west (Fig. 1). The Central Kansas Uplift is a mature oil-producing province while the western Kansas shelf, although it has drilled in since the 1950's is being actively explored today.

This report focuses on the interpretations of a set of regional structural, isopach, and log-derived facies maps pertaining to the J-Zone cycle of the Kansas City Group in western Kansas (Fig. 2). The cycle is tentatively correlated to the Dennis Limestone in the outcrop. To better understand the accumulation of oil in the J-Zone carbonate, a primary producing unit over much of the western shelf of Kansas, maps were chosen that would help interpret the depositional and diagenetic setting of the western Kansas shelf during the deposition of this cycle.

Although cores are an integral part of this work, particularly in documenting the development of the cycles, they will be mentioned only briefly. Interested readers can refer to previous work for a detailed documentation of the cycle (Watney, 1980).

Oil has been produced from Lansing-Kansas City pools in prolific amounts from the CKU and in lesser amounts across the western Kansas shelf (Fig. 3). While the CKU is a very mature area, it is still being actively drilled today for field extensions and infield locations.

Western Kansas is becoming more densely drilled, but it is far from completely evaluated.

Today the question is, where should we focus to find the remaining oil. To anyone who has worked this area, the inherent risks are obvious. The Lansing-Kansas City reservoirs in western Kansas are erratic in development and methods must be found to predict the distribution of the reservoirs in conjunction with structure.

The answer, in part, can be approached by examining the detailed stratigraphy of the sedimentary cycles in which the oil occurs, using logs and cores at increasing stages of refinement, until fairways of porosity are isolated. The maps shown here are not to be taken as prospect maps, but are to be used to describe the regional setting and provide information for generalizations about the producing interval.

LOG-DERIVED MAPS OF J-ZONE CYCLE

The Central Kansas Uplift developed in Late Mississippian through Early Pennsylvanian time. An extended period of erosion followed. The entire shelf then subsided until all areas of the uplift were finally buried by sediment in Mid to Late Pennsylvanian time. The CKU is defined here by a broad, elongate thinning of the isopach of the interval from near the top of the Kansas City Group to the base of the Pennsylvanian section (Fig. 4). The Cambridge Arch on the north is separated from the CKU by a west to east trending thick in Ellis County. The Lansing-Kansas City (L-KC) production on the CKU closely follows the isopach thin of this map (see Fig. 3).

A structural contour map of the top of the J-Zone regressive carbonate (Fig. 5) shows a subdued outline of the CKU, bordered on the west by a southerly plunging anticline that defines the northern reaches of the Hugoton Embayment.

Figure 6 is an isopach of the combined thickness of the H, I, J, and K-Zone cycles in the Kansas City Group. Figure 7 is an isopach of the regressive carbonate and underlying transgressive phase of the J-Zone cycle, representing the marine interval of this cycle. These maps look similar: the CKU and CA are distinguishable as separate features, and the centers of thinning extend westward beyond the earlier outlines of both the CKU and CA as defined in Figure 4. The center of greatest thinning on the CKU is located over the feature called the Rush Rib. Western Kansas is an area of slow and minor changes in thickness while areas southeast and southwest of the CKU changed in thickness more rapidly.

A contour map of the ratio of thickness of the marine portion of the cycle to the thickness of the regressive shale (Fig. 8) complements the previous two isopach maps, but indicates that, as sea level fell during late regression in the cycle, a wedge of clastics advanced over much of the northern shelf. This wedge originated north of the mapped area, covered the CA and northwestern Kansas, and reached down as a narrow lobe along the west side of the CKU.

The regressive shale in this cycle was mapped by taking the difference between the base of the I-Zone cycle and the top of the J-Zone regressive carbonate. Contouring of the upper northwest Kansas shelf is missing because the I-Zone cycle has pinched out in this area. The pinchout is defined by the northern edge of contours along the heavy line. Note that the I-Zone pinchout follows the wrapping contour in the area with a higher proportion of regressive shale.

Locally this regressive shale is missing over the CKU; in the southwest the marine interval (essentially carbonate) consistently exceeds 90% of the thickness of the cycle.

The maximum gamma radiation (GR) recorded in each well for the marine shale of the J-Zone cycle is contoured in Figure 9. The GR value in this shale reflects the abundance of the radioactive elements in the U or Th series thought to be associated with the clay minerals and organic matter of the shale (Hassan, et al., 1976; Watney, 1979; Schmoker, 1981). Shales with GR values exceeding 160 API units are visually identified as dark shales, organic rich, and commonly black and fissile. Heckel (1978) suggests that these black, fissile marine shales were deposited in a deep, stagnant anoxic water. Others suggest that the waters were very shallow. In contrast, regressive shales average from 70 to 100 API units, are red-brown to gray or green in color, and are generally non-fossiliferous.

The maximum GR intensity of the marine shale closely coincides with the pattern of the previous maps. The diminished GR values over the CA and CKU suggest that the sea-floor conditions under which these shales were deposited were more oxidizing and could be explained by shallower water with better circulation. Thinning of the previous isopachs over similar locations also suggests this.

If the marine shale represents the deepest water deposit of the cycle, then the relief over these positive areas must have been sufficient to affect the physical-chemical conditions of the bottom. The amount of thinning does not suggest that the paleo-relief was very great nor does the distribution of the regressive shale suggest any substantial relief.

Low GR values along northwestern Kansas reflect an influx of sediment, which diluted the organic matter and caused thickening of the marine-shale interval into Nebraska.

Finally, the map of the thickness of porous, regressive carbonates that exceeds 8% (Fig. 10) is easily discussed in relation to the previous maps because of many similarities in overall pattern. An 8% porosity value is used as the cutoff value for effective porosity (Watney, 1980). Oomoldic porosity does not, however, fit this determination. Relatively large areas of closed contours of porosity thickness are referred to as regionally connected porosity (RCP). Areas over the northern CKU and most of the area overlying the CA do not have RCP or significant carbonate thicknesses. Developments of RCP over the western Kansas shelf are scattered; few show any trends or fairways of porosity. In contrast, the southwest and southeast map areas are filled with thick trends of RCP.

An important observation in comparing the map of L-KC oil fields (Fig. 3) with this map (Fig. 10) is that the thick trends of RCP (>12 ft.) in the southwestern and southeastern areas of the map do not coincide with locations of many L-KC oil fields; however, the intermediate values over the CKU do reflect locations of excellent oil pools. At the other extreme the CA crestal area in Norton County, with very low thickness values, is barren of L-KC oil pools.

In comparison, the western shelf is intermediate in thickness of porous interval, in the amounts of regressive shale, in maximum GR values in the marine shale, and in thickness of the marine interval. The western shelf is unique in that the oil fields are small and scattered across the area.

A well log-stratigraphic cross section (Fig. 2) that reaches from the southwestern to the northeastern area of the study illustrates the changing but conformable character of four cycles in the Kansas City Group, including the J-Zone cycle across the CKU. Noticeable thinning occurs over the CKU while substantial porosity develops in the southwestern area of the map.

VARIATION OF J-ZONE CYCLE AS OBSERVED IN CORE

A map of the locations and simplified graphic descriptions of selected cores of the J-Zone cycle across the study area provides the necessary information to briefly comment on the mechanisms of reservoir development (Fig. 1). Integration with the other maps allows an extrapolation of depositional and diagenetic facies.

The Cities Service Company #506 Dorr and the Conoco #9 Morel cores are located on the CA. The #9 Morel is situated on the southeastern rim of the porosity thickness minimum and isopach thin centered in Norton County. Portions of the grain-support and mud-rich carbonates in the #9 Morel core are both cut by large, open, vertical fractures. These fractures and the vuggy, secondary porosity are attributed to intense, early diagenesis by undersaturated waters. Subaerial conditions are strongly suggested by paleosoils and shale and debris-filled solution fissures.

The #506 Dorr and the Clinton #2-D Stegman cores both contain relatively thick intervals of solution-altered, poorly fossiliferous, fenestral, mud-cracked lime mudstone (Dunham's classification, see Dunham, 1962) that lie above a thin, grain-supported carbonate. The restricted lime mud-stone reflects an extensive period of shallow-water, low-energy, restricted-marine conditions. The rocks were later exposed to subaerial processes, documented by the formation of caliche crusts. These carbonates and their associated early, intense diagenesis are common across the positive and upper (northern) shelf areas of the CA and the CKU.

The #2-D Stegman core is located on the northern edge of the Rush Rib positive area identified earlier. The marine shale is missing in both the #2-D Stegman and #9 Morel cores, probably reflecting their positive location on the shelf. Furthermore, each contains a basal lag deposit that grades rapidly into the regressive carbonate.

The Stanolind #3 Denker and the Conoco #11 Ainsworth cores located on the southeastern portion of the CKU contain more open marine, fossiliferous wackestones thin oolitic-grainstone in the upper portion of the regressive carbonate. Subaerial processes are still very apparent with solution vugs and fracture porosity important in reservoir development.

Other intervals oolitic grainstone in adjacent cycles of the Kansas City Group in the #3 Denker core suggest that extended periods of high-energy conditions on the sea-floor occurred late in these cycles.

As contrasted with areas north of this location, the oolite bodies become thicker and more widespread to the south and around the periphery of the CKU to the east. The Texaco #1 Becker core in western Finney County just off the southwestern corner of the study area contains a thick, oolitic grainstone interval typical of most of the upper regressive carbonate of the Kansas City Group along this area of the shelf. The cross-stratified oolite strata separated by thin lime wackestone intervals apparently represent multiple episodes of prograding submarine dunes. The oomoldic porosity typical of these units, a reflection of leaching by under-saturated waters, does not in itself result in effective porosity. What is necessary for reservoir formation is the development and preservation of inter-granular porosity or the formation of fractures.

INTEGRATION OF CORES AND MAPS

The oolite trend as identified from cores and records of sample cuttings coincides in the southwestern and southeastern map areas with trends of thick, porous carbonate (Fig. 10), relatively rapid thickening of the cycle interval (Fig. 7), and greater than 90% carbonate (Fig. 8). The maximum GR value of the marine shale exceeds 200 API units over much of this same area (Fig. 9).

This southern area of the map is interpreted to be the location of a break in the slope from the more gentle shelf to the north. The break in slope runs generally east-west, wraps around the CKU, and extends eastward off the mapped area. A comparison with the producing L-KC oil fields (Fig. 3) indicates that, where the thickness of log-derived porosity exceeds 12 feet, oil accumulation is hampered either by non-effective oomoldic porosity or by small structural closures which were not sufficient to contain the oil in these thick zones of widespread porosity when the area underwent structural deformation and differential subsidence. If any units produce, it is usually the thinner limestone units of different cycles, interbedded with the thick oolite layers.

SUMMARY

The J-Zone regressive carbonate in proximity to the crest of the Cambridge Arch is dominated by mud-rich carbonates affected by intense levels of leaching by waters undersaturated with respect to calcium carbonate. This has resulted in an erratic distribution of small oil reservoirs. Farther south over the CKU and rimming the CA the grain-supported carbonates are more abundant. They helped to focus and direct undersaturated water through the carbonate layer, forming more laterally extensive reservoir rocks and prolific oil fields.

Oolitic grainstones are thick and widespread in the southern area of the map, because of changes in shelf configuration (break in slope, increase southerly dip of paleoslope) that focused wave and current action when waters became shallow in the later portion of the cycle when terrigenous influx was minimal. Oil exploration in the Kansas City Group in this oolite tract is more risky than over the northwestern shelf. Much of Ness County and the areas south and southwest of the CKU extending down to the southern map border are part of the more risky oolite tract. Ness County, although heavily explored, has had only two L-KC field developments in the northeast corner of the county. Just north of Ness in Gove, Lane, and Trego counties on the northwestern platform area, new L-KC fields are rapidly being developed (Fig. 3). There the thickness of porosity is moderate although structures are subtle. Nevertheless the trapping mechanism of the oil apparently relies in part on the isolated nature of the porous section of the carbonate.

The northwestern Kansas platform (the western mapped area) is a location of moderate carbonate thickness and gentle structural undulations and holds the greatest potential for oil exploration. There are fewer trends of any significant regional continuous porosity than in other areas and it might be expected, and is presently experienced, that small fields would be the norm.

Local paleo-highs (isopach minimums) on the sea floor are important in focusing the waves and currents of the sea to produce shallow-water, grain-rich carbonates. Also during late regression these paleo-highs would assist in directing the effects of early freshwater diagenesis (Watney, 1980). Nevertheless, the extent of subaerial processes cannot be expected to be as intense in extreme northwestern Kansas as over the Central Kansas Uplift or the Cambridge Arch; thus mud-rich carbonates only occasionally will be altered enough to produce reservoir-quality rocks. The thin layers and lenses of grainstones should continue to be economically feasible prospects for the immediate future as the price of oil continues to climb. Prospects will require more than seismic prospecting; but new advances in high-resolution seismology may help identify the various facies tracts. Nevertheless, knowledge of cycle-by-cycle stratigraphy and sedimentology as revealed by logs and cores should improve the success of finding additional reserves on the western Kansas shelf.

REFERENCES CITED

Brown, H.A., 1963, Examination of Pennsylvanian carbonate banks in south western Kansas: Amoco Production Company, Central Division Geological Report 13-A, Kansas Geological Survey Open File Report.

Choquette, P.W., and Pray, L.C., 1970, Geological nomenclature and classification of porosity in sedimentary carbonates: American Association of Petroleum Geologists Bulletin, Vol. 54, p. 207-250.

Crowell, J.C., 1978, Gondwanan glaciation, cyclothems, continental positioning, and climate change: American Journal of Science, Vol. 278, p. 1345-1372.

DuBois, Martin, K., 1979, Factors controlling the development and distribution of porosity in the Lansing-Kansas City "E" Zone, Hitchcock County, Nebraska: M.S. Thesis, University of Kansas, Lawrence, 100 p.

Duff, P.M.D., Hallam, A., and Walton, E.K., 1967, Cyclic sedimentation - Developments in Sedimentology 10, Amsterdam, Elsevier, 280 p.

Dunham, R.J., 1962, Classification of carbonate rocks according to depositional texture, in Ham, W.E., ed., Classification of carbonate rocks, American Association of Petroleum Geologists Memoir 1, p. 108-121.

Hassan, M., Hossin, A., and Combaz, A., 1976, Fundamentals of the differential gamma ray log interpretation technique: Transactions 17th Annual Logging Symposium, Society Professional Well Log Analysts, Paper H, 18 p.

Heckel, P.H., 1977, Origin of phosphatic black shale facies in Pennsylvanian cyclothems of mid-continent North America: American Association of Petroleum Geologists Bulletin: Vol. 61, p. 1045-1068.

Heckel, P.H., 1980, Paleogeography of eustatic model for deposition of mid-continent Upper Pennsylvanian cyclothems, in Fouch, T.D. and Magathan, E.R., eds., Paleozoic Paleogeography of the West-Central United States, Rocky Mountain Paleogeography Symposium 1: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, p. 197-216.

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

Moore, G.E., 1979, Pennsylvanian paleogeography of the southern Mid-Continent region: Tulsa Geological Special Publication 1, p. 2-12.

Morrison, E.R., 1979, Subsurface study of the Lansing Group in Gove and Trego Counties: M.S. Thesis, West Texas State University, Cayon, 53 p.

Rascoe, Bailey, Jr., 1962, Regional stratigraphic analysis of Pennsylvanian and Permian rocks in western Mid-Continent, Colorado, Kansas, Oklahoma, Texas: American Association of Petroleum Geologists Bulletin, Vol. 46, p. 1345-1370.

Rona, P.A., 1973, Relations between rates of sediment accumulation on continental shelves, sea-floor spreading, and eustacy inferred from the central North Atlantic: Geological Society of America Bulletin, Vol. 84, p. 2851-2872.

Schmoker, J.W., 1981, Determination of organic-matter content of Appalachian Devonian Shales from gamma ray logs: American Association of Petroleum Geologists Bulletin, Vol. 67, p. 1285-1298.

Vail, P.R., Mitchum, R.M., and Thompson, S., III, 1977, Seismic stratigraphy and global changes of sea level, Part 4: Global cycles of relative changes of sea level, in Payton, C.E., ed., Seismic Stratigraphy--applications to hydrocarbon exploration, American Association of Petroleum Geologists Memoir 26, p. 83-97.

Wanless, H.R., and Shepard, F.P., 1936, Sea level and climatic changes related to late Paleozoic cycles: Geological Society of America Bulletin, Vol. 47, p. 1177-1206.

Watney, W.L., 1979, Gamma ray-neutron cross plots as an aid in sedimentological analysis, in Gill, D. and Merriam, D.F., eds., Geomathematical and Petrophysical Studies in Sedimentology, Computers and Geology, Vol. 3, Oxford, Pergamon Press, p. 81-100.

Watney, W.L., 1980, Cyclic Sedimentation of the Lansing-Kansas City Groups in northwestern Kansas and southwestern Nebraska: Kansas Geological Survey Bulletin 220, 72 p.

Watney, W.L., and Ebanks, W.J., Jr., 1978, Early subaerial exposure and freshwater diagenesis of Upper Pennsylvanian cyclic sediments in northern Kansas and southern Nebraska: American Association of Petroleum Geologists Bulletin, Vol. 62, p. 570-571.

Figure Captions

Figure 1. Geophysical well log control. Logs are primarily gamma ray in combination with resistivity or porosity device. 1825 wells encompass Central Kansas Uplift and Cambridge Arch on the east and Hugoton Embayment and Western Kansas Shelf to the west extending to the Colorado border (Merriam, 1963).

Figure 2. Southwest to northeast stratigraphic cross section of a portion of the Kansas City Group including the H, I, J, and K-Zone Cycles, A-A', extending across the northern end of the Central Kansas Uplift into the Salina Basin. Logs used include gamma ray (GR), Neutron (N), and Laterolog (LL). Standard scales for these logs are provided. Thickness of porous carbonate is listed along margins of each log. Datum is the base of the J-Zone cycle. A structural cross section of the same wells is inset on this illustration. Measured depth of top of displayed log-sections ranges from 4200 feet on the southwest to 3200 feet on the northeast.

Index to wells included on cross section:

Section #	Well Name	Location
1	Thunderbird #1 Maxwell	NWSW 32-23-29W
2	Goff #1 Chennel	SWSW 21-21-28W
3	Kern-Landis #1 Ward	SWNE 4-19-26W
4	Hawley Tr. #2 Brungardt	SWNE 13-15-25W
5	Slawson #1-A Weedin Tr.	SWNW 1-14-22W

6	Conoco #9 Morel	NENENE 15-9-21W
7	Imperial #1 Lesage	SESENE 18-7-20W
8	Nat. Assoc. Pet. #1-A Lafferty	NWSWSE 19-4-19W
9	Dreiling et al. #1 Conway	NESWSE 3-3-13W

Figure 3. Producing oil fields from carbonate reservoirs in the Lansing and Kansas City Groups in western Kansas. Fields producing from this interval are in solid while other fields with other pay zones are outlined only.

Figure 4. Interval isopach base of G-Zone Cycle (near top of Kansas City Group) to basal Pennsylvanian unconformity. This and following contour maps were produced by computer graphics software, Surface II, using equipment at the Kansas Geological Survey. Contours are truncated at edge of well control. Central Kansas Uplift (CKU) distinctly outlined on this map.

Figure 5. Structural contour on top of J-Zone carbonate. Faults are not mapped by this automated procedure, but are suggested by trends of closely-spaced contours. West side of CKU identifiable where contours converge as west dip increases into the Hugoton Embayment. Regional closure over crest of CKU, SW-NE oriented. Voshell Anticline trend found in extreme southeast portion of contoured area.

Figure 6. Interval isopach of combined H-, I-, J-, and K-Zone Cycles. Two centers of substantial thinning over western portions of CKU and CA. Greater rate of thickening in southwest and southeast areas of maps off of CKU.

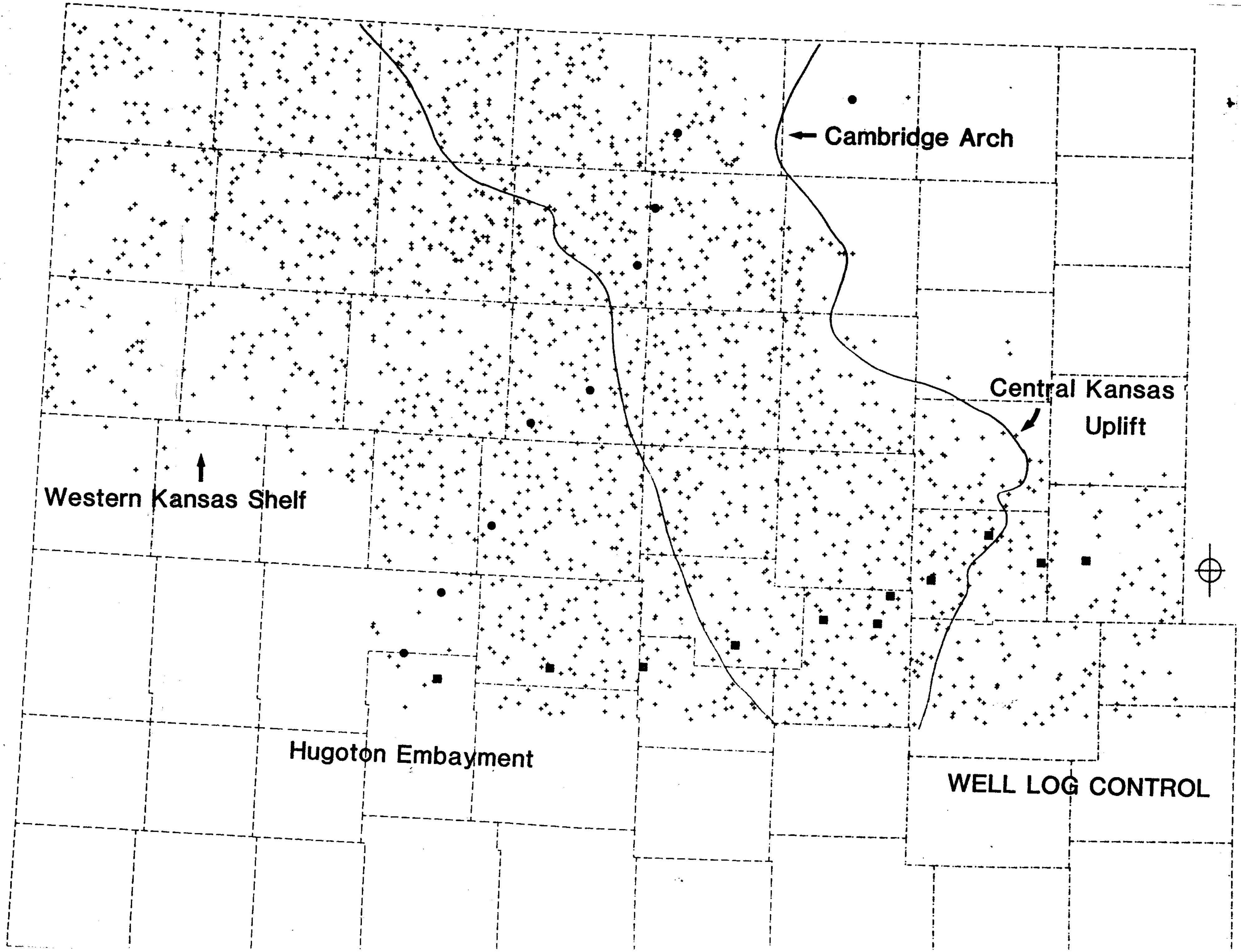
Figure 7. Isopach of the interval from top of the regressive carbonate, J-Zone, to base of this cycle. Thinning again over centers in the western portions of the CKU and CA while interval rapidly thickens and thins in southwest and southeast. By comparison, variation in northwestern Kansas is rather uniform and less significant.

Figure 8. Contour map of ratio of thickness of marine portion of cycle to that of the thickness of the regressive shale of J-Zone cycle expressed in percent. Minimum values represent a relatively thick regressive shale that extends down from the northwest as a lobe along the west side of the CKU. The northwestern limit of contours are positioned along the northern pinchout of the I-Zone, the upper datum for this isopach.

Figure 9. Contour map of maximum gamma radiation recorded for marine shale of J-Zone Cycle. Data obtained from peak reading on gamma ray adjacent to shale. Areas of minimum values occur over the CKU and CA.

Figure 10. Contour map of cumulative thickness of carbonate porosity exceeding eight percent for J-Zone carbonate. Upper shelf including CKU and CA covered by broad areas of less than two feet of "regionally connected porosity" interrupted by isolated trends of porosity exceeding four feet. Complex porosity patterns of values up to 40 feet are located in the southwestern and southeastern map area.

Figure 11. Simplified graphic core descriptions of selected cores of the J-Zone cycle keyed to location of cores on map of study area. Standard lithologic symbols.



Cambridge Arch
Central Kansas
Uplift
Western Kansas Shelf
Hugoton Embayment
WELL LOG CONTROL

Fig. 1

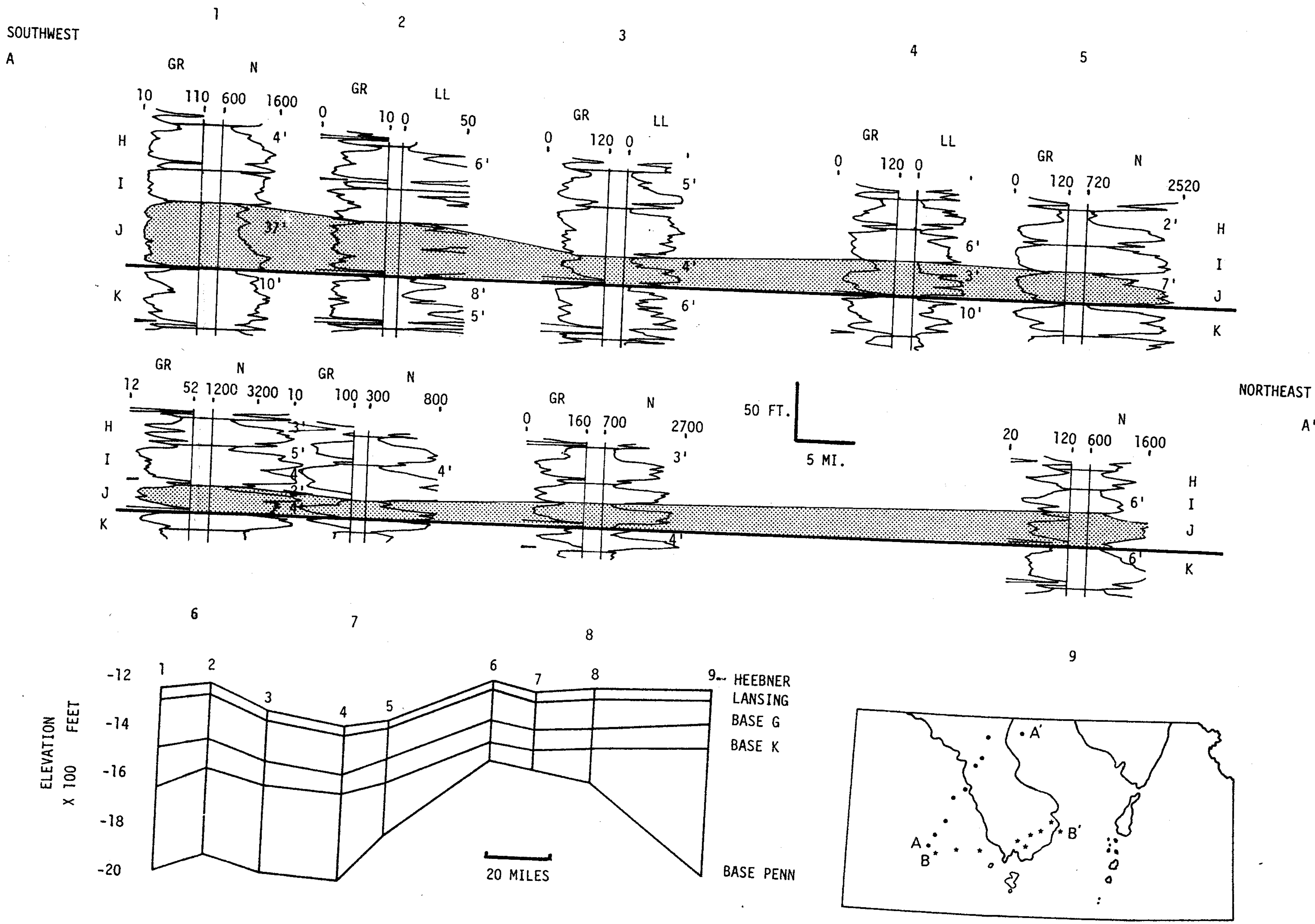
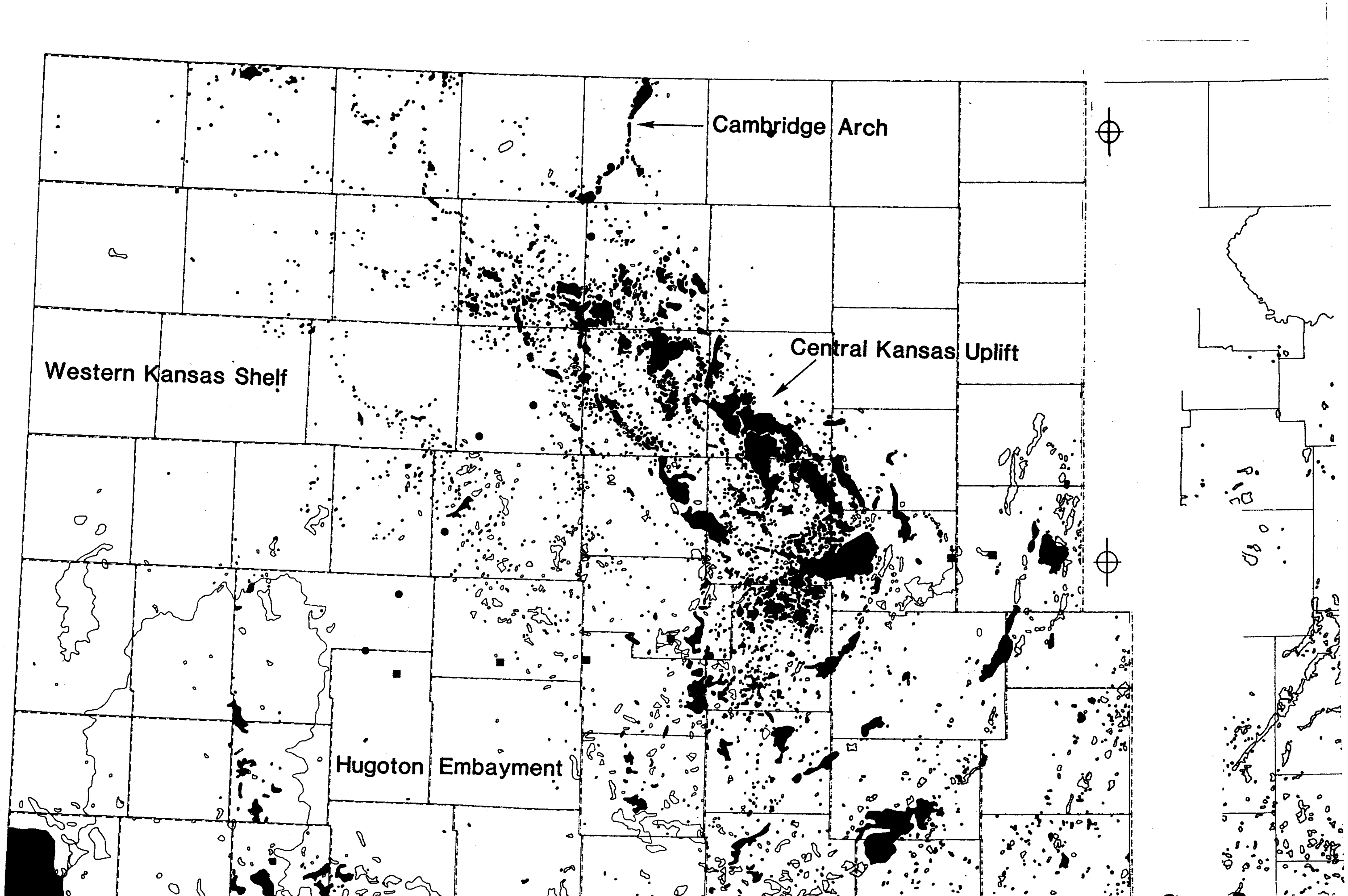
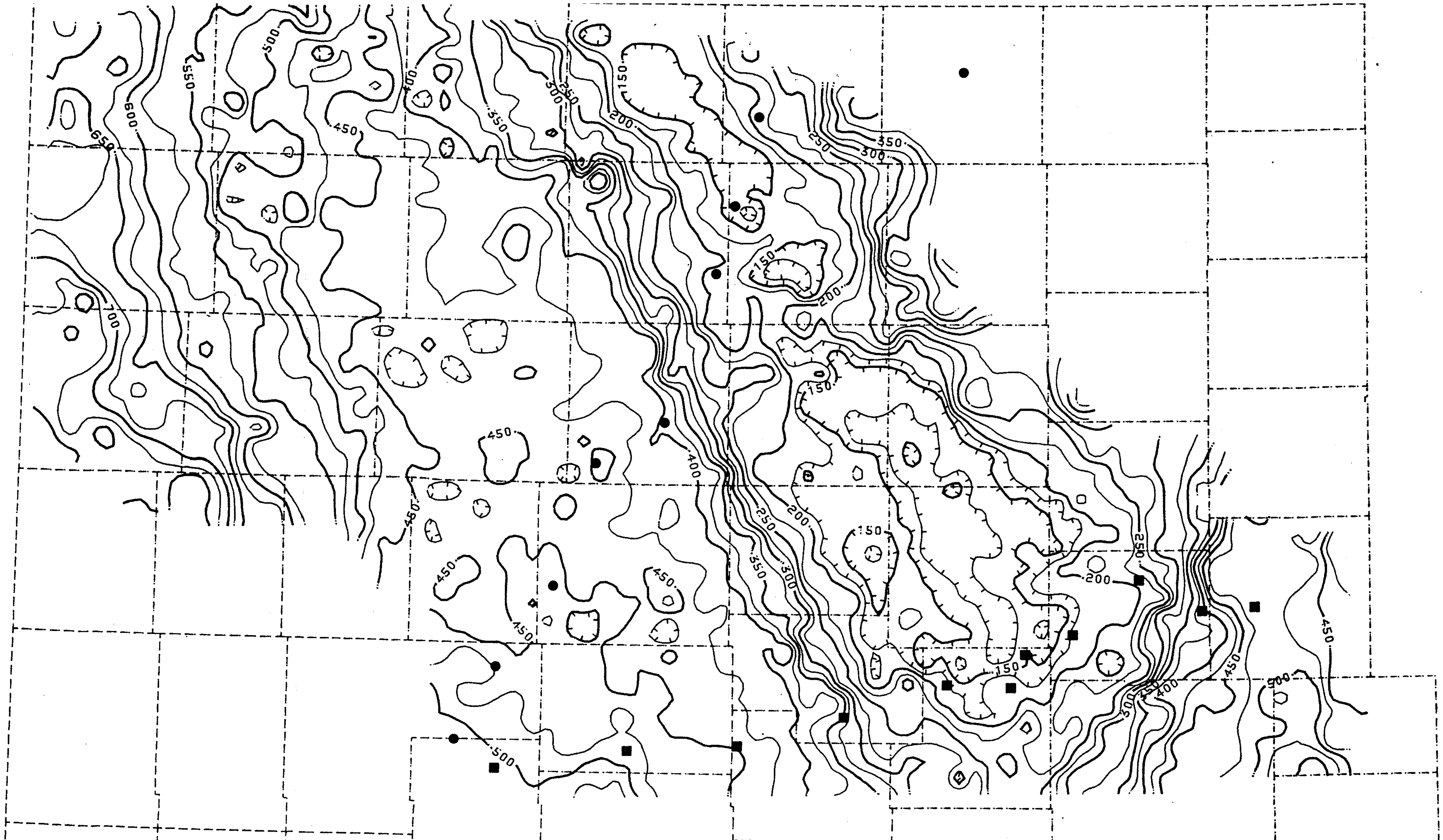

SOUTHWEST
A
NORTHEAST
A'
GR
N
LL
H
I
J
K
50 FT.
5 MI.
ELEVATION X 100 FEET
-12
-14
-16
-18
-20
HEEBNER
LANSING
BASE G
BASE K
BASE PENN
20 MILES
A
B
A'
B'

Fig. 2



Cambridge Arch
Central Kansas Uplift
Western Kansas Shelf
Hugoton Embayment

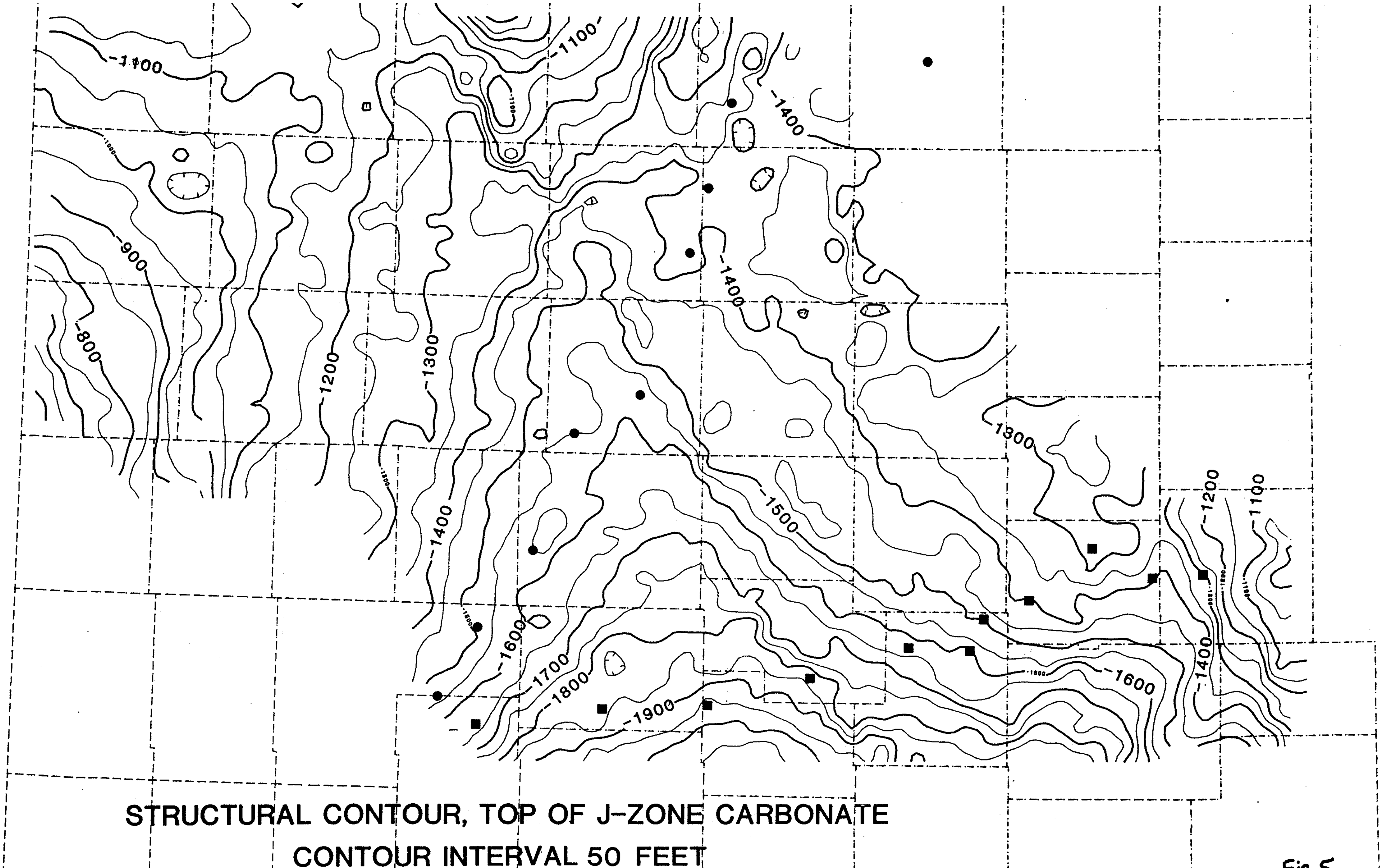
Figure 3



INTERVAL ISOPACH, BASE G-ZONE CYCLE TO BASE PENNSYLVANIAN

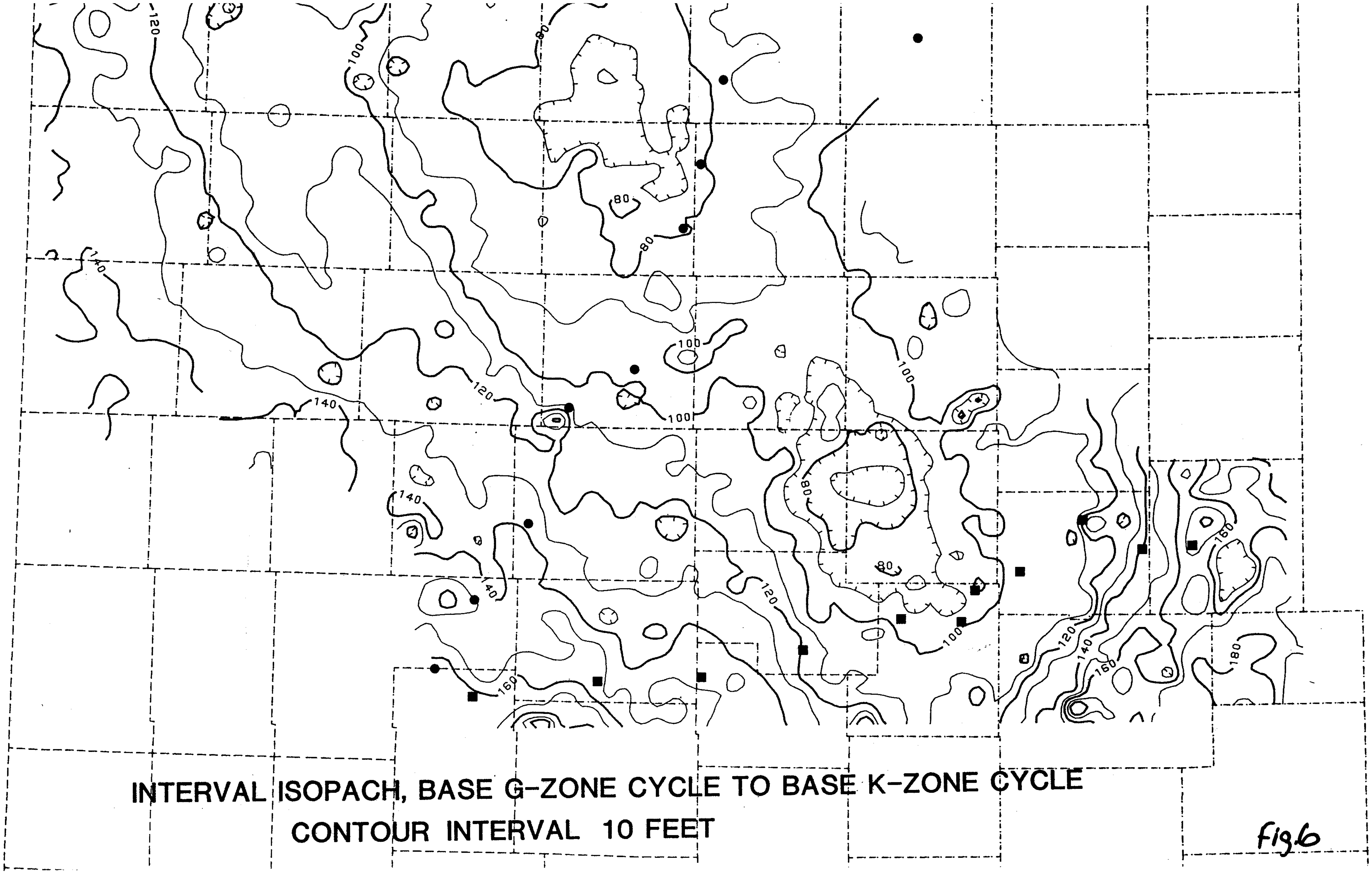
CONTOUR INTERVAL 25 FEET

Fig. 4



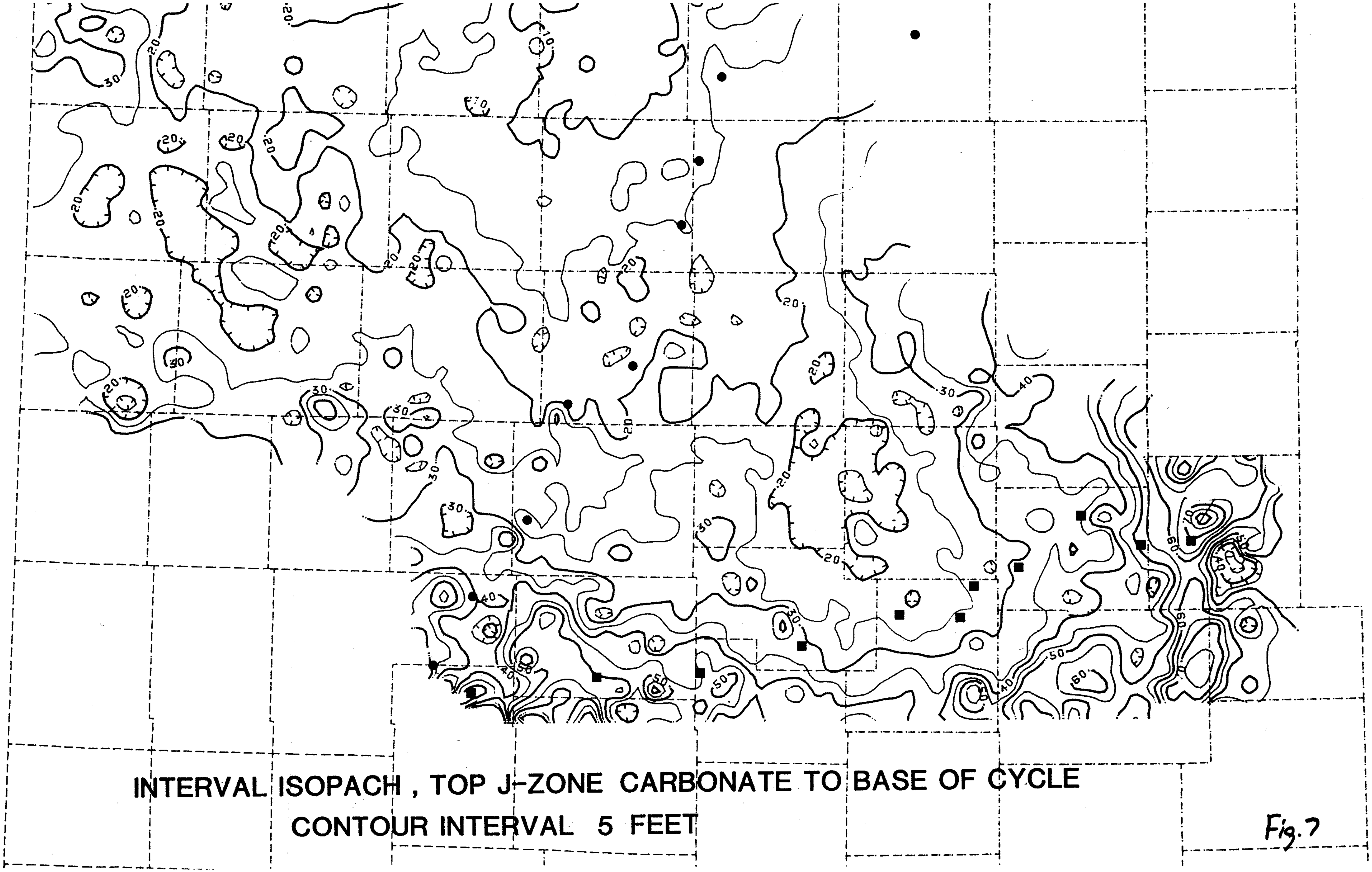
STRUCTURAL CONTOUR, TOP OF J-ZONE CARBONATE
CONTOUR INTERVAL 50 FEET

Fig.5



INTERVAL ISOPACH, BASE G-ZONE CYCLE TO BASE K-ZONE CYCLE
CONTOUR INTERVAL 10 FEET

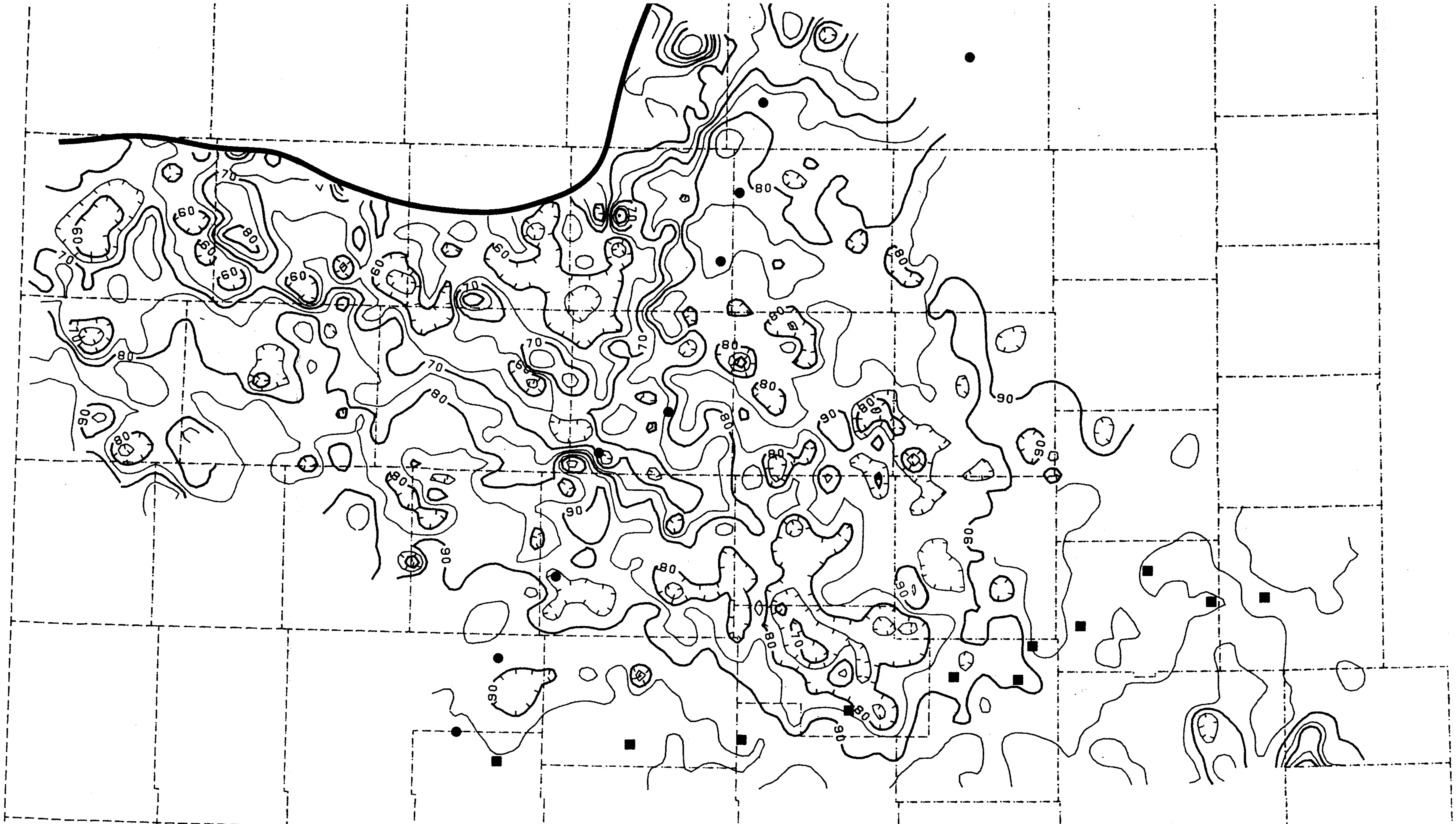
Fig.6



INTERVAL ISOPACH, TOP J-ZONE CARBONATE TO BASE OF CYCLE

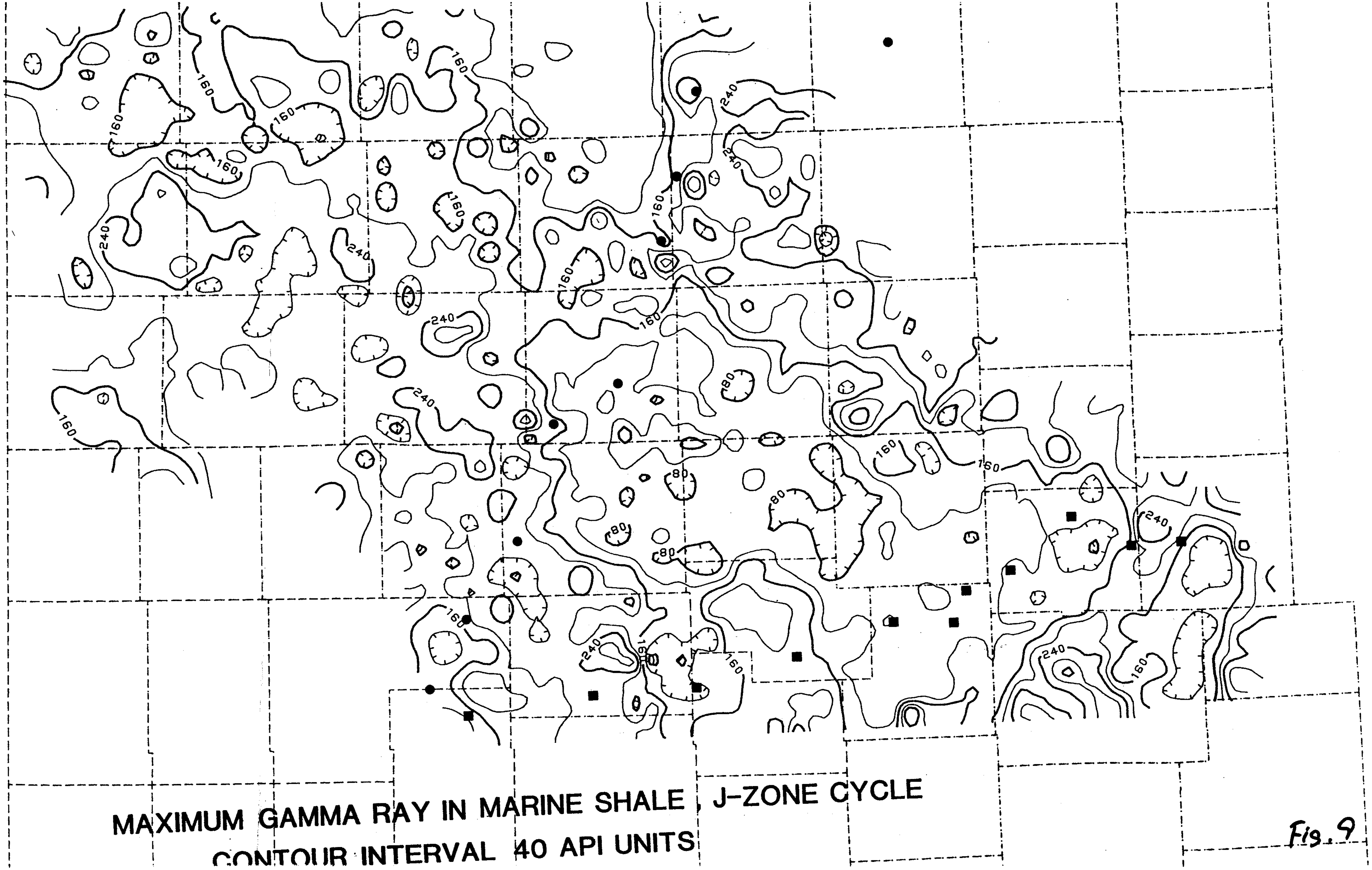
CONTOUR INTERVAL 5 FEET

Fig. 7



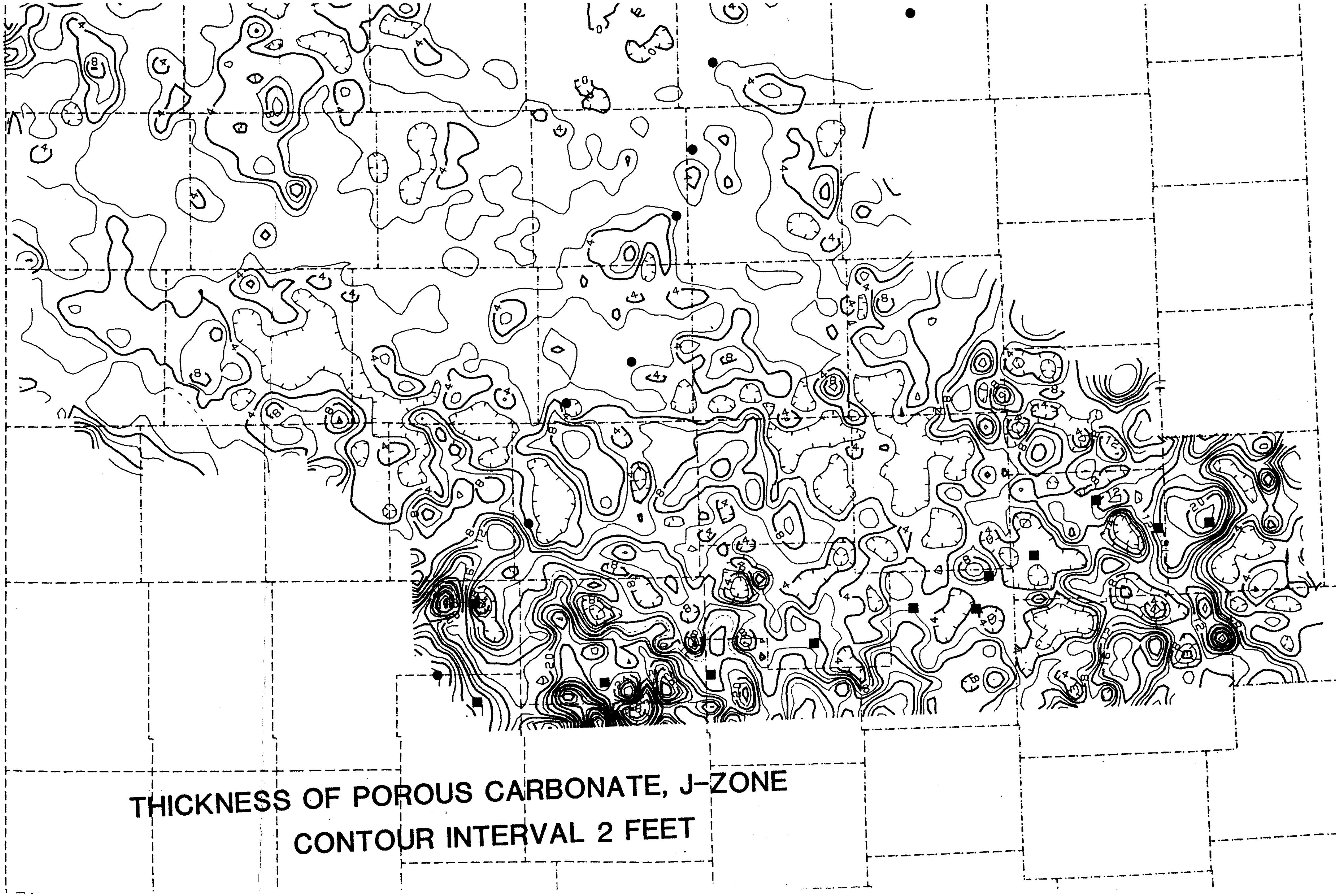
RATIO OF CARBONATE TO REGRESSIVE SHALE, J-ZONE CYCLE
CONTOUR INTERVAL 5 PERCENT

Fig. 8



MAXIMUM GAMMA RAY IN MARINE SHALE , J-ZONE CYCLE
CONTOUR INTERVAL 40 API UNITS

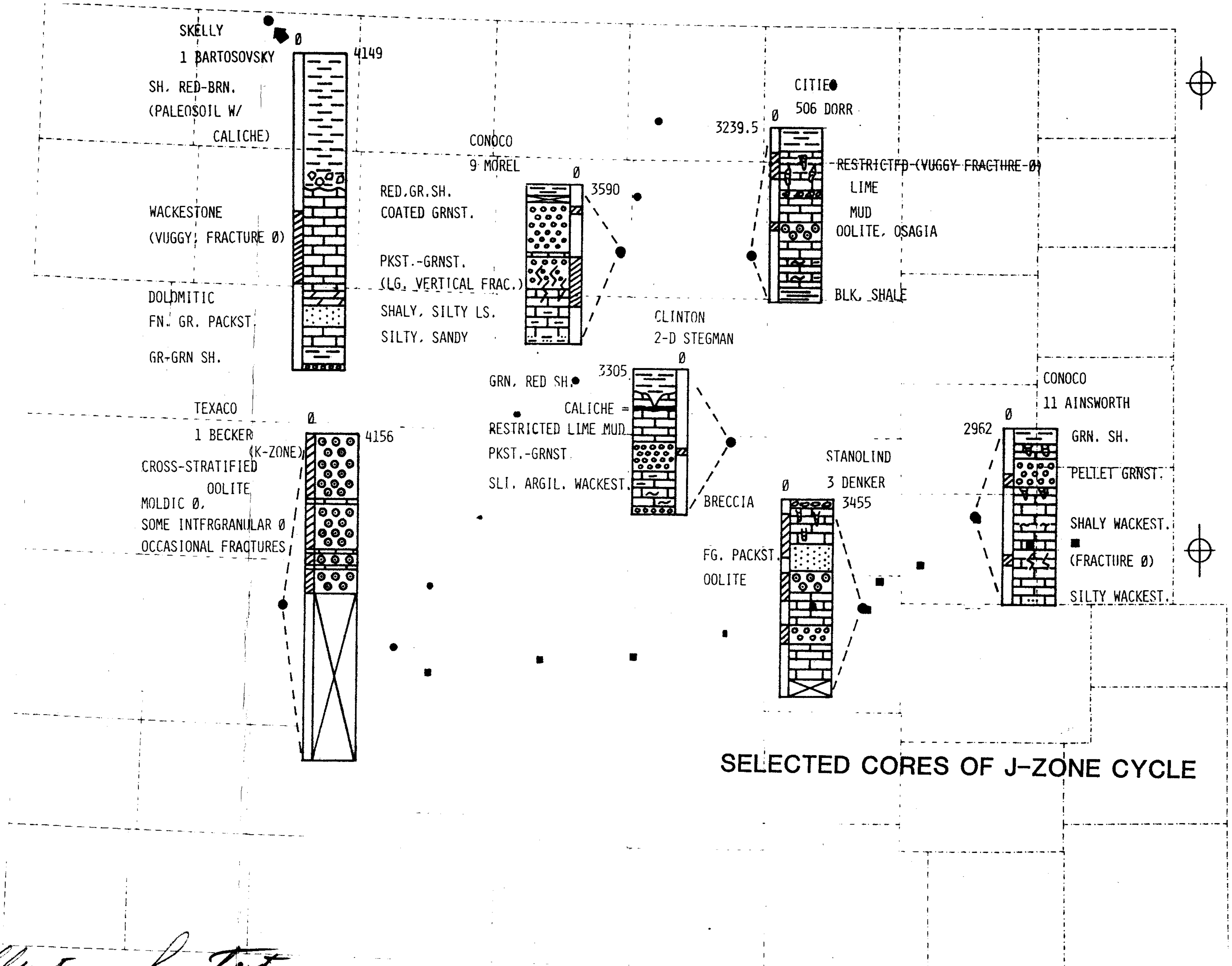
Fig. 9



THICKNESS OF POROUS CARBONATE, J-ZONE

CONTOUR INTERVAL 2 FEET

Fig 10



SELECTED CORES OF J-ZONE CYCLE

illustr. for text

Fig. 11