TECHNIQUES USED IN INTERPRETING SEISMIC DATA IN KANSAS

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ABSTRACT

Many of the structures of Kansas are small and of low relief. The unknown quantities assumed in conventional seismic computation may result in errors of such magnitude that they completely mask oil field structures or relative dip adjacent to points of geologic control. Improvement in recording techniques and interpretation has decreased this error greatly. Knowledge, gained only by experience with many problems, makes the seismologist aware of the cause of error. This paper lists many of the problems and suggests new methods of solving them.

INTRODUCTION

The seismograph has been a very important and valuable tool for oil exploration in Kansas throughout the years. It has been successful; it is relatively inexpensive and, combined with shallow subsurface information obtained from electric logs, is becoming more and more accurate.

Although seismic record quality in Kansas generally is good, many of the oil field structures are of such low relief that they can be discerned only through close approach to the normal limits of seismic accuracy. The major seismic problems are found in shallow formations, from the surface down to the Stone Corral anhydrite of Permian age. Lesser problems are caused by deeper formations. Concentrated study and research by the geologist and geophysicist on the shallow formations is necessary in locating the new oil fields, which are increasingly more difficult to find.

This paper lists briefly the problems that arise in interpreting seismic data in Kansas and suggests possible methods for overcoming some of these difficulties.

PROBLEMS

Unusual conditions in Kansas introduce errors in conventional seismic methods of computation. Some of the problems facing the interpreter of seismic data are discussed below. The weathering problem is omitted because it is universal.

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Irregular topography.—Areas of irregular topography in some parts of Kansas are characterized by greater average velocities on hills, as compared with average velocities in valleys. It has been suggested that the additional sediment weight causes higher velocities. Insufficient research has been conducted in Kansas to prove this conclusion or to establish a usable velocity ratio for hills and valleys.

Varied outcropping formations.—Different kinds of outcropping rocks in the same area are a source of near-surface velocity variation. In addition, record quality is poor, owing to "character" changes and "phasing". In such areas, field procedure usually is altered so that explosive charges are placed in geologically comparable material. This methods of correction requires much experimentation in the field. Parts of Rooks and Ellis Counties are typical problem areas.

Thick Pleistocene or Tertiary mantle.—Inasmuch as Pleistocene or Tertiary mantle rock has a low velocity, it must be treated as a second weathering layer, which must be penetrated by the shot hole or measured for velocity. This mantle rock is as much as 750 feet thick and in places has a very irregular bedrock contact. If shot-hole penetration is not economically feasible, interval maps are used.

Regional lateral velocity changes.—In Kansas, a regional southward velocity increase is found in rocks below the Stone Corral anhydrite. The problem is especially vexing where there is insufficient velocity control.

Wellington salt.—The salt of the Wellington formation of Permian age has a much higher seismic velocity than the overlying or underlying shales. Problems arise because of thickness and velocity changes from one shot hole to the next. The velocity changes are caused by variation in salt density. In such areas conventional seismic maps are in error on horizons below the salt; time-isopachous or "isotime" maps using the Stone Corral anhydrite as a datum also are in error. Data on deeper beds are obtained from interval maps based on two reflections below the salt; it is assumed that thinning is the result of structure. Record quality must be at its best for precise construction of interval maps.

Blaine salt.—The Blaine salt, a salt of the Blaine formation, causes error also because of thickness and velocity change, but because the salt is relatively shallow, "isotime" maps usually are accurate. Widess (1952) has discussed the seismic problems due to the Blaine salt in the Blaine Salt Basin for an area in and adjacent to Clark County, Kansas.

Reference plane relief.—The "isotime" method of seismic interpretation (discussed more fully under Method of Interpretation) is based on the assumption that the reference plane is flat. The assumption may not be valid. For example, the Stone Corral anhydrite, a widely used reference marker, is not flat in many areas and the irregularity causes errors in interpretation.

Arbuckle unconformity.—The rocks of Kansas are sufficiently conformable that most seismic reflections are of adequate quality, even though velocity control for depth computation and identification of mappable stratigraphic horizons is sparse. One notable exception is the erosion surface at the top of the Arbuckle, which may yield no reflection or one too complex to be discerned on the records. The low areas of this old Arbuckle surface usually are filled or partly filled with conglomerate. It is possible that detailed velocity studies of conglomerate and Arbuckle may reveal a velocity difference of sufficient magnitude that the Arbuckle lows can be determined by measuring time differences from a Lower Pennsylvanian reflection to a reflection within the Arbuckle.

METHODS OF INTERPRETATION

Many of the problems of seismic interpretation cannot be solved by any single method of interpretation. Indeed, it is likely that experience and good velocity control are the most important factors in successful interpretation. Figure 1 shows the location of some typical seismic records (Fig. 2, 3, 4, 5) in various Kansas counties, which may aid the geophysicist in acquiring familiarity with Kansas records and record quality. An aid to velocity control is the partial list (Table 1) of well velocity surveys in Kansas through 1957. This list was taken mainly from the compilations of wells shot for velocity (Swan, 1944, 1946, 1949, 1951; Gaither, 1956, 1957, 1957a).

In the following paragraphs, the methods of interpretation employed in Kansas are listed with a discussion of the advantages and disadvantages of each and the limit of error involved.

Normal uphole method.—This method of determining thickness of the weathered layer from uphole time is the universal method of seismic computation. Inasmuch as it is familiar to all seismologists, it will be mentioned only briefly.

Its limitations stem from difficulties in controlling error and from assumptions made in extending of the "weathering" thickness or near surface velocities. It is assumed that the "weathering" at the timing geophones is the same as at the shot hole. The accumulation of slight errors in reading all the various times from the records is another source of error. These errors add up to about .005 second, the usual limit of error acceptable for seismograph work.

Modified uphole method.—This method determines the "weathering" time or depth at the position of the center traces used for timing. When the timing geophones are 55 to 75 feet from the shot hole, the greatest accuracy is obtained and the error can be reduced to about .003 to .004 second.

About .0005 second greater accuracy can be gained by firing the shot so that it explodes at exactly zero time on the record (exactly on a heavy timing line). This is, then, one time that is always zero and no reading error can be made in interpolating the time of the explosion.

The above methods of computation are, of course, also subject to error introduced by velocity changes in rocks between the depth of the shot and the reflecting bed. By drilling 20 to 50 feet into "bed rock", errors caused by the weathered zone at the surface usually can be eliminated. The velocity change from the

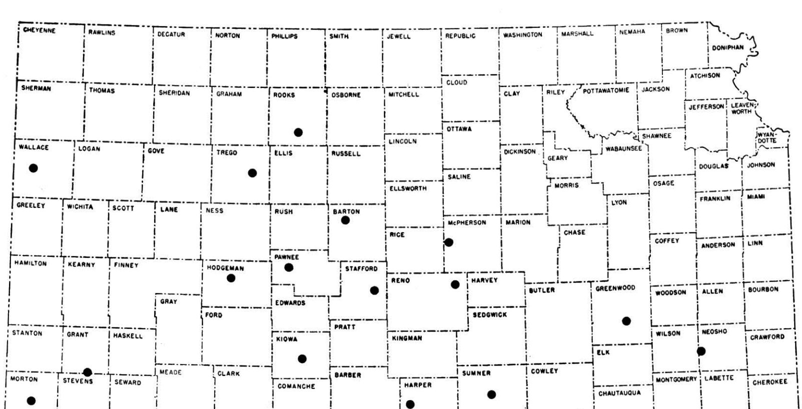

FIG. 1.—Map showing location of seismic records.

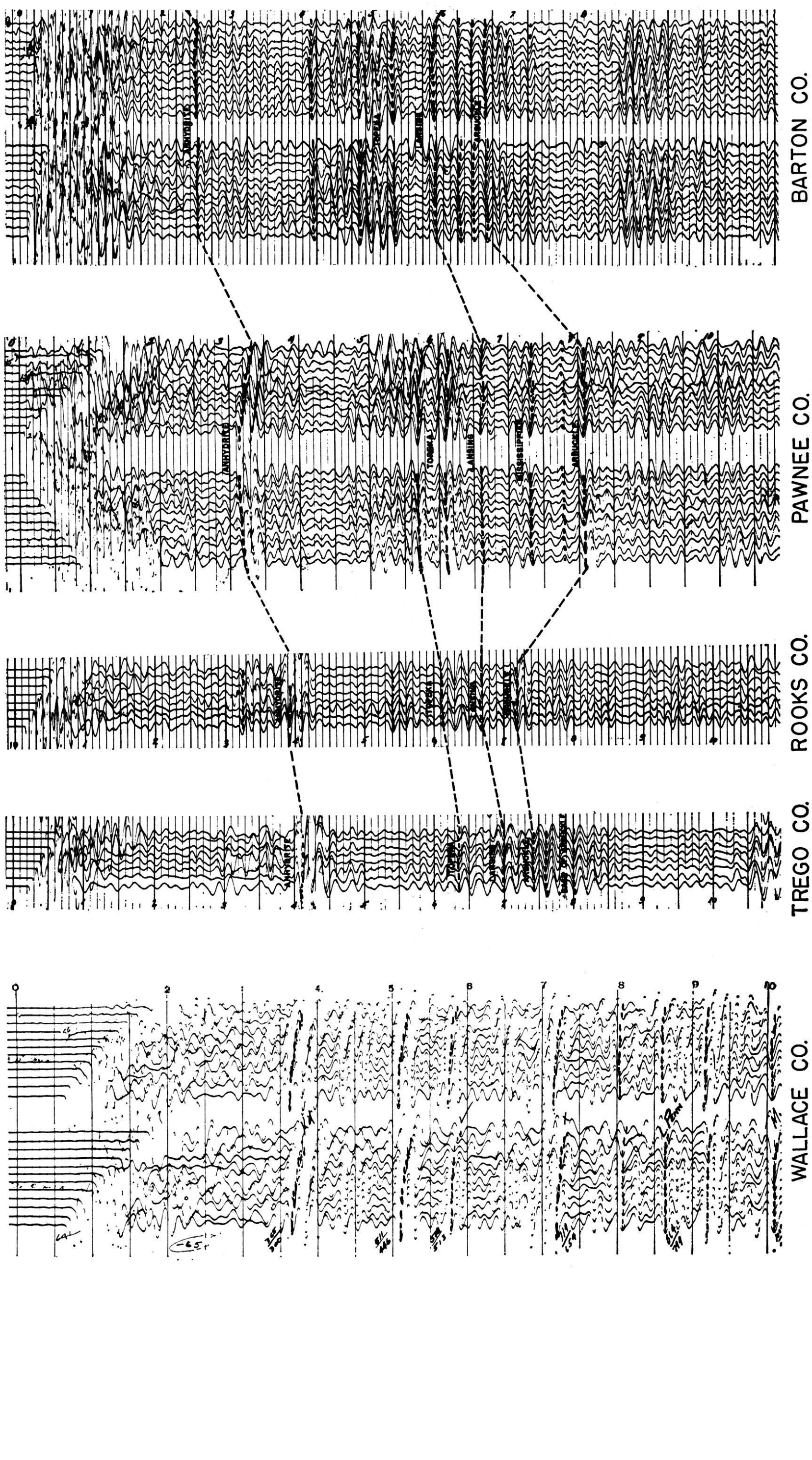

FIG. 2.—Typical seismic records, Kansas counties.

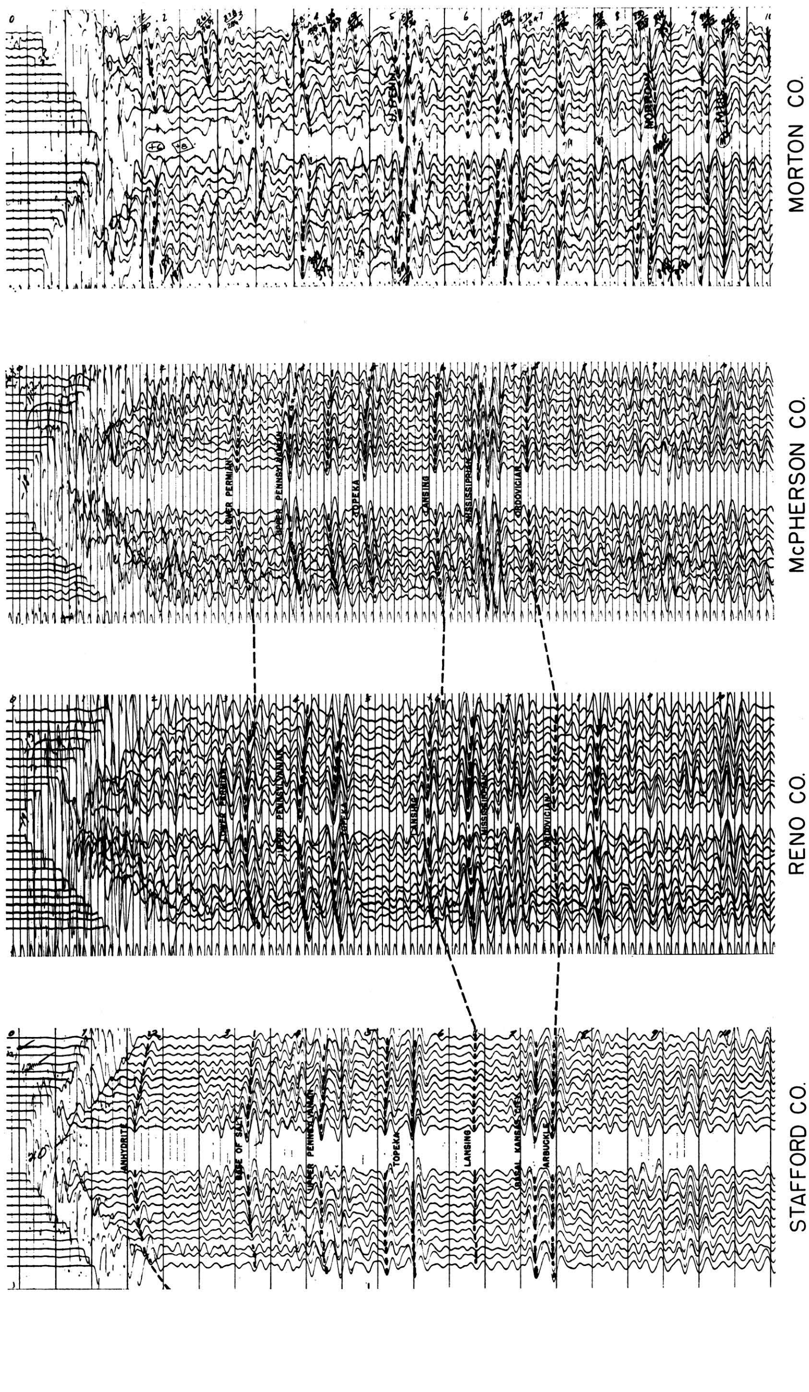

FIG. 3.—Typical seismic records, Kansas counties.

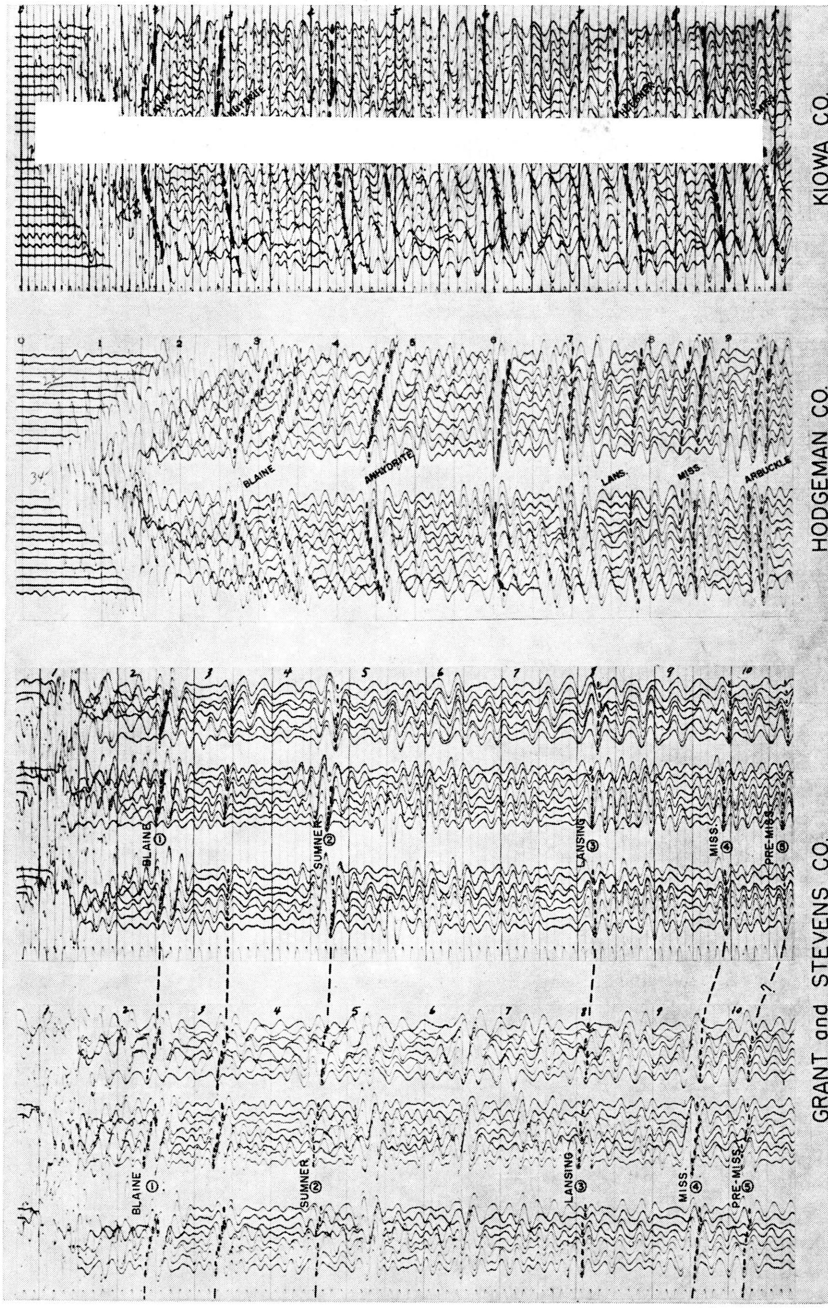

FIG. 4.—Typical seismic records, Kansas counties.

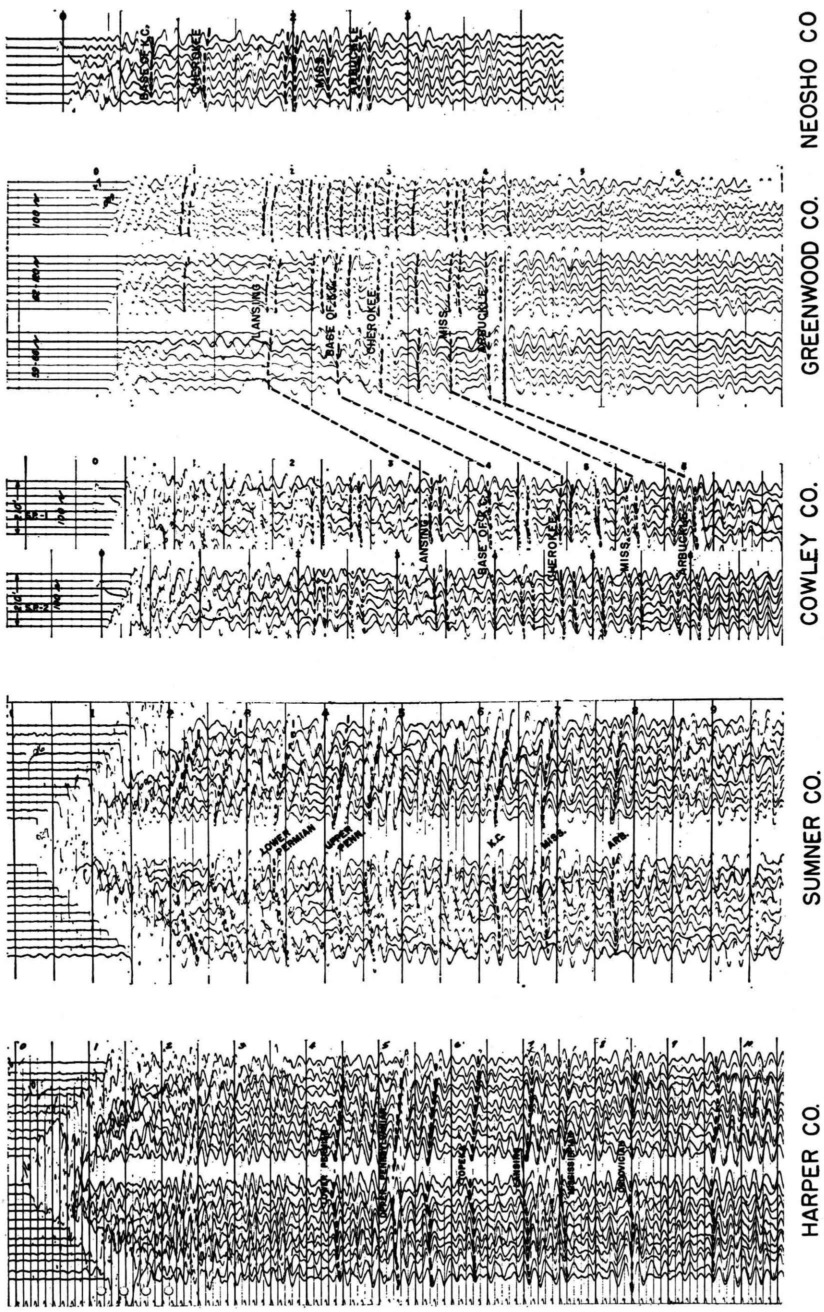

FIG. 5.—Typical seismic records, Kansas counties.

base of the shot to the Stone Corral anhydrite, possibly the greatest local source of error, is at least partly due to the unconformity between Cretaceous and Permian beds. Most of the regional southward velocity increase in Kansas occurs in rocks below the Stone Corral anhydrite, but seemingly the increase is gradual.

Velocity gradient structure maps.—This method has the limitations of the normal uphole and "modified" uphole methods except that it takes into account the regional velocity change. When actual velocities are not available, the map must be constructed by the use of "mis-ties" to wells and its accuracy is dependent on the accuracy of the well tops and the amount of well control. Extreme caution must be used to be certain that the error is not due to miscorrelation. This methods does not appreciably affect definition of local structure and normally is not used, as long as the problem of regional velocity change is considered in the evaluation.

Rough topography method.—Areas of irregular topography may pose extreme problems in Kansas. It is not unusual to have 200 feet of relief. This method assumes that the average velocity should be applied from the base of the shot rather than adjusted to a flat plane as is in the previously mentioned methods. The "rough topography" method tends to reduce the effect of the topographic changes. It suffers from most of the previously mentioned errors and is used mainly as a check against other methods of computation.

A certain amount of success has been obtained by drilling to a constant datum plane, either into the same formation on all holes or to a level datum plane. Velocity data so acquired have contributed to closer correlation of geologic and seismic information.

"Isotime" method using Stone Corral anhydrite.—In this method, time intervals are determined between reflections from the Stone Corral anhydrite, of Permian age, and reflections from lower rocks of Pennsylvanian, Mississippian, or Ordovician age. The "isotime" method is useful because the accuracy required in many areas of Kansas is much greater than ordinary seismograph methods will allow. The method assumes that the Stone Corral anhydrite is flat or essentially flat and that thinning is due to the structural attitude of deeper beds. It cancels all weathering and velocity errors from the Stone Corral to the sur-

TABLE 1.—*List of wells shot for velocity in Kansas through 1957**

County	Company	Lease	Location	Survey depth	Shot by	Date	Sponsored by
Barber	Drillers Gas	No. 2 Skinner	9-31S-14W	4,325	KVI	1946	KVI
Barber	Champlin Ref. Co.	Beardmores Calloway	20-31S-12W	4,663			Champlin
Barber	Continental	No. 1 Lake	SE SE SW 11-32S-14W	4,918	KVI	1946	KVI
Barber	Pure	No. 1 Palmer	SE NE SW 10-33S-10W	4,700	SSC	1937	OKWSA
Barber	Lindas & Armer, et al.	No. 1 Pfaff	NW SE NE 15-34S-10W	5,301	KVI	1948	Atlantic
Barber	Barber Oil Co.	No. 1 Brach	17-34S-15W	5,549	National	1954	Chicago Corp.
Barber	Chicago Corp.	Barabara Oil No. 1 Brach	17-34S-15W	5,549			Champlin
Barber	Conoco and City Prod.	No. 1 Sternberger	5-35S-13W	5,584	Conoco	1955	OKWSA
Barton	Sinclair-Pr.	No. 1A Davidson	9-16S-11W	3,343	Petty	1937	OKWSA
Barton	C. C. Millerd Sy	No. 1 Boertz	13-18S-12W	3,400	GRC	1931	
Barton	Derby Oil	No. 1 Berscheidt	12-20S-11W	3,000	GRC	1932	
Barton	Atlantic	No. 1 Schneider	15-20S-13W	2,438	....	1933	....
Brown	Carter	No. 1 Strat. Test	SW SW SW 24-4S-16E	3,475	Carter	1939	
Chautauqua	Frankfort	No. 1 Brazle	11-33S-9E	2,750	SSC	1955	Frankfort
Clark	Olson Oil	No. 1A Morrison	C SE SW 17-32S-21W	6,458	GSI	1941	
Comanche	Conoco	No. 1 Cole	8-34S-18W	6,426	Mayes-Bevan	1955	Conoco-Pure
Comanche	Pure	No. 1 Beal	5-34S-17W	5,937	SSC	1955	Conoco-Pure
Cowley	Barrett, et al.	No. 8 Waite	SW NW 21-31S-4E	3,100	Shell	1939	OKWSA
Cowley	Carter	No. 1 Radcliff	32-32S-7E	2,780	Carter	1951	Carter
Cowley	Texas	No. 1 Walton	31-33S-4E	3,724	SSC	1956	Texas
Decatur	Helmerich-Payne	No. 1 Penn	NW NW SW 16-2S-29W		SSC	1943	Texas
Decatur	Stanolind	No. 1 Hale	SE SE SE 32-2S-26W	4,019	Stanolind	1943	
Edwards	Kewanee	No. 1 Samuel	29-24S-19W	5,053	SSC	1956	Kewanee
Edwards	Stanolind	No. 1 Arensman	NE SE 23-25S-19W	5,065	Stanolind	1941	OKWSA
Edwards	Amerada	No. 1 Tansil	32-25S-19W	4,950	GRC	1929	
Ellis	Stanolind	No. 1 Furthmeyer	SE SE SE 25-12S-16W	3,025	GSI	1932	OKWSA?
Ellis	Darby	No. 1 Younger	NW NW NW 20-13S-17W	3,605	SSC	1941	Sunray?
Ellis	Pam Kar	No. 1 Moore	32-14S-19W	3,743	Western	1955	Stanolind
Ellsworth	Frankfort	No. 1 Kuch	8-14S-10W	4,290	SSC	1955	Frankfort
Ellsworth	Gypsy	No. 2 Kozisek	NE SE SE 16-16S-10W	3,300	SSC	1934	OKWSA
Finney	Shell	No. 1 Case	NE SE NW 7-21S-30W	5,530	SGC	1950	Shell
Finney	W. L. Hartman	No. 11 Damme	21-22S-33W	4,676	Central	1953	W. L. Hartman

Finney	Conoco	No. 1 Kleysteuber	29-26S-31W	5,662	Conoco	1953	Conoco
Graham	Shell	No. 8 Knipp	SE SW 14-9S-21W	3,835	Shell	1948	Shell
Gray	Champlin	No. 1 Becker	C NE SW 34-28S-29W	6,270	Stanolind	1939	OKWSA
Hamilton	Barnsdall-Denv.	No. 1 Porter	SW NE 30-25S-41W	3,000	Shell	1937	OKWSA
Hamilton	Shell	No. 1 Scott	SW NE 28-22S-43W	5,525	KVI	1948	KVI
Harper	Barry	No. 1 Anthony	17-31S-9W	4,812	GRC	1934	GRC
Harper	Texaco	No. 1 Baker	24-34S-5W	5,091	Texaco	1952	Texaco
Harper	Texaco	No. 1 Harrison	13-33S-6W	5,026	Texaco	1955	Texaco
Harper	Gulf	No. 1 Rife	31-33S-6W	5,133	Conoco	1954	Conoco
Harper	Anschutz	No. 1 Hoyt	7-33S-8W	5,075	Conoco	1955	Conoco
Harper	Texaco	No. 1 Baker	24-34S-5W	5,091	Texaco	1952	Texaco
Harper	Amerada	Mandeville	24-34S-6W	4,761	GRC	1929	GRC
Harper	Amerada-Dixie	No. 1 Misak	25-34S-6W	5,100	GRC	1931	
Harvey	Shell	No. 1 Neufeldt	SE SW NW 8-22S-3W	3,406	SSC	1934	OKWSA
Haskell	Huber and Conoco	No. 1 Weirauch	23-28S-31W	6,480	GGC	1955	Conoco
Hodgeman	Shell	No. 1 Springer	SE SW SW 24-22S-24W	5,100	SGC	1950	Shell
Hodgeman	Armer-Koplin	No. 4 Schraeder	SE NW NW 3-24S-24W	5,223	National	1951	Armer-Koplin
Kearny	Stanolind	No. 1 Judd	SE SE 15-21S-38W	5,275	Stanolind	1940	Stanolind
Kingman	Jack Heathman	No. 1 Woodridge	16-27S-7W	4,301	Central	1954	Heathman
Kingman	Skelly	No. 1 Rouse	C N/2 SE 20-27S-10W	4,282	Empire	1934	OKWSA
Kingman	Texaco	No. 1 Callison	31-29S-5W	4,561	Texaco	1954	Texaco
Lane	Virginia Drlg. Co.	No. 1 Harper	26-16S-30W	5,200	SSC	1957	Phillips
Logan	Gruenerwald	No. 1 Swart	12-11S-32W	4,757	Central	1956	OKWSA
Logan	Texas	No. 1 Smith	NE NE SW 30-11S-36W	5,321	Texaco	1943	OKWSA
Logan	Wycoff Bros.	No. 1 Uhland	8-14S-35W	4,888	SSC	1956	Phillips
Lyon	Wilkinson Drlng. Co.	No. 1 Gregory	30-15S-10E	3,301	SSC	1957	Carter
McPherson	Darby	No. 5 Coons	NW NE SW 20-19S-1W	3,361	SSC	1934	Carter
Meade	Texaco	No. 1 McJones	19-33S-29W	5,870	Texaco	1956	Texaco
Meade	Helmerich-Payne	No. 1 R. E. Adams	SW NW 11-35S-29W	6,150	Gulf	1946	OKWSA
Mitchell	Carter	No. 1 Victor (Strat. Test)	SE SW 20-9S-7W	3,725	Carter	1939	
Morris	Stanolind	No. 1 B. V. Carpenter	29-17S-7E	2,148	Central	1955	Stanolind
Morris	Fred Drolte	No. 1 T. Loy	28-17S-9E	3,224	SSC	1956	Carter
Morton	Colorado Oil & Gas	No. 1 Hayward	9-32S-42W	5,218	Central	1952	Colorado Oil & Gas
Nemaha	Carter	No. 1 Gillbert Land Bank	NW NW SE 14-2S-14E	3,228	Carter	1949	Carter
Ness	Atlantic	No. 1 J. R. Elmore	7-16S-21W	4,472	Central	1955	Atlantic

TABLE 1.—*List of wells shot for velocity in Kansas through 1957** (Cont.)

County	Company	Lease	Location	Survey depth	Shot by	Date	Sponsored by
Ness	Gulf	No. 1 Keough	3-18S-21W	4,600	SSC	1956	OKWSA (Conoco)
Osborne	Carter	No. 1 Neushwanger	SW NE SW 15-8S-14W	3,774	Carter	1943	Carter
Osborne	N. Ordnance	No. 1 Vandement	C NW NW 3-9S-13W	4,118	Carter	1943	Carter
Ottawa	Stanolind	No. 1 Duggan	NW NW SW 12-12S-1W	3,360	Stanolind	1943	
Pawnee	Bennett & Roberts	No. 1 Fox	31-21S-18W	4,517	SSC	1956	Conoco
Pawnee	Adair & Morton	No. 1 Thompson	NW NE NW 16-22S-20W	4,960	SSC	1942	OKWSA
Phillips	Carter	No. 1 Robb	SE SW 3-4S-18W	3,574	Carter	1942	Carter
Pratt	Skelly	No. 1 Gilcreast	C SE 7-28S-11W	4,200	SSC	1935	OKWSA
Pratt	Lion	No. 1 Mico	30-29S-11W	5,164	Tomlinson Geo.	1956	Lion
Pratt	Lario	No. 1 Lemon	SE SE NW 12-29S-13W	4,360	GRC	1936	OKWSA
Reno	Roth & Faurot	No. 1A Yoder	C NW NW 15-24S-5W	3,915	SSC	1934	OKWSA
Reno	T & M Oil and Tom Allen	No. 1 Stewart	16-24S-6W	4,171	Tomlinson Geo.	1956	Lion
Reno	Tatlock Oil	No. 1 Vernon Tonn	17-25S-4W	4,000	GRC	1932	
Reno	Stanolind	No. 1 Hilger	SE SE NW 16-26S-4W	3,944	GRC	1936	OKWSA
Reno	Sinclair-Pr.	No. 1 Shephard	SE SE NW 22-26S-9W	4,333	SSC	1934	OKWSA
Rice	Continental	No. 1A Lansing	NE NE SW 25-18S-8W	3,100	GRC	1934	OKWSA
Rice	Elwell, et al.	No. 1 Springer	NW NE NW 35-18S-10W	3,273	SSC	1934	OKWSA
Rice	Nickerson, et al.	No. 1 Lyons	SE NW 27-20S-8W	3,559	Petty	1935	OKWSA
Rice	Cities Service	No. 1 Heckel	NW NW SW 18-20S-9W	3,303	CSO	1934	CSO
Rice	Deitrick, et al.	No. 1 Fitzpatrick	C NE NE 30-21S-8W	3,628	SSC	1934	OKWSA
Rush	Republic Nat.	No. 1 Eva Webb "C"	16-19S-20W	4,200	SSC	1954	Republic
Rush	Conoco	Solar No. 1 Schmidt	28-16S-19W	3,840	SSC	1956	Conoco
Russell	Empire	No. 1 Ehrlich	NE NE SE 28-13S-14W	3,274	GRC	1935	OKWSA
Russell	ElDorado	No. 1 Strattman	SW SE SE 32-14S-11W	3,210	SSC	1934	OKWSA
Russell	Empire	No. 1 Mai	C NW SW 24-15S-14W	3,247	SSC	1934	OKWSA
Scott	Atlantic	No. 1 Dague	C SW NW 14-20S-33W	4,563	WGC	1935	OKWSA
Sedgwick	Empire	No. 1 Shawver	NE NE NE 13-28S-2W	3,704	GRC	1934	OKWSA
Sedgwick	O. A. Sutton	No. 1 Peltz	SE SE NW 32-28S-2W	4,202	Central	1954	O. A. Sutton
Sheridan	Continental	No. 1 Pope	SW SW SE 18-7S-29W	4,779	SSC	1950	Conoco
Sherman	Kingwood-Aurora	No. 1 Rauckman	11-8S-40W	5,565	National	1952	Kingwood
Sherman	Sinclair-Pr.	No. 1 Mercer	NE NW 28-10S-40W	5,868	SSC	1942	OKWSA
Stafford	Shell	No. 1 Schilling	C SW NW 26-21S-13W	3,721	SSC	1934	OKWSA

Stafford	Trigg & Allen	No. 1 Helmers	2-22S-12W	3,600	GSI	1940	....
Stafford	Midwest Refg.	No. 1 Richardson	36-22S-12W	3,509	GSI	1932	
Stafford	Atlantic	No. 1 Hohner	SE NE 31-23S-14W	4,077	SSC	1935	
Stafford	Shaffer	No. 1 Newell	NE SE 20-24S-11W	4,050	Stanolind	1938	
Stafford	Stanolind	No. 1 Ray McComb	NE NE 27-24S-11W	3,850	Stanolind	1938	
Stafford	Rose Spring	No. 1 Toland	NW NW SE 2-25S-14W	3,000	SSC	1935	OKWSA
Stanton	Killman & Hurd	Rorick Unit No. 1	18-30S-42W	5,460	SSC	1956	Superior
Sumner	Carter	No. 1 Weber	C NW SE 26-31S-4W	4,617	Carter	1945	Carter
Sumner	Wentz-Conoco	No. 1 Kern	SE SE NE 6-34S-2W	4,500	GSI	1934	OKWSA
Sumner	Texas Co.	No. 1 Hobbisiefkin	3-35S-3W		Texaco	1950	Texaco
Thomas	Texas	No. 1 Daugherty	NW SW SW 23-6S-33W	5,023	Texaco	1943	OKWSA
Thomas	National Coop. Ref.	No. 1 Wright	34-7S-36W	5,040	SSC	1956	Phillips
Thomas	Virginia Drlg. Co.	No. 1 Cooper	12-7S-33W	4,675	SSC	1956	Phillips
Trego	Stanolind	No. 1 F. B. Rinker	SE NE NW 6-12S-22W	4,171	WGC	1954	Stanolind
Trego	Central Comm.	No. 1A Wagg	NW SE 17-13S-21W	4,494	SSC	1936	SSC
Trego	Bennett & Roberts	No. 1 Kline	19-14S-24W	4,504	SSC	1956	Conoco
Wabaunsee	Carter	No. 1 Dorgan	SW SW NE 6-15S-10E	3,307	SSC	1949	Carter
Wallace	Van-Grisso Oil Co.	No. 1 Frazier Farms	15-15S-39W	5,130	SSC	1956	Phillips
Wichita	Benedum-Trees	No. 1 Knobbe	18-18S-35W	5,101	SSC	1957	Phillips

*Gaither 1956, 1957, 1957a; Swan 1944, 1946, 1949, 1951; by permission of Society of Exploration Geophysicists and others. Abbrevations: CSO, Cities Service Oil Co.; GGC, General Geophysical Co.; GRC, Geophysical Research Corp.; GSI, Geophysical Service, Inc.; KVI, Key Velocities, Inc.; OKSWA, Oklahoma-Kansas Well Shooting Association; SGC, Southern Geophysical Co.; SSC, Seismograph Service Corporation; WGC, Western Geophysical Co.

face. Its accuracy is dependent upon the validity of the assumptions, the ability of the interpreter to discern and choose the best data on the recordings and to read record times accurately on the reflections involved, and good record quality. This method has been successful on local structures, but when used on large prospects, the interpreter must keep in mind that in certain areas the anhydrite dips regionally north whereas the lower beds dip regionally south to southwest. The combined dips produce exceptional regional thinning to the north. Here again, most local anomalies are not affected.

Stone Corral anhydrite as a variable reference plane.—The discussion of the previous paragraph indicates that the dip of the Stone Corral is important in mapping areas of large size. The variable-reference-plane method requires construction of a structural contour map of the Stone Corral anhydrite from electric-log and core-drill data. It is not out of order to let the conventional seismic map on the anhydrite influence the contouring of the structural map to a very slight degree.

Time intervals from the anhydrite to the lower reflecting beds are then mapped. These intervals are converted to thickness and applied directly to the sloping anhydrite plane. Maps so constructed tend to be slightly conservative because most real, positive anomalies show to some degree in the anhydrite.

The accuracy of such a method is dependent mainly on the validity of the assumptions regarding the slope of the Stone Corral; the greater the geologic control on the anhydrite, the greater the accuracy. The fact that more and more electric logs are run up through the anhydrite and to the surface is a tremendous aid to the seismologist in Kansas. Anhydrite data used on the shot points are interpolated from the contoured map. A perfect "setup" for this type of computation is in the area of the Hugoton Gas Field of southwestern Kansas, where Permian geologic data are available on one-mile control.

"Cretaceous" as a variable reference plane.—The variable-reference-plane method described for the Stone Corral is used, except that more dense control is obtained on shallow horizons. The ideal situation, of course, would be a Stone Corral electric-log datum at every shot point. The cost of obtaining such information would be excessive, but shallow marker beds are almost as useful. It has been discovered that excellent electric-log correla-

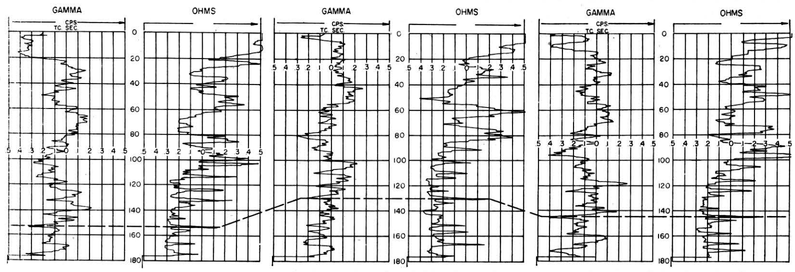

FIG. 6.—Electric-radioactivity logs of shot holes in Sumner County showing a shallow Permian marker bed.

tions can be obtained for most of the Cretaceous and Permian sections (Fig. 6). These correlations are surprisingly consistent. Field procedure requires drilling shot holes deeper than usual into bed rock. The cost is not prohibitive and the method attempts to make seismic data in Kansas as accurate as possible.

The data are computed as above, except that the variable plane is taken from the known electric-log markers on each shot point and the assumption is made that the marker parallels the shallowest consistent reflections. In most areas this reflection surface is the Stone Corral anhydrite, but in some areas, such as parts of Sheridan and Gove Counties, it actually is a Cretaceous reflection. In areas where these markers are reasonably near parallel, seismic accuracy has reached a fine point.

There are other areas in Kansas where it is known that the Cretaceous and the Stone Corral markers are not parallel. In many of these areas, the lack of conformity seemingly is manifest by uniform thinning in a definite direction. The amount and direction of thinning can be determined from Stone Corral electric-log information at key wells in the area and shallow log information on the Cretaceous beds at these key wells. By obtaining shallow log or core-drill information over the intermediate area and applying the estimated thickness as determined above, one can make a reliable map on the Stone Corral. Then, by use of time intervals from the Stone Corral to the deeper beds, maps can be made on the Pennsylvanian, Mississippian, and Ordovician beds with a reasonable degree of accuracy.

Other variable reference planes.—The above discussion has been concerned with the area where Cretaceous rocks crop out or lie below the Tertiary and Pleistocene mantle in north-central Kansas. The same method may be applied to the southern and eastern parts of the state, where Permian and Pennsylvanian beds crop out. Because there is more conformity within the Permian and Upper Pennsylvanian section, the method should be accurate where Permian core markers are applied to lower Permian or upper Pennsylvanian reflections. The time interval from these shallow reflections to lower Pennsylvanian, Mississippian, and Ordovician reflections gives accurate control on these lower beds in most places.

CONCLUSIONS

Oil is becoming increasingly difficult to find in Kansas, but more information is becoming available. The fact that more electric logs are run to the surface has been a great aid to the seismologist who is searching for structures in Kansas. All velocity surveys should be conducted to measure the velocity in the Wellington salt. Information can be acquired from study of the Stone Corral anhydrite and the Wellington salt sections of the Permian, and the entire Cretaceous section. It is believed that Permian, Cretaceous, and near-surface rocks create most of the errors and problems of seismic interpretation in Kansas. A thorough study of the attitude, composition, and velocity of the shallow formations is necessary to further improve seismograph accuracy in Kansas.

The seismologist must admit his need for, and accept the advice, suggestions, and cooperation of the geologist in solving the problems of oil exploration.

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