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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

MEMORANDUM FOR: Harold R. Denton, Director
Office of Nuclear Reactor Regulation

Robert B. Minogue, Director
Office of Standards Development

FROM: Saul Levine, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER NO. 70
SEISMICITY AND TECTONIC RELATIONSHIPS OF THE NEMAHA UPLIFT IN OKLAHOMA, PART II, JANUARY 1979

REFERENCES:
1. Letter W. R. Stratton to Dixie Lee Ray, dated May 16, 1973, Subject: Report on Seismic Research
2. Title 10, Chapter 1, Part 100, CFR Appendix A - Seismic and Geologic Siting Criteria for Nuclear Power Plants
3. Memo N. B. Steuer to R. J. Mattson, dated July 15, 1975, Subject: U.S. Tectonic Province Map

INTRODUCTION

This memo transmits NUREG/CR-0875 entitled, "Seismicity and Tectonic Relationships of the Nemaha Uplift in Oklahoma, Part II." The research effort to produce this report was conducted by the Oklahoma Geological Survey. This research is a cooperative geologic, seismic and geophysical effort of the State Geological Surveys of Oklahoma, Kansas, Nebraska, Iowa and Minnesota to study the earth science parameters of the Nemaha Uplift (NU) and the Midcontinent Gravity Anomaly (MGA). The NU and MGA are buried geologic structures along with which some scientists have associated a history of earthquake activity. Hence, a knowledge of the NU and MGA is of vital importance in the siting and licensing of nuclear power plants.

SUMMARY

The Oklahoma Geological Survey's geologic and seismologic investigations of the NU continued in FY 1978. The geologic studies concentrated on (1) the completion of structure-contour maps on the top of the Viola Formation, the base of the Pennsylvanian, and the top of the Oswego Formation; and (2) a detailed structure-history study of the NU in the Oklahoma City area. The contour-mapping phase of this program is complete. A detailed study of the tectonics of the Oklahoma City Uplift was

completed. The investigation involved construction of four subsurface cross sections as well as several isopachous maps in order to reconstruct the structural history for this area. The final report should be available this fiscal year.

The seismologic studies can be grouped into two basic categories: (1) seismograph-station installation, maintenance, and operation; and (2) data processing. The statewide seismograph network was completed last year. Seven semipermanent, volunteer-operated seismograph stations, which now make up Oklahoma's regional network, have been installed in such a way as to provide detailed coverage of the Nemaha Ridge as well as of most of Oklahoma (Panhandle excluded). To the radiotelemetry seismograph-station network, a second station, Slick (SIO), was added.

A local earthquake-location program, named HYPERCUBE, was developed. It calculated individual and average magnitudes of up to four types: m3Hz, mbLg, mbeus, and MDUR. All the output data are formatted into a 4,000-byte buffer set up to be the image of an 8.5- by 11-inch page with margins. The operator can print this buffer any number of times on a thermal printer and/or impact printer, and can archive the buffer in a magnetic-tape file. Dr. James E. Lawson developed a formula for magnitude calculated from duration, which gives magnitudes consistent with Nuttli's m3Hz and mbLg scales. An alternate magnitude scale was needed where data were insufficient to calculate a m3Hz or mbLg magnitude, particularly with small-magnitude earthquake events. Lawson's magnitude-duration scale, which uses the following equation:

$$MDUR = 1.49 + 1.86 \log(DUR),$$

is used for local and regional earthquakes recorded at Oklahoma seismograph stations. A three-state catalog of earthquakes from January 1, 1977, to September 30, 1978, was printed in a new page format. Approximately 100 earthquakes in Oklahoma, Kansas, Nebraska, and nearby areas were located. In Oklahoma, a seismic trend, evident in this limited data set, includes a roughly linear zone extending northeast from the El Reno area and forming a line that crosses the NU at a 30° angle. In south-central Oklahoma, a concentration of earthquakes occurred near Wilson. In southeastern Oklahoma, several epicenters parallel the northern front of the Ouachita Uplift.

Detailed magnetic and gravity surveys are being conducted near the Medford and Kingfisher maxima, which might form the Oklahoma extension of the Greenleaf anomaly of Kansas.

Geological Investigations

Oklahoma can be subdivided into several major geologic and tectonic provinces (Fig. 1). One of these structural features, the Nemaha Ridge, is a long north-south uplift that extends northward from central Oklahoma through Kansas and into Nebraska. The Oklahoma portion of the ridge is 10 to 20 miles wide and nearly 150 miles long. A number of earthquakes have occurred along or west of the Nemaha Ridge, with those near El Reno, Oklahoma, being most intense.

The Nemaha Ridge consists of a number of small crustal blocks that were raised sharply along the axis of the uplift. These uplifted crustal blocks are typically 3 to 5 miles wide and 5 to 20 miles long and are bounded by faults on the east and/or west sides. These blocks were uplifted and eroded during Late Mississippian and Early Pennsylvanian time and, subsequently, they were covered by later Pennsylvanian and Permian sediments. At least some of the deep-seated faults near the axis of the Nemaha Ridge were reactivated during Middle Pennsylvanian time.

Structure-Contour Program

To better understand the geologic and tectonic history of the Nemaha Ridge, a series of structure-contour maps was constructed on key stratigraphic horizons. The area contoured is bounded by 98° longitude on the west and 97.5° longitude on the east and lies between 35° and 37° latitude (Fig. 2). Three horizons were selected for structure-contour mapping: the top of the Oswego Formation (Middle Pennsylvanian), the base of the Pennsylvanian, and the top of the Viola Formation (Ordovician). In the far eastern portion of the study area, the Wewoka Formation (Middle Pennsylvanian) was substituted for the Oswego. These units were selected because they have been penetrated by a large number of bore holes and because of the easy identification on electric logs.

Elevation tops for each unit were posted on 1:250,000 AMS maps and contoured. These data are now being adjusted to fit information from published and unpublished sources. After the final adjustments are made, all data will be recompiled at a reduced scale of 1:500,000. Final maps should be available by the middle of 1979.

BACKGROUND

Refer to RIL No. 48, "A Tectonic Overview of the Midcontinent." The background information in RIL No. 48 applies equally to this RIL. It covers ACRS recommendations, relevance of 10 CFR Part 100 Appendix A to the study, and previous NRC effort and organization of the current programs.

Preliminary Results

The structure-contour maps reveal a complex fault pattern and geologic history in the vicinity of the NU. There is some evidence to indicate reoccurring slippage along some fault segments throughout Paleozoic time as well as movement reversals. Some of the fault blocks are rotated and moved laterally such as in wrench-fault tectonics (Lon Turk, Oklahoma City, personal communication).

Correlation between historical as well as recent earthquake activity to the NU structures is unclear. Some of the Ordovician structures, compiled from Jordon (1962), Wheeler (1960), and unpublished reports, are shown in Figure 3. Pre-1977 earthquake data (circles) and post-1977 earthquake data (triangles) are also shown. There appears to be a zone of earthquakes, beginning near El Reno, that strikes northeast and cuts diagonally across the Nemaha structures. It is not clear what this trend represents; however, it is subparallel to a regional northeast-southwest structural grain in northwestern Oklahoma. It is hoped that additional earthquake data, coupled with more detailed microearthquake studies, will better delineate this feature.

A detailed study of the tectonics of the Oklahoma City Uplift by Koff (1978) is near completion. The study area lies from T. 9 N. to T. 12 N. and R. 2 W. to R. 7 W. (Figs. 4 and 5). Approximately 1,100 wells have been drilled in the study area. However, only 100 wells are scattered in the western part of the study area, which, unfortunately, coincides with the recent and historical earthquake activity. The initial stages of Koff's investigation involved the construction of four subsurface cross sections, and seven isopachous maps were prepared to illustrate three-dimensional changes of the Arbuckle Limestone (Cambrian-Ordovician) surface. These data were used to reconstruct the structural history for this area. The final report should be completed by early 1979.

Geophysical Investigations

A Bouguer gravity-anomaly map of Oklahoma (Lyons, 1964) and a vertical-intensity magnetic map of Oklahoma (Jones and Lyons, 1964) were published by the Oklahoma Geological Survey. The map scales are 1:750,000. The contour interval on the gravity map is 5 milligals, whereas the contour interval for the magnetic map is 100 gammas. A search was conducted to determine the availability, quantity, and quality of new gravity and magnetic data in the NU area since 1964. It was determined that new data were quite limited and that new surveys were required in order to augment and refine published information.

Lyons (1964) identified two gravity anomalies, the Medford maximum (P5) and the Kingfisher maximum (P6), that might form the Oklahoma extension of the Greenleaf anomaly of Kansas (Fig. 4). Detailed gravity and magnetic surveys will be conducted this fiscal year on these maxima, P5 in Grant and Garfield Counties, and P6 in southern Kingfisher County. We hope these surveys will be of sufficient detail to (1) better define the limits of these anomalies, and (2) develop causative models that may lead to a better understanding of the basement configuration and geologic processes operating in Precambrian time.

Seismological Studies - Regional Net

The goals and instrumentation of the seismological stations were discussed in the 1977 Interim Report (Luza and others, 1978). That report indicated that the Oklahoma network of seismograph stations consisted of three distinct parts. One part is the Oklahoma Geophysical Observatory (TUL), which includes seismographs to record both vertical and horizontal ground motion in several frequency passbands. The second part consists of two or three radio-transmitting stations. Each station has a high-frequency vertical seismometer whose signals are telemetered to TUL in the 216- to 220-MHz radio-frequency band. The third part consists of seven volunteer-operated seismograph stations. Each volunteer station comprises an ink-recording, high-frequency vertical seismograph operated by a volunteer who furnishes his or her own daily services to change records and set the timing system with WWV Bureau of Standards transmissions. The volunteers also furnish a location for the seismometer tank vault and an indoor location for the drum recorder and timing system (in four cases, the volunteers live on State Forestry or State Park property, and the stations were established by permission of the appropriate directors). We will discuss changes in active station locations, and, afterward, changes will be made in equipment and procedures at some or all stations.

Present Station Configuration

Twenty-four seismograph stations are operating in Oklahoma, Kansas, and Nebraska (Fig. 5). Ten stations are presently operating in Oklahoma (Table 1). The Oklahoma network consists of seven volunteer-operated stations (NRC), two radiotelemetry stations (NRC), and TUL. Ten seismograph stations are operating in Kansas. Of these, six consist of NRC-supported borehole-telephone-telemetry stations, three U.S. Army Corps of Engineers-supported borehole-telephone-telemetry stations, and one University-operated station. In Nebraska, three stations--one at the University of Nebraska-Lincoln and two supported by the NRC--are presently recording seismological data.

Between January 1, 1977, and September 30, 1978, 100 earthquakes were located in Oklahoma, Kansas, Nebraska, and areas immediately adjacent (usually less than 100 km) to these three states. Table 2 shows the number of earthquakes by state.

CRITERIA FOR STUDY AREA SELECTION AND OBJECTIVES OF STUDY

Please refer to the RIL entitled, "A Study of the Regional Tectonics and Seismicity of Eastern Kansas - Summary of Project Activities and Results to the End of the Second Year or September 30, 1978."

PLANNING

Initially, a 5-year program was planned. Project work is separated into the three phases listed below. This report presents results of work conducted in Phase

Phase I
- Purchase and installation of equipment to establish the seismic network.
- Recruitment and training of volunteer operators.
- Compilation and synthesization of existing geologic and geophysical data.
- Analysis of the seismograms.
- Prepare an interim report for fiscal year ending October 1977.

Phase II
- Installation of a microearthquake network.
- Operation and monitoring of the seismic network.
- Analysis of the seismograms.
- Aeromagnetic studies.
- Prepare an interim report for fiscal year ending October 1979.

Phase III
- Gravity profiles.
- Operation and monitoring of the seismic network.
- Analysis of the seismograms.
- Field studies of known or inferred fault areas.
- Final compilation and report after fiscal year ending October 1981.

RECOMMENDATIONS

It is recommended that the information contained in NUREG/CR-0875 be considered by the Office of Standards Development and the Office of Nuclear Reactor Regulation as input to the development of a tectonic province or seismic zoning map of the eastern U.S. and to provide a basis and guide for ongoing studies in the area.

Additionally, RES recommends that studies and data gathering be continued in this area so that we may better understand the geology and seismicity of the eastern U.S. Redirection and modification of projects should be made as deemed necessary by ongoing work.

It is also recommended that researchers make annual oral presentations to all NRC geologists and seismologists so that work progress can be discussed and studies redirected, if necessary. Technical questions concerning NUREG/CR-0875 results may be directed to Neil B. Steuer at 427-4370.

Saul Levine

Saul Levine, Director
Office of Nuclear Regulatory Research

Enclosures:
1. NUREG/CR-0875
2. Figures
3. Tables

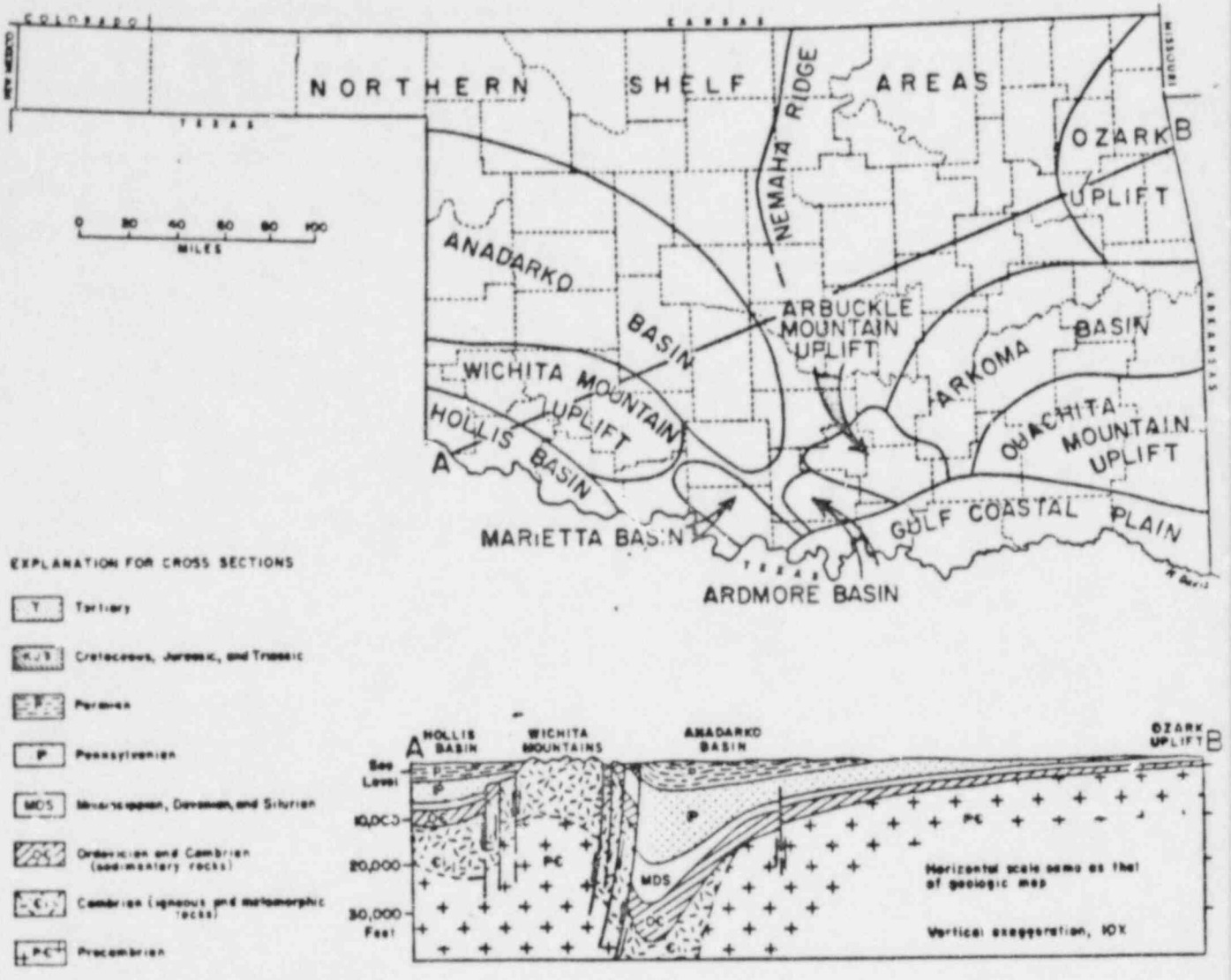

Fig. 1. Major geologic and tectonic provinces of Oklahoma.

Fig. 2. Structure-contour index map. Solid black line denotes approximate location of Nemaha Uplift.

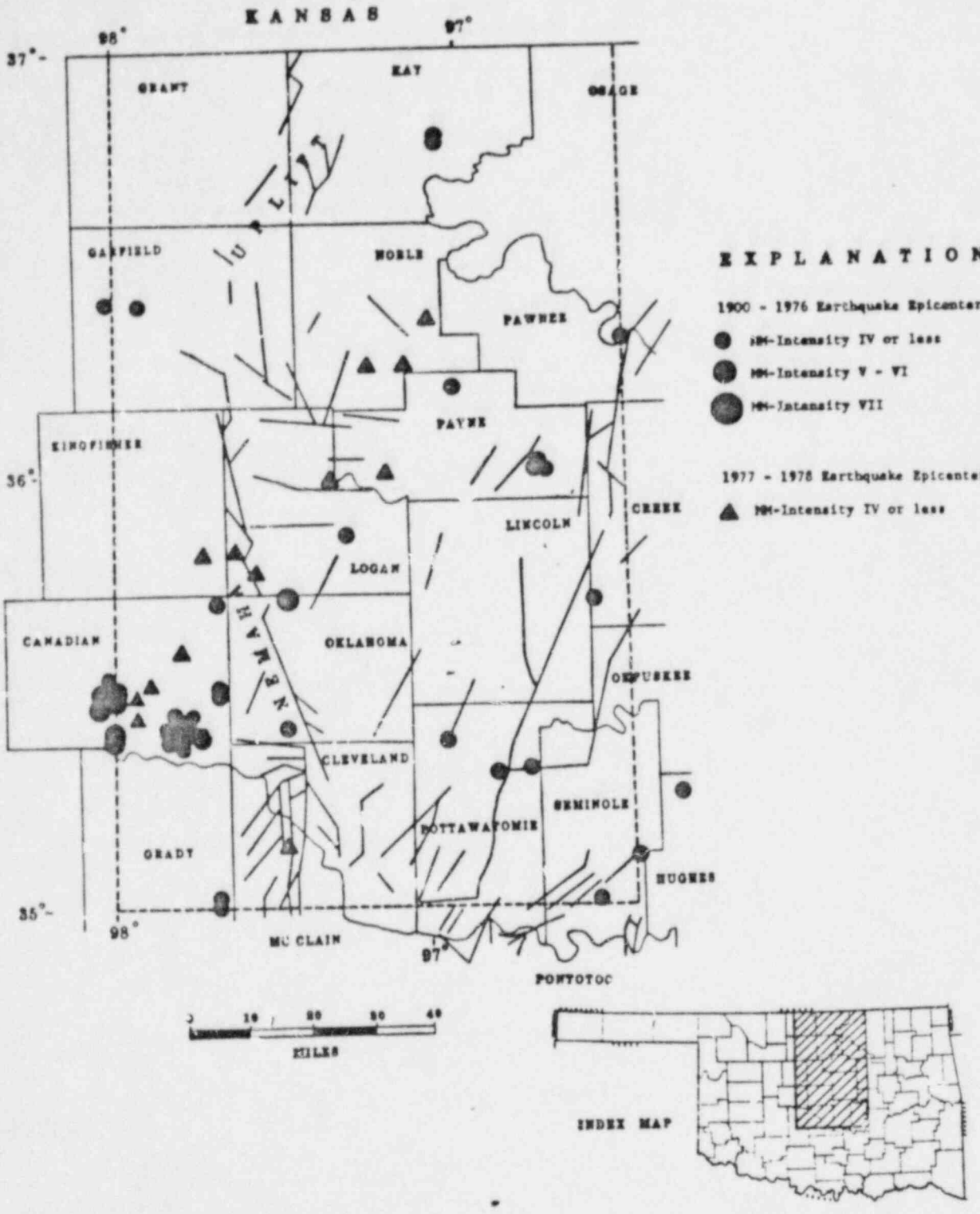

Fig. 3. Distribution of pre-Pennsylvanian structures and earthquake epicenters for north-central Oklahoma (Wheeler, 1960; Jordan, 1962; unpublished reports).

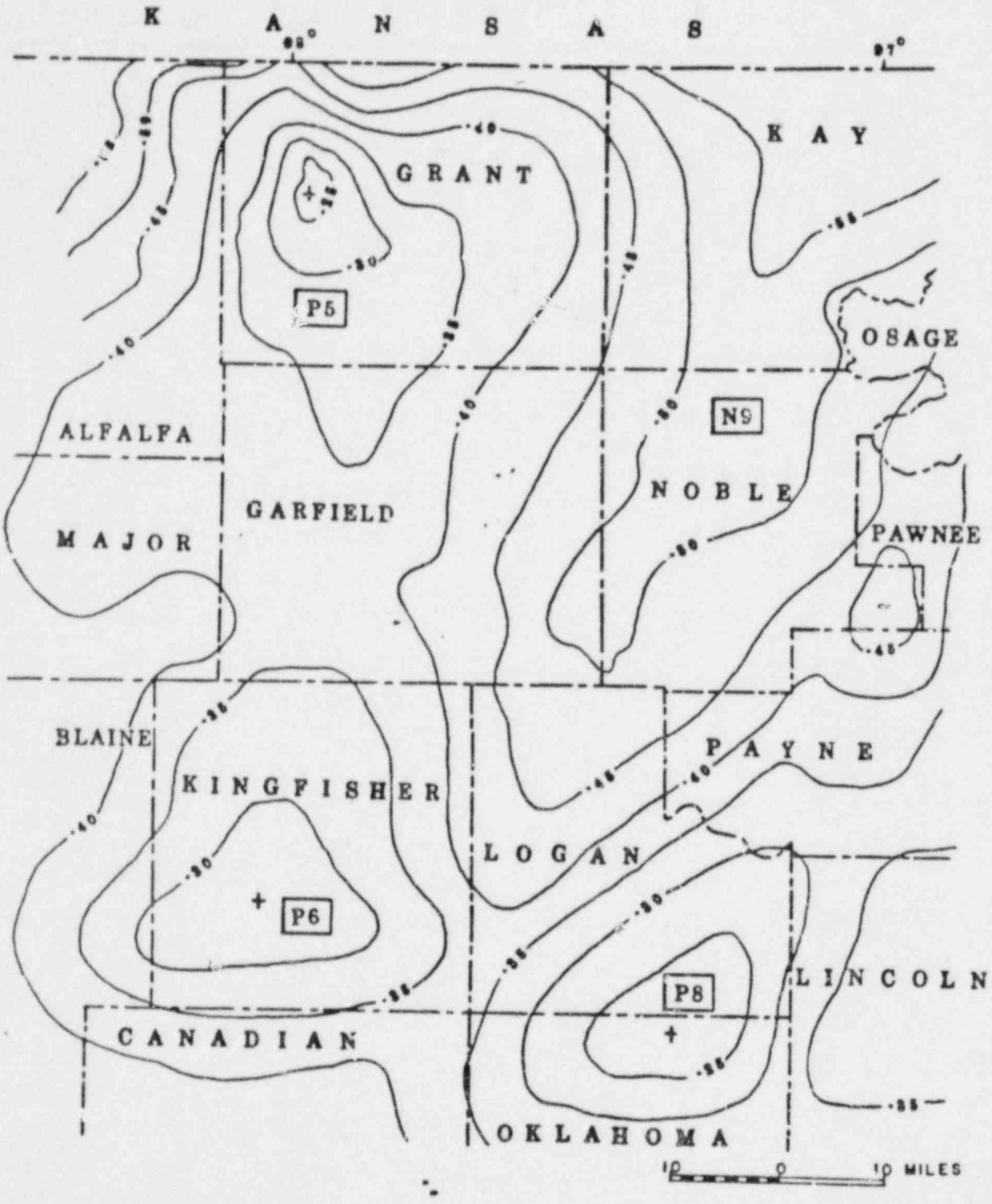

Fig. 4. Gravity anomalies: Medford maximum (P5), Kingfisher maximum (P6), Edmond maximum (P8), and granite ridge minimum (N9), identified by Lyons (1964); contour interval 5 milligals.

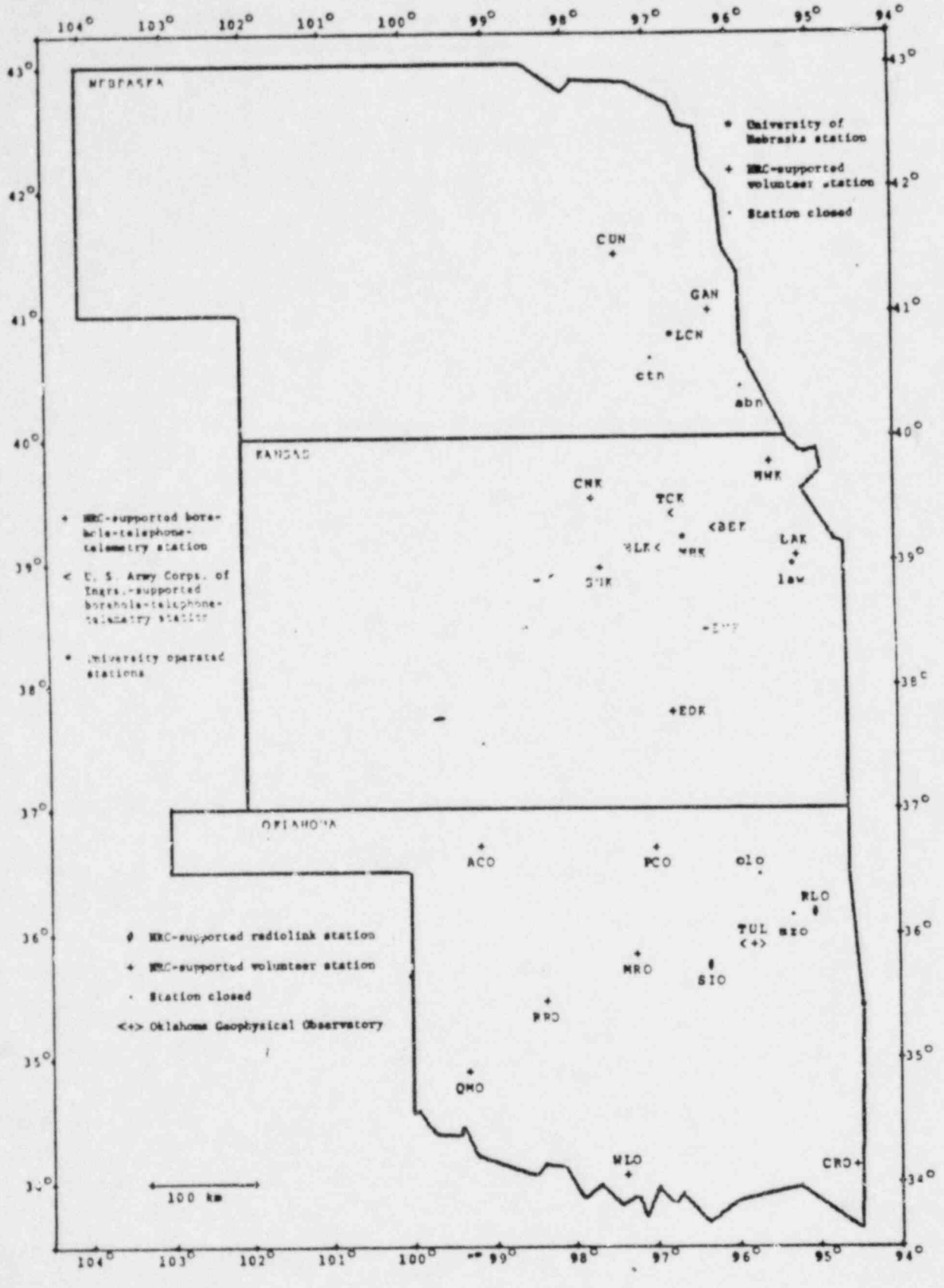

Fig. 5 Seismograph stations operating in Oklahoma, Kansas, and Nebraska.

Table 1. Oklahoma station locations, operators, and ratings.

Abb	Geographic Name and County	Latitude (Deg. N.)	Longitude (Deg. W)	Elev. (meters)	Volunteer operator or Telemetry RF and AF operating date(s)	Geographic importance to network: At time of installation	Geographic importance to network: In final network configuration	Quality and continuity operation	Ground noise
TUL	Okla. Geophys. Obs. Tulsa County	35.900000	95.792500	256	OGO staff P/J/K/S 611208				
MZO	Mazie Landing (CLOSED) Mayes County	36.131639	95.300139	182	Randy Blackwell 760916-780616	(A)	(D)	(A)	(B)
OLO	Oologah (CLOSED) Rogers County	36.457250	95.710778	196	T/T/C Estes 761128-770807	(A)	(C)	(B)	(D)
WLO	SE of Wilson Love County	34.064778	97.369722	284	James L. Stael 770425	A	A	B	B
CRO	Carnasaw Mtn Lookout Tower McCurtain Co.	34.149917	94.555611	302	Wanda Webb 770517	A	A	A	A
ACO	Alabaster Cavern State Park Woodward Co.	36.698556	99.146083	521	L. H. Shepherd 770622	A	A	A	B
PCO	Ponca City Kay County	36.691222	96.978227	325	H. Walther 770705	A	A	A	C
RLO	Rose Lookout Twr. Mayes County	36.167000	95.025194	363	218.0 MHz 1360 Hz 770722	A	A	A	A
QMO	Quartz Mtn. St. Park Greer County	34.892917	99.307056	479	J. Briley 770729	A	A	B	A
MRO	Meridian Logan County	35.835556	97.226528	294	Roy F. Starks 780316	A	A	C	C
SIO	Slick Creek County	35.746333	96.307056	323	219.00 MHz 680 Hz 780712	A	A	A	A
RRO	Red Rock Canyon State Park Caddo County	35.456917	98.358444	482	Bud Turner 780809	A	A	A	B

* A. Excellent; very strong reason for every necessary effort to continue operation of station
B. Good; no reason to move station.
C. Less satisfactory than desired; may consider moving station, though the move will have low priority if only one "C" is noted.
D. Although station is producing useful data, it should be moved or should be temporarily closed whenever part of the equipment is required by a higher rated station.

Table 2. Number of phases from Oklahoma stations used in locating earthquakes (January 1977 to September 1978) in different regions.

Total Number of Earthquakes by Region	Number of Recorded Phases Per Station for Each Region											
	TUL	MZO	OLO	WLO	CRO	ACO	PCO	QMO	RRO	RLO	SIO	MRO
60 - Oklahoma	54	35	9	32	44	15	25	9	5	31	10	18
6 - Kansas	5	1			2		2			3		
7 - Nebraska	7	5		1	6	6	4	2		7		2
16 - West Arkansas	8	9	3	1	15	1				5		
8 - North Texas	8	6	1	5	8	4		4		4		
1 - SW Iowa												
2 - SW Missouri	1	1			1		1			1		

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