Oklahoma GEOLOGY Notes

OKLAHOMA GEOLOGICAL SURVEY VOL. 47, NO. 2 APRIL 1987

On the cover —

Atoka Formation in the Frontal Belt of the Ouachita Mountains

The Atoka Formation is observed here on the east side of Oklahoma Highway 82, between Red Oak and Bengal in Latimer County. The Atoka Formation is composed of turbidites and is characterized by thin, very fine-grained sandstone beds, and thicker shale intervals. Strata shown here are in the Choctaw thrust sheet, north of the Pine Mountain fault. The dip is steeply south, with a small, overturned, north-vergent anticline and syncline. Neil Suneson (pictured) of the OGS writes observations on these exposures. [Note: This is stop 34B in OGS Guidebook 19, 1979, p. 63–64.]

Jock A. Campbell

OKLAHOMA GEOLOGICAL SURVEY
CHARLES J. MANKIN, *Director*
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Oklahoma Geology Notes, ISSN 0030-1736, is published bimonthly by the Oklahoma Geological Survey. It contains short technical articles, mineral-industry and petroleum news and statistics, abstracts, notices of new publications, and announcements of general pertinence to Oklahoma geology. Single copies, $1.50; yearly subscription, $6. Send subscription orders to the Survey at 830 Van Vleet Oval, Room 163, Norman, Oklahoma 73019. Short articles on aspects of Oklahoma geology are welcome from contributors; general guidelines will be sent on request.

This publication, printed by the University of Oklahoma Printing Services, Norman, Oklahoma, is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes 1981, Section 3310, and Title 74, Oklahoma Statutes 1981, Sections 231–238. 1,800 copies have been prepared for distribution at a cost of $1,400 to the taxpayers of the State of Oklahoma. Copies have been deposited with the Publications Clearinghouse of the Oklahoma Department of Libraries.

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MEASURED SECTIONS, OKLAHOMA OUACHITA MOUNTAINS

Neil H. Suneson[1]

Introduction

Since the very early twentieth century and the distribution of the first modern geologic map of part of the Ouachita Mountains by J. A. Taff in 1902 (U.S. Geological Survey Folio 79), the Ouachita Mountains in Oklahoma have been an excellent classroom for geologists of all persuasions. Sedimentologists, structural geologists, stratigraphers, petroleum geologists, paleontologists, biostratigraphers—among others—continue to map contacts, collect and analyze samples, drill wells, and run seismic surveys in an attempt to arrive at a better understanding of the depositional environment and tectonic history of the Ouachita Mountains. Despite an enormous volume of literature on the Ouachita Mountains (Dr. R. O. Fay of OGS is currently completing a bibliography of references on the mountains), important questions remain, and controversy still exists regarding some fundamental interpretations of the surface and subsurface geology.

In 1984, the Oklahoma Geological Survey, Arkansas Geological Commission, and the U.S. Geological Survey initiated the Ouachita COGEOMAP project, designed to examine existing information on the Ouachita Mountains, map at a scale of 1:24,000 areas for which modern geologic maps do not exist, and re-map areas of significant geologic and/or resource interest. New geologic mapping of the frontal Ouachita Mountains in Oklahoma started in the fall of 1986. While reviewing published literature and preparing for field work, I compiled a list of all the measured sections in the Oklahoma Ouachita Mountains. This was not done in an attempt to correlate sections described by different authors; rapid facies changes, complex structure, and (possibly) misinterpreted stratigraphic position make such a task impossible. Rather, the compilation of measured sections has facilitated (1) location of good outcrops, (2) identification of general characteristics of the units, and (3) documentation of specific sedimentological, faunal, and/or structural features. In addition, the geologists who measured the sections clearly spent time in the field; therefore, the reference list at the end of this paper is a list of original gatherers of stratigraphic data.

Following is a list of stratigraphic units (groups, formations, members, informal units) that have been measured and described in the Oklahoma Ouachita Mountains. Next to the unit name is the abbreviation used below. These units are arranged in approximate stratigraphic order, youngest at the top and oldest at the bottom. On the left side of the list are those units found only

[1]Oklahoma Geological Survey.

north of the Ti Valley fault; these units generally have been interpreted to represent shelf rocks. Units on the right side of the list are deep-water Ouachita-facies rocks. The Atoka Formation is the only unit found on both sides of the Ti Valley fault.

Stratigraphic Units

North of Ti Valley Fault	South of Ti Valley Fault
Atoka (Ato)	
Barnett Hill (Bar)	Lynn Mountain (LnM)
Wapanucka (Wap)	Johns Valley (JsV)
Chickachoc (Chc)	Jackfork (Jfk)
Limestone Gap (LsG)	Union Valley (UnV)
Primrose (Pmr)	Game Refuge (GmR)
	Wesley (Wes)
Springer (Spr)	Markham Mill (Mar)
	Prairie Mountain (PrM)
	Prairie Hollow (PrH)
	Wildhorse Mountain (WhM)
	Stanley (Stn)
	Chickasaw Creek (Chs)
Caney (Can)	Moyers (Moy)
	Tenmile Creek (Ten)
	Hatton Tuff (Hat)
Woodford (Wdf)	Arkansas Novaculite (ArN)
Pinetop (Pnt)	Missouri Mountain (MMt)
	Blaylock (Bll)
	Polk Creek (PoC)
	Bigfork (Bgf)
	Womble (Wom)
	Blakely (Blk)
	Mazarn (Maz)
	Crystal Mountain (CMt)
	Collier (Col)
	Lukfata (Luk)

Two lists of measured sections are provided. The first is a units list, showing where the various units described in the literature are exposed in the Ouachita Mountains. For example, the Arkansas Novaculite (ArN) has been described from 14 townships. In addition, secs. 27, 29, and 32, in T4S, R23E, contain described exposures of the novaculite. The second is a location list, showing which units have been described from any particular section/township/range. For example, sec. 3, T3N, R19E, contains described exposures of the Game Refuge, Johns Valley, and Atoka Formations.

The units list shows locations of measured sections by stratigraphic unit. This list is arranged alphabetically by unit. The locations are arranged by township (north to south), range (west to east), and section(s). The included townships are T5N, R17–23E; T4N, R16–27E; T3N, R13–27E; T2N, R12–27E; T1N, R12–27E; T1S, R12–27E; T2S, R11–27E; T3S, R13–27E; T4S, R16–27E; T5S, R19–27E; and T6S, R23–27E. Only those parts of these townships south of the Choctaw fault and north of the Cretaceous overlap are included. Parentheses around land-survey sections indicate that the measured section covered parts of more than one land-survey section. In some cases, a measured section crossed into an adjacent township; this is indicated in the location list.

Units List

Arkansas Novaculite

T3N, R20E—31; **T2N**, R20E—18, R21E—6,8; **T1S**, R12E—10; **T2S**, R11E—(13,14),14, R12E—21,32, R26E—33; **T3S**, R24E—34, R26E—17,22; **T4S**, R23E—27,29,32, R24E—8,10,(10,15),15,(16,17), R26E—9,14; **T5S**, R24E—14, R25E—3,10.

Atoka

T5N, R18E—35, R19E—19,(19,20,29,33),(23,26),(27,33,34),(29,30,31,32), R21E—27,(28,33),34, R22E—(17,20),20,21, R23E—19,(19,20,29),29,35; **T4N**, R16E—35, R17E—9, R18E—(2,11),(21,22),22, R19E—(3,4),5, R22E—13,18, R23E—1,6, R24E—34, R25E—12, R26E—19; **T3N**, R14E—(30,31), R16E—1,(2,11),3, R19E—3, R25E—23,(23,24),(23,24,25,26),(23,26),24,26, R26E—10,16,17,(17,18,19),19, R27E—6,34; **T2N**, R15E—7, R21E—(25,31,36),36, R22E—30, R25E—(23,24,25,26,27,32,33),32, R27E—3; **T1N**, R21E—1, R22E—(4,5,6,9), R23E—(32,33), R25E—5; **T1S**, R12E—10, R23E—(2,3,4,11), R24E—19.

Barnett Hill

T4N, R16E—31, R17E—18; **T2N**, R13E—31.

Bigfork

T3N, R20E—31; **T2N**, R20E—10; **T1S**, R12E—10,16,29; **T2S**, R12E—21; **T3S**, R25E—27; **T4S**, R25E—33.

Blakely

T4S, R23E—29, R24E—(10,15), R25E—23; **T5S**, R25E—9.

Caney

T4N, R21E—11; **T2N**, R15E—4.

Chickachoc

T3N, R14E—(31,32), R15E—2,18,19; **T2N**, R13E—10,12,15,32, R14E—5; **T1N**, R12E—1,15,22,23.

Chickasaw

T2N, R20E—(13,24,27,34), R21E—18,24,(25,31,36), R22E—30, R24E—22, R25E—(23,24,25,26,27,32,33),(23,26); **T1N**, R15E—19, R21E—1, R24E—(34,35), R25E—5; **T1S**, R12E—26, R13E—7, R16E—(14,15,23,24,25), R24E—(1,2); **T2S**, R15E—15, R22E—(17,18),19; **T3S**, R16E—18.

Crystal Mountain

T5S, R23E—27, R24E—17.

Collier

T5S, R23E—27.

Game Refuge

T3N, R19E—(2,3), R27E—34; **T2N**, R21E—36, R22E—30, R27E—3; **T1N**, R22E—(4,5,6,9), R23E—(32,33); **T1S**, R13E—18, R16E—(14,15,23,24,25), R23E—(2,3,4,11).

Hatton Tuff

T4S, R23E—20; **T5S**, R22E—15, R25E—14.

Jackfork

T4N, R23E—19; **T3N**, R25E—(23,24,25,26), R26E—19; **T1N**, R15E—19, R26E—22; **T3S**, R21E—22, **T5S**, R19E—17.

Johns Valley

T4N, R21E—24, R22E—18; **T3N**, R19E—(2,3),3, R25E—(23,24,25,26),12, R26E—19, R27E—34; **T2N**, R21E—(25,31,36),36, R22E—30, R27E—3; **T1N**, R18E—33, R21E—1, R22E—(4,5,6,9), R23E—(32,33); **T1S**, R12E—12, R23E—(2,3,4,11).

Lynn Mountain

T1N, R19E—(21,22,26,27,35).

Limestone Gap

T2N, R13E—31.

Lukfata

T5S, R24E—(8,17).

Markham Hill

T3N, R27E—34; **T2N**, R21E—(25,31,36), R22E—30, R25E—(23,24,25,26,27,32,33),32, R27E—3; **T1N**, R21E—1, R23E—(32,33), R25E—5; **T1S**, R13E—(11,12), R23E—(2,3,4,11); **T3S**, R21E—1.

Missouri Mountain

T3N, R20E—31; **T2N**, R20E—11,18; **T1S**, R12E—10; **T2S**, R12E—21,32; **T4S**, R23E—29, R24E—(10,15); **T5S**, R25E—9.

Moyers

T3N, R21E—2; **T2N**, R20E—(13,24,27,34), R21E—18,24, R25E—(23,26); **T1N**, R18E—8, R24E—(34,35); **T1S**, R16E—24, R17E—19, R19E—(29,30), R24E—(1,2); **T2S**, R15E—(15,16),15, R16E—32, R18E—2,(9,16), R21E—(21,27,28), R22E—(17,18); **T3S**, R16E—5,18.

Primrose

T2N, R13E—31.

Pinetop

T2N, R15E—4.

Polk Creek

T3N, R20E—31, R21E—31; **T2N**, R21E—6; **T2S**, R12E—32.

Prairie Hollow

T2N, R21E—(25,31,36), R22E—30, R25E—(23,24,25,26,27,32,33); **T1N**, R21E—1, R23E—(32,33), R25E—5; **T1S**, R16E—(14,15,23,24,25), R23E—(2,3,4,11); **T3S**, R21E—19; **T5S**, R20E—9.

Prairie Mountain

T3N, R27E—34; **T2N**, R21E—(25,31,36), R22E—30, R25E—(23,24,25,26,27,32,33),32, R27E—3; **T1N**, R21E—1, R23E—(32,33), R25E—5; **T1S**, R23E—(2,3,4,11); **T2S**, R21E—36; **T3S**, R21E—1.

Springer

T3N, R14E—(30,31); **T2N**, R15E—4.

Stanley

T3N, R20E—31, R25E—(23,24,25,26), R26E—19; **T2N**, R22E—(18,19,30), R25E—23; **T1N**, R26E—22; **T2S**, R12E—21,32, R22E—(17,18), R25E—9; **T3S**, R23E—20, R26E—16,17; **T5S**, R25E—10, R26E—8.

Tenmile Creek

T2N, R20E—(13,24,27,34),15,19,22, R21E—18, R25E—(23,26); **T1S**, R26E—35, R27E—32; **T2S**, R15E—(15,16), R24E—32; **T3S**, R15E—(11,14,16,20,21), R24E—20,28, R25E—16; **T4S**, R23E—20; **T5S**, R22E—15, R23E—6.

Union Valley

T2N, R21E—(25,31,36), R22E—30; **T1N**, R21E—1.

Wapanucka

T5N, R18E—26,33, R19E—(19,20),20,22,23, R20E—23,24, R21E—23,27,29; **T4N**, R16E—13,(23,26),31,34, R17E—9,10,17,18,20, R18E—6; **T3N**, R13E—36, R14E—24,29,(29,30),(30,31),31,(31,32), R15E—2,10,11,18,19, R16E—6; **T2N**, R12E—36, R13E—10,12,29,31, R14E—5; **T1N**, R12E—1,15,29, R13E—1,10.

Woodford

T4N, R21E—11; **T2N**, R15E—4.

Wesley

T3N, R16E—26, R27E—34; **T2N**, R14E—(13,24), R15E—9, R21E—(25,31,36), R22E—

30, R25E—(23,24,25,26,27,32,33),32, R27E—3; **T1N**, R13E—20, R21E—1, R23E—(32,33), R25E—5; **T1S**, R12E—12, R13E—(11,12),18,30, R16E—(14,15,23,24,25), R23E—(2,3,4,11), R24E—7; **T2S**, R12E—2, R13E—11; **T3S**, R21E—1.

Wildhorse Mountain

T3N, R27E—34; **T2N**, R21E—(25,31,36), R22E—30, R25E—(23,24,25,26,27,32,33),25, R27E—3; **T1N**, R21E—1, R23E—(32,33), R24E—(34,35), R25E—5; **T1S**, R23E—(2,3,4,11), R24E—(1,2); **T2S**, R16E—(30,31), R21E—36, R22E—(17,18); **T3S**, R21E—1; **T5S**, R19E—1, R20E—9.

Womble

T3N, R20E—31, R21E—31; **T1S**, R12E—9,10,29; **T5S**, R23E—22.

In the location list, as in the units list, locations are given by township (north to south), range (west to east), and section. Two or more section numbers separated by a comma indicate that the measured stratigraphic section is in more than one land-survey section. The abbreviations of the described stratigraphic units follow the section numbers. These are followed by a number corresponding to a cited reference and the page numbers in that reference. Following the page numbers is the name or number of the measured section according to the original author. In some cases the author both named and numbered the measured section; in other cases the measured section was described without name or number. The last entry indicates if and where the measured section extends into an adjacent township, or it may be a note regarding location of the measured section or unit correlation.

Location List

T5N, R17E: none. **T5N, R18E**: sec. 26, Wap, 17 (p. 82–83), M.S. XI; sec. 33, Wap, 14 (p. 295–300), Gravel Pit Section (M.S. 32); sec. 35, Ato, 31 (p. 33–36), White Rock Section, extends to 11/4N/18E. **T5N, R19E**: sec. 19, Ato, 24, (p. 113–114), Drill Pad Section; secs. 19,20, Wap, 46 (p. 66), M.S. 22; secs. 19,20,29,33, Ato, 31 (p. 49–50), Damon Section, extends to 3,4/4N/19E; sec. 20, Wap, 7 (p. 31–32); sec. 20, Wap, 17 (p. 84–86), M.S. XII; sec. 20, Wap, 14 (p. 217–224), Bandy Cr. North and Bandy Cr. South Sections (M.S. 12,13); sec. 22, Wap, 17 (p. 87–88), M.S. XIII; sec. 23, Wap, 14 (p. 227–231), Wilburton SE Section (M.S. 15); secs. 23,26, Ato, 24 (p. 109–112), Blue Mountain Section; secs. 27,33,34, Ato, 24 (p. 115), Highway 2 Section; secs. 27,33,34, Ato, 31 (p. 59–60), Highway Section; secs. 29,30,31,32, Ato, 31 (p. 42–43), Lloyd Lake Section, extends to 5/4N/19E. **T5N, R20E**: sec. 23, Wap, 17 (p. 89), M.S. XIV; sec. 23, Wap, 14 (p. 225–226), Spring Cr. Gap Section (M.S. 14); sec. 24, Wap, 46 (p. 66). **T5N, R21E**: sec. 23, Wap, 14 (p. 215–216), Red Oak South Section (M.S. 11); sec. 27, Wap, 6 (p. 17b), Locality 66, (note: correct section may be 23); sec. 27, Ato, 6 (p. 17b), Locality 67, (note: correct section may be 23); secs. 28,33, Ato, 24 (p. 116–121), Hoot Owl Cr. Section; sec. 29, Wap, 17 (p. 90), M.S. XV; sec. 34, Ato, 35 (p. 42–43), M.S. 918. **T5N, R22E**: secs. 17,20, Ato, 24 (p. 122–123), Long Creek Section; sec. 20, Ato, 24 (p. 124), Long Cr. East Section; sec. 21, Ato, 35 (p. 45), Cedar Creek Le Flore Section (M.S. 505A). **T5N, R23E**: sec. 19, Ato, 35 (p. 46), Cedar Cr. Summerfield Section (M.S. 509A); secs. 19,20,29, Ato, 24 (p. 125–129), Cedar Cr. Section; sec. 29, Ato, 6 (p. 17d), Locality 29; sec. 35, Ato, 35 (p. 163), M.S. 607. **T5N, R24E**: none. **T4N, R15E**:

none. **T4N, R16E**: sec. 13, Wap, 17 (p. 70–72), M.S. VIII; secs. 23,26, Wap, 14 (p. 210–212), Blue Cr. Section (M.S. 9); sec. 31, Wap, 46 (p. 62), North Ridge Section; sec. 31, Wap, Bar, 2 (p. 21); sec. 31, Wap, 17 (p. 66–69), M.S. VII; sec. 34, Wap, 14 (p. 213–214), New State Mtn. Section (M.S. 10); sec. 34, Wap, 14 (p. 286–289), Blue Valley Ranch Section (M.S. 30); sec. 35, Ato, 31 (p. 23–24), Microwave Section, extends to 1/3N/16E. **T4N, R17E**: sec. 9, Wap, 14 (p. 281–285), Carlton's Quarry Section (M.S. 29); sec. 9, Ato, 6 (p. 17d), Locality 8; sec. 10, Wap, 14 (p. 277–280), Latimer–Pittsburg County Line Section (M.S. 28); sec. 17, Wap, 17 (p. 79–81), M.S. X; sec. 17, Wap, 36 (p. 263–267), M.S. PT 23; sec. 18, Wap, 46 (p. 64); sec. 18, Wap, Bar, 16 (p. 906–908), Hartshorne Quarry Station 48; sec. 18, Wap, 12 (p. A1–A6), Hartshorne Quarry Section; sec. 18, Wap, 17 (p. 73–78), Hartshorne Quarry (M.S. IX); sec. 18, Wap, 36 (p. 259–263), M.S. PT 21; sec. 18, Wap, 14 (p. 191–195), Hartshorne Quarry Section (M.S. 6); sec. 20, Wap, 14 (p. 274–276), Hugle Ranch Section (M.S. 27). **T4N, R18E**: secs. 2,11, Ato, 31 (p. 33–36), White Rock Section, extends to 35/5N/18E; sec. 6, Wap, 46, (p. 65); secs. 21,22, Ato, 6 (p. 17b), Locality 11; sec. 22, Ato, 6 (p. 17d), Locality 12. **T4N, R19E**: secs. 3,4, Ato, 31 (p. 49–50), Damon Section, extends to 19,20,29,33/5N/19E; sec. 5, Ato, 31 (p. 42–43), Lloyd Lake Section, extends to 29,30,31,32/5N/19E. **T4N, R20E**: none. **T4N, R21E**: sec. 11, Wdf, Can, 11 (p. 97); sec. 24, JsV, 35 (p. 162), Gobbler's Knob Section (M.S. 906), (note: correlation to Johns Valley Fm. made by author). **T4N, R22E**: sec. 13, Ato, 43 (in pocket), M.S. 271-14; sec. 18, Ato or JsV, 35 (p. 44), M.S. 909, (note: correlation to Atoka or Johns Valley Fm. made by author). **T4N, R23E**: sec. 1, Ato, 35 (p. 164), Holson Cr. Section (M.S. 606); sec. 6, Ato, 35 (p. 40), M.S. 514; sec. 19, Jfk, 35 (p. 160), Windingstair Mtn. Section (M.S. 551). **T4N, R24E**: sec. 34, Ato, 35 (p. 41), Upper Holson Cr. Section (M.S. 602). **T4N, R25E**: sec. 12, Ato, 27 (p. 134), M.S. 1. **T4N, R26E**: sec. 19, Ato, 27 (p. 184–185), M.S. 2. **T4N, R27E**: none. **T3N, R13E**: sec. 36, Wap, 17 (p. 57–59), Section IV, extends to 31/3N/14E; sec. 36, Wap, 14 (p. 242–246), Kiowa East Section (M.S. 17). **T3N, R14E**: sec. 24, Wap, 17 (p. 64–65, Section VI, extends to 19/3N/15E; sec. 29, Wap, 46 (p. 61); secs. 29,30, Wap, 45 (p. 27); secs. 29,30, Wap, 2 (p. 14–16); secs. 29,30, Wap, 17 (p. 60–63), Section V; secs. 30,31, Spr, Wap, Ato, 24 (p. 111–115); secs. 31,32, Wap, 45 (p. 26); secs. 31,32, Wap, 2 (p. 13–14); sec. 31, Wap, 12 (p. B1–B5), Pittsburg Section; sec. 31, Wap, 17 (p. 57–59), M.S. IV, extends to 36/3N/13E; secs. 31,32, Wap, Chc, 14 (p. 178–184), Pleasant Valley I Section (M.S. 3); secs. 31,32, Wap, Chc, 14 (p. 185–187), Pleasant Valley II Section (M.S. 4). **T3N, R15E**: sec. 2, Wap, Chc, 14 (p. 158–162), Indian Nation Turnpike 3 Section (M.S. 1); sec. 10, Wap, 46 (p. 61), North Ridge Section; sec. 11, Wap, 14 (p. 203–209), Natural Arch Section (M.S. 8); sec. 18, Wap, Chc, 14 (p. 163–177), Indian Nation Turnpike 1 and offset partial section (M.S. 2 and 2W); sec. 19, Wap, 17 (p. 64–65), M.S. VI, extends to 24/3N/14E; sec. 19, Wap, Chc, 14, (p. 232–236), Indian Nation Turnpike 2 Section (M.S. 16); sec. 19, Wap, 14 (p. 154–159), Blanco East Section (M.S. 19). **T3N, R16E**: sec. 1, Ato, 31 (p. 23–24), Microwave Section, extends to 35/4N/16E; secs. 2,11, Ato, 31 (p. 9–15), Katy Club Section; sec. 3, Ato, 31 (p. 25–26), Deadwood Section; sec. 6, Wap, 14 (p. 196–202), Powerline Cut Section (M.S. 7); sec. 26, Wes, 15 (p. 189–191), South of Hartshorne Section (Loc. K). **T3N, R17E**: none. **T3N, R18E**: none. **T3N, R19E**: secs. 2,3, GmR, JsV, 7 (p. 40–41); sec. 3, JsV, Ato, 45 (p. 32–34); sec. 3, JsV, Ato, 7 (p. 35–37); sec. 3, JsV, Ato, 6 (p. 17f), Hairpin Curve Section (Loc. 1); sec. 3, Ato, 31 (p. 64), South Section. **T3N, R20E**: sec. 31, Wom, Bgf, PoC, MMt, ArN, Stn, 3 (in pocket), figure 18; sec. 31, Bgf, PoC, MMt, ArN, 28 (p. 53–55), (note: partially published in 31 (p. 73, M.S. 3)); sec. 31, Bgf, 34 (p. 73), M.S. 3; sec. 31, Bgf, 37 (p. 132–133), Section F; sec. 31, ArN, 41 (p. 220–222), Potato Hills Section; sec. 31, ArN, 34 (p. 74), M.S. 6. **T3N, R21E**: sec. 2, Moy, 38 (p. 75); sec. 31, Wom, 34 (p. 73), M.S. 1; sec. 31, PoC, 34 (p. 73), M.S. 4, extends to 6/2N/21E. **T3N, R22E**: none. **T3N, R23E**: none. **T3N, R24E**: none. **T3N, R25E**: sec. 12, JsV, 27 (p. 141), M.S. 4, (note: Johns Valley Fm. interpreted by author); secs. 23,24, 25,26, Stn, Jfk, JsV, Ato, 18 (p. 71–84), extends to 19/3N/26E; secs. 23,24, Ato, 43 (in pocket), M.S. 103S; secs. 23,26, Ato, 24 (p. 130–135), Spring Mountain Section; sec. 23, Ato, 27 (p. 138), M.S. 10; sec. 24, Ato, 27 (p. 188–189), M.S. 9; sec. 24, Ato, 27 (p. 190), M.S. 11; sec. 24, Ato, 27 (p. 140), M.S. 12; sec. 26, Ato, 27 (p. 139), M.S. 13. **T3N, R26E**: sec. 10, Ato, 27 (p. 137), M.S. 5; sec. 16, Ato, 27 (p. 186), M.S. 6; secs. 17,18,19, Ato, 43 (in pocket), M.S. 103N; sec. 17, Ato, 27 (p. 187), M.S. 7; sec. 17, Ato, 27 (p. 135), M.S. 8; sec. 19, Stn, Jfk, JsV, Ato, 18 (p. 71–84), extends to 23,24,25, 26/3N/25E. **T3N, R27E**: sec. 6, Ato, 27 (p. 136), M.S. 3; sec. 34, WhM, (PrM, Mar, Wes), GmR, (JsV, Ato), Ato, 39 (p. 151–162), Rich Mountain Section, extends into Arkansas and to 3/2N/27E. **T2N, R12E**: sec. 36, Wap, 12 (p. E1–E3), East Chockie Section, (note: location is somewhat questionable based on description of location of land-survey section). **T2N, R13E**: sec. 10, Wap, 46 (p. 60), Ward's Creek Section; sec. 10, Wap, 12 (p. C1–C4), Buck Creek Section; sec. 10, Wap, Chc, 14 (p. 247–253), Reynolds Lake Section (M.S. 18); sec. 12, Wap, Chc, 14 (p. 271–273), Country Club Lake Section (M.S. 26); sec. 15, Chc, 14 (p. 269–270), Hungry Cows Section (M.S. 25); sec. 29, Wap, 12 (p. D1–D3), Limestone Gap Section; sec. 31, Pmr, LsG, Wap, Bar, 16 (p. 904–905), Section at Limestone Gap; sec. 31, Wap, 46 (p. 59), Limestone Gap Section; sec. 31, Wap, 36 (p. 251–259), M.S. A18; sec. 31, Wap, 14 (p. 301–305), Limestone Gap Section (M.S. 33); sec. 32, Chc, 14 (p. 267–268), Limestone Creek Tributary Section (M.S. 24). **T2N, R14E**: sec. 5, Wap, Chc, 14 (p. 188–190), Pleasant Valley 3 Section (M.S. 5); secs. 13,24, Wes, 15 (p. 183–184), Locality H. **T2N, R15E**: sec. 4, Pnt, Wdf, Can, Spr, 45 (p. 23–24); sec. 7, Ato, 19 (p. 8–9); sec. 9, Wes, 15 (p. 186–188), Locality J. **T2N, R16E**: none. **T2N, R17E**: none. **T2N, R18E**: none. **T2N, R19E**: none. **T2N, R20E**: sec. 10, Bgf, 34 (p. 73), M.S. 2; sec. 11, MMt, 34 (p. 74), M.S. 5; secs. 13, 24,27,34, Ten, Moy, Chs, 34 (p. 74–75), M.S. 8, extends to 18/2N/21E; sec. 15, Ten, 34 (p. 78), M.S. 10; sec. 18, MMt, ArN, 41 (p. 223), Dry Creek Section; sec. 19, Ten, 25 (p. 108), Dry Creek Section (M.S. F); sec. 22, Ten, 45 (p. 35). **T2N, R21E**: sec. 6, PoC, 34 (p. 73), M.S. 4, extends to 31/3N/R21E; sec. 6, ArN, 41 (p. 224–225), Walnut Creek Section; sec. 8, ArN, 34 (p. 74), M.S. 7; sec. 18, Ten, Moy, Chs, 34 (p. 74–75), M.S. 8, extends to 13,24,27,34/2N/20E; sec. 24, Moy, Chs, 38 (p. 76–77); secs. 25, 31,36, Chs, WhM, PrH, PrM, Mar, Wes, UnV, JsV, Ato, 8 (p. 4–11), Stratigraphic Section I, extends to 30/2N/22E and 1/1N/21E; sec. 36, GmR, JsV, Ato, 43 (in pocket), Indian Service Road Section, extends to 4,5,6,9/1N/22E. **T2N, R22E**: secs. 18,19,30, Stn, 25 (p. 109–110), Indian Road Section (M.S. G); sec. 30, Chs, WhM, PrH, PrM, Mar, Wes, UnV, JsV, Ato, 8 (p. 4–11), Stratigraphic Section I, extends to 25,31,36/2N/21E and 1/1N/21E; sec. 30, Chs, 13 (in pocket), Indian Service Road Section (Loc. 8). **T2N, R23E**: none. **T2N, R24E**: sec. 22, Chs, 13 (in pocket), Muse Section (Loc. 6); sec. 22, Chs, 30 (p. 149b), Type Section. **T2N, R25E**: sec. 23, Stn, 25 (p. 111–112), Big Cedar Section (M.S. H); secs. 23,26, Ten, Moy, Chs, 21 (in pocket), Big Cedar Section (M.S. A); secs. 23,24,25,26,27,32,33, Chs, WhM, PrH, (PrM, Mar), Wes, Ato, 8 (p. 15–18), Stratigraphic Section II, extends to 5/1N/25E, (note: see also changes proposed in reference 4, p. 29–31); secs. 23,26, Chs, 13 (in pocket), Big Cedar Section (Loc. 5); sec. 25, WhM, 26 (p. 120–135), Sections OK-20, OK-19, OK-40, OK-4; sec. 32, (PrM, Mar), Wes, Ato, 43 (in pocket), M.S. 103K, extends to 5/1N/25E; sec. 32, Ato, 6 (p. 17f), Kiamichi Mountain Section (Loc. 2), extends to 5/1N/25E. **T2N, R26E**: none. **T2N, R27E**: sec. 3, WhM, (PrM, Mar, Wes), GmR, (JsV, Ato), Ato, 39 (p. 151–162), Rich Mountain Section, extends to 34/3N/27E and into Arkansas. **T1N, R12E**: sec. 1, Wap, 46 (p. 58); sec. 1, Wap, 36 (p. 248–251), M.S. A20; sec. 1, Chc, 14 (p. 265–266), Burg, Oklahoma Section (M.S. 22); sec. 15, Wap, 36 (p. 245–247), M.S. A19; sec. 15, Wap, Chc, 14 (p. 290–294), Penitentiary Quarry Section (M.S. 31); sec. 22, Chc, 14 (p. 260–262), Chilly Creek tributary Section (M.S. 20); sec. 23, Chc, 14 (p. 263–264), Chilly Creek Section

(M.S. 21); sec. 29, Wap, 12 (p. F1–F3), Industrial School Section. **T1N, R13E**: sec. 1, Wap, 17 (p. 49–54), M.S. II; sec. 10, Wap, 17 (p. 55–56), M.S. III; sec. 20, Wes, 15 (p. 153–158), Type Locality (Loc. O). **T1N, R14E**: none. **T1N, R15E**: sec. 19, Chs, Jfk, 34 (p. 80), Type Section (M.S. 14). **T1N, R16E**: none. **T1N, R17E**: none. **T1N, R18E**: sec. 8, Moy, 25 (p. 107), Little Cedar Creek Section (M.S. E); sec. 33, JsV, 34 (p. 82), M.S. 20; sec. 33, JsV, 34 (p. 83), M.S. 21. **T1N, R19E**: secs. 21,22,26,27,35, LnM, 34 (p. 83–88). **T1N, R20E**: none. **T1N, R21E**: sec. 1, Chs, WhM, PrH, PrM, Mar, Wes, UnV, JsV, Ato, 8 (p. 4–11), Stratigraphic Section I, extends to 25,31,36/2N/21E and 30/2N/22E. **T1N, R22E**: secs. 4,5,6,9, GmR, JsV, Ato, 43 (in pocket), Indian Service Road Section, extends to 36/2N/21E. **T1N, R23E**: secs. 32,33, WhM, PrH, PrM, Mar, Wes, GmR, JsV, Ato, 40 (p. 68–72), M.S. I, extends to 2,3,4,11/1S/23E. **T1N, R24E**: secs. 34,35, Moy, Chs, WhM, 40 (p. 75–76), M.S. V, extends to 1,2/1S/24E. **T1N, R25E**: sec. 5, Chs, WhM, PrH, (PrM, Mar), Wes, Ato, 8 (p. 15–18), Stratigraphic Section II, extends to 23,24,25, 26,27,32,33/2N/25E, (note: see also changes proposed in reference 4 (p. 29–31); sec. 5, (PrM, Mar), Wes, Ato, 43 (in pocket), M.S. 103K; sec. 5, Ato, 6 (p. 17f), Kiamichi Mountain Section (Loc. 2), extends to 32/2N/25E. **T1N, R26E**: sec. 22, Stn, Jfk, 22 (p. 165–173), Section on Beech Creek. **T1N, R27E**: none. **T1S, R12E**: sec. 9, Wom, 20 (p. 26); sec. 10, Wom, Bgf, MMt, ArN, 20 (p. 23–24), Grant's Gap Section, (note: section includes undifferentiated Pennsylvanian beds); sec. 10, Wom, Bgf, MMt, ArN, Ato, 45 (p. 15), Grant's Gap Section; sec. 10, ArN, 41 (p. 217–219), Grant's Gap Section; sec. 12, Wes, JsV, 15 (p. 166–169), Mayne's Ranch Section (Loc. M); sec. 16, Bgf, 37 (p. 131–132), M.S. E; sec. 26, Chs, 16 (p. 875–876), Second Type Locality; sec. 29, Wom, Bgf, 20 (p. 24–25), North Boggy Creek Section; sec. 29, Bgf, 37 (p. 129–131), M.S. D. **T1S, R13E**: sec. 7, Chs, 16 (p. 874–875), Type Locality; secs. 11,12, Mar, Wes, 15 (p. 170–173), Peacock Meadow Section (Loc. R); sec. 18, Wes, GmR, 15 (p. 160–165), Stringtown Syncline Section (Loc. O); sec. 30, Wes, 15 (p. 175–177), Round Prairie Section (Loc. U). **T1S, R14E**: none. **T1S, R15E**: none. **T1S, R16E**: secs. 14,15,23,24,25, Chs, PrH, Wes, GmR, 34 (p. 79–80), M.S. 13, (note: includes unnamed sandstones); sec. 24, Moy, 25 (p. 106), Dunbar Section (M.S. D), extends to 19/1S/17E. **T1S, R17E**: sec. 19, Moy, 25 (p. 106), Dunbar Section (M.S. D), extends to 24/1S/16E. **T1S, R18E**: none. **T1S, R19E**: secs. 29,30, Moy, 47 (p. 54). **T1S, R20E**: none. **T1S, R21E**: none. **T1S, R22E**: none. **T1S, R23E**: secs. 2,3,4,11, WhM, PrH, PrM, Mar, Wes, GmR, JsV, Ato, 40 (p. 68–72), M.S. I, extends to 32,33/1N/23E. **T1S, R24E**: secs. 1,2, Moy, Chs, WhM, 40 (p. 75–76), M.S. V, extends to 34,35/1N/24E; sec. 7, Wes, 40 (p. 73), M.S. III; sec. 29, Ato, 40 (p. 74), M.S. IV. **T1S, R25E**: none. **T1S, R26E**: sec. 35, Ten, 30 (p. 20b), (note: part E–E′ of composite section). **T1S, R27E**: sec. 32, Ten, 32 (p. 329), M.S. III. **T2S, R11E**: secs. 13,14, ArN, 20 (p. 25), Antler's Road Section; sec. 14, ArN, 45 (p. 14); sec. 14, ArN, 41 (p. 215–216), Atoka Section. **T2S, R12E**: sec. 2, Wes, 15 (p. 174–175), Camel Creek Section (Loc. T); sec. 21, Bgf, MMt, ArN, Stn, 20 (p. 24); sec. 32, PoC, MMt, ArN, Stn, 20 (p. 25–26). **T2S, R13E**: sec. 11, Wes, 15 (p. 179–182), Pine Tree Ranch Section (Loc. D). **T2S, R14E**: none. **T2S, R15E**: secs. 15,16, Ten, Moy, 25 (p. 98–99), Jumbo Valley Section (M.S. A); secs. 15,16, Ten, 34 (p. 75–78), Type Section (M.S. 9); sec. 15, Moy, 34 (p. 79), Type Section (M.S. 12); sec. 15, Chs, 5 (p. 117–118), M.S. 1. **T2S, R16E**: secs. 30,31, WhM, 16 (p. 879), Type Locality; sec. 32, Moy, 16 (p. 871), Type Section, extends to 5/3S/16E. **T2S, R17E**: none. **T2S, R18E**: sec. 2, Moy, 47 (p. 54–55); secs. 9,16, Moy, 47 (p. 55–56). **T2S, R19E**: none. **T2S, R20E**: none. **T2S, R21E**: secs. 21,27,28, Moy, 34 (p. 78), M.S. 11; sec. 36, WhM, PrM, 34 (p. 82), M.S. 18, extends to 1/3S/R21E. **T2S, R22E**: secs. 17,18, Stn, 21 (in pocket), Pickens Section (M.S. C); secs. 17,18, Moy, Chs, WhM, 40 (p. 72–73), M.S. II; sec. 19, Chs, 34 (p. 81), M.S. 15. **T2S, R23E**: none. **T2S, R24E**: sec. 32, Ten, 32 (p. 329), M.S. II. **T2S, R25E**: sec. 9, Stn, 21 (in pocket), Narrows Section (M.S. B). **T2S, R26E**: sec. 33, ArN, 29 (in pocket), Smithville Quadrangle M.S. 10. **T2S, R27E**: none. **T3S, R13E**: none. **T3S, R14E**: none.

T3S, R15E: secs. 11,14,16,20,21, Ten, 16 (p. 867), Type Section. **T3S, R16E**: sec. 5, Moy, 16 (p. 871), Type Section, extends to 32/2S/16E; sec. 18, Moy, Chs, 44 (p. 64–72). **T3S, R17E**: none. **T3S, R18E**: none. **T3S, R19E**: none. **T3S, R20E**: none. **T3S, R21E**: sec. 1, WhM, PrM, 34 (p. 82), M.S. 18, extends to 36/2S/21E; sec. 1, Mar, Wes, 34 (p. 82), M.S. 19; sec. 19, PrH, 34 (p. 81), M.S. 17; sec. 22, Jfk, 34 (p. 81), M.S. 16, (note: called WhM by reference cited in 31). **T3S, R22E**: none. **T3S, R23E**: sec. 20, Stn, 22 (p. 152–163). **T3S, R24E**: sec. 20, Ten, 30 (p. 145b), Type Locality of informal Mud Creek Tuff, (note: part D–D′ of composite section); sec. 20, Ten, 30 (p. 146b), Type Section of informal Lower Mud Creek Tuff, (note: part D–D′ of composite section); sec. 20, Ten, 30 (p. 147b), Type Section of informal Upper Mud Creek Tuff, (note: part D–D′ of composite section); sec. 20, Ten, 32 (p. 329), M.S. I; sec. 28, Ten, 21 (in pocket), Carter Creek Section (M.S. E); sec. 34, ArN, 41 (p. 230–231), Carter Mountain Section. **T3S, R25E**: sec. 16, Ten, 30 (p. 148b), (note: called Sparsely Speckled Tuff [informal] sequence); sec. 27, Bgf, 22 (p. 74–79); sec. 27, Bgf, 37 (p. 134–136), M.S. H. **T3S, R26E**: sec. 16, Stn, 22 (p. 145–146); sec. 17, ArN, Stn, 22 (p. 119–120,142–143); sec. 22, ArN, 29 (in pocket), Smithville Quadrangle M.S. 7. **T3S, R27E**: none. **T4S, R16E**: none. **T4S, R17E**: none. **T4S, R18E**: none. **T4S, R19E**: none. **T4S, R20E**: none. **T4S, R21E**: none. **T4S, R22E**: none. **T4S, R23E**: sec. 20, Ten, Hat, 30 (p. 20b), (note: part C–C′ of composite section); sec. 27, ArN, 29 (in pocket), Golden Quadrangle M.S. 9; sec. 29, Blk, MMt, ArN, 22 (p. 91–94,105–107,117–118); sec. 32, ArN, 41 (p. 228–229), Glover Creek Section. **T4S, R24E**: sec. 8, ArN, 29 (in pocket), Golden Quadrangle M.S. 6; secs. 10,15, Blk, MMt, ArN, 9 (p. 111–112), Table 7-1, (author's note: exact location unclear from text); sec. 10, ArN, 41 (p. 232–233), North Middle Section; sec. 10, ArN, 41 (p. 234–235), Middle Section; sec. 15, ArN, 41 (p. 236), Southern Section; secs. 16,17, ArN, 29 (in pocket), Golden Quadrangle M.S. 8. **T4S, R25E**: sec. 23, Blk, 22 (p. 88–91); sec. 33, Bgf, 37 (p. 133–134), M.S. G. **T4S, R26E**: sec. 9, ArN, 29 (in pocket), Welch Mountain M.S. 4; sec. 14, ArN, 29 (in pocket), Welch Mountain M.S. 5. **T4S, R27E**: none. **T5S, R19E**: sec. 1, WhM, 10 (p. 60–61), Youngman Quarry Section; sec. 17, Jfk, 1 (p. 55), Clement Brothers Quarry Section. **T5S, R20E**: sec. 9, WhM, PrH, 10 (p. 60). **T5S, R21E**: none. **T5S, R22E**: sec. 15, Ten, Hat, 30 (p. 20b), (note: B–B′ part of composite section). **T5S, R23E**: sec. 6, Ten, 30 (p. 20b), (note: A–A′ part of composite section); sec. 22, Wom, 33 (p. 25); sec. 27, Col, 33 (p. 17); sec. 27, CMt, 33 (p. 20). **T5S, R24E**: secs. 8,17, Luk, 33 (p. 14); sec. 14, ArN, 41 (p. 226–227), Bear Mountain Section; sec. 17, CMt, 33 (p. 20). **T5S, R25E**: sec. 3, ArN, 42 (p. 59–62); sec. 3, ArN, 41 (p. 237–238), Beavers Bend Pool Section; sec. 3, ArN, 29 (in pocket), Beavers Bend M.S. 2; sec. 9, Blk, 42 (p. 38–47); sec. 9, MMt, 42 (p. 51–53); sec. 10, ArN, 41 (p. 239–240), Beavers Bend section; sec. 10, ArN, 29 (in pocket), Beavers Bend M.S. 1; sec. 10, ArN, 29 (in pocket), Beavers Bend M.S. 3; sec. 10, Stn, 42 (p. 68–72), Rattlesnake Bluff Section; sec. 10, Stn, 21 (in pocket), Mountain Fork Section (M.S. D); sec. 10, Stn, 30 (p. 143b), Rattlesnake Bluff Section (Type Section), (note: Beavers Bend Tuff sequence); sec. 14, Hat, 30 (p. 144b), Representative Section. **T5S, R26E**: sec. 8, Stn, 22 (p. 146–147). **T5S, R27E**: none. **T6S, R23E**: none. **T6S, R24E**: none. **T6S, R25E**: none. **T6S, R26E**: none. **T6S, R27E**: none.

References Containing Measured Sections

References containing the measured sections are numbered in correspondence with the location list.

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Discussion

Brief mention should be made of certain units that have been renamed, misnamed, or misused in the Ouachita Mountains. The Lukfata Sandstone (Pitt, 1955) is now considered to be the Crystal Mountain Formation and Collier Shale (Repetski and Ethington, 1977). The Union Valley Sandstone of Cline and Moretti (1956) correlates with the Game Refuge Formation of the Jackfork Group (Harlton, 1959). The Primrose, Limestone Gap, and Barnett Hill Formations were separated by Harlton (1938) from the Wapanucka in the frontal Ouachitas. Gordon (*in* Cohee and Wright, 1976) restricted the Barnett Hill to the northern Arbuckle Mountains region and correlated it with the Atoka in the Ouachitas. He also restricted the Primrose to the southern Arbuckle Mountains and correlated it with the Springer of the frontal Ouachitas and upper Jackfork and lower Johns Valley of the central Ouachitas, and did not use the name Limestone Gap. The Lynn Mountain Formation was used by Pitt (1982), who correlated it with the Atoka Formation of most other workers in the Ouachita Mountains.

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A NEW LOWER PERMIAN VERTEBRATE SITE IN THE WELLINGTON FORMATION OF OKLAHOMA

***Roger J. Burkhalter*[1]**

Abstract

A new vertebrate-fossil site was found during an investigation of the Lower Permian Wellington Formation in Noble County, Oklahoma. This site, designated Perry site 7, has yielded numerous three-dimensional remains of various fish, amphibians, and reptiles. It is the second reported site in which *Dictyobolus tener* is known to occur. The other site in which this reptile has been reported has been covered.

The Site and the Fauna

The type locality for *Dictyobolus tener* Olson was described by Dr. E. C. Olson as Perry site 6 (Olson, 1967, p. 42–44; 1970, p. 376–394). The site subsequently has been covered by the construction of a farm livestock pond. A new site was located during a survey of the Wellington Formation about a quarter of a mile to the east of Perry site 6. This new site, herein designated Perry site 7, is located in a westward-facing county barrow pit. Perry site 7 is ~20 ft stratigraphically higher than Olson's locality and contains essentially the same terrestrial fauna, with the addition of *Diadectes* sp. and *Archeria* sp., but contains far fewer fish remains (see tabular faunal list in Simpson, 1979, p. 9).

Perry site 7 is located in the NE¼SW¼SW¼ sec. 25, T23N, R2W, Noble County, Oklahoma. A section measured from west to east in the barrow pit shows a sequence of thin, alternating beds of shale, sandstone, and dolomite typical of the upper unit of the Wellington Formation (Shelton, 1979, p. 18–19). Local dip was measured at $<2°$ WSW. Bone is confined to bed 15, a shale unit which grades laterally into a fine-grained, light-gray sandstone to the north. This sandstone is nearly barren of fossils, although some predepositionally weathered bone occurs. In the transition zone between the shale and the sandstone, small, poorly preserved plant fragments occur with small (0.125–0.5 in.) malachite and azurite nodules. The plant fragments are mostly small stem casts with no discernible morphologic features or cell structure. No compression flora was noted at the site. The fossils in the shale are three-dimensional, and articulated sections occasionally can be recovered. A faunal list from the shale of bed 15 is shown below.

Dictyobolus tener is a minor element of the fauna at this site, but it is important because this is only the second reported occurrence of this small, unique, araeoscelid reptile. Unlike occurrences of this reptile at Perry site 6, where

[1]Director, Anadarko Basin Museum of Natural History, Elk City, Oklahoma.

Measured Section, Perry Site 7

Bed	Description	Thickness (ft)
17	Gray-brown shale	1.0
16	Alternating red-brown shale and sandstone	3.0
15	Light-gray shale grading to light-gray sandstone to south; abundant fossil bone, plant fragments, malachite and azurite	2.0
14	Dark-red-brown shale	3.0
13	Red-brown alternating shale and sandstone	3.5
12	Light-brown sandstone	1.5
11	Dark-red-brown shale	0.2
10	Dark-gray shale	0.3
9	Light-gray dolomite	0.1
8	Medium-gray shale	1.0
7	Light-gray shale with sandstone partings	0.9
6	Red-brown sandstone, becoming lighter in color to the south	0.2
5	Red-brown shale	0.3
4	Blue-gray shale	3.5
3	Blue-gray mudstone with some dolomite	0.7
2	Red-brown mudstone	0.5
1	Red-brown shale	0.7

Faunal List, Bed 15, Perry Site 7

Chondrichthyes
- *Orthacanthus compressus* (Newberry)

Osteichthyes
- Dipnoi
  - *Gnathoriza serrata* Cope
- Actinopterygia
  - *Sphaerolepis arctata* (Cope)
  - Undifferentiated palaeoniscoids

Amphibia
- *Archeria* sp.
- *Diadectes* sp.
- *Diplocaulus* sp. cf. *D. magnicornis* Cope
- *Eryops megacephalus* Cope
- *Trimerorhachis insignis* Cope

Reptilia
- *Captorhinus* sp. cf. *C. aguti* Cope
- *Captorhinomorpha* sp. indet.
- *Dimetrodon limbatus* (Cope)
- *Dictyobolus tener* Olson
- *Ophiacodon uniformis* (Cope)

large sandstone bone beds occurred, only isolated elements were found at this new site. *Dimetrodon limbatus* and *Eryops megacephalus* are the most common animals at this site and are well represented by numerous elements.

Only a few isolated patches of articulated palaeoniscoid scales, two shark teeth, and a single lungfish tooth plate were found. This contrasts strongly with Perry site 6, where large numbers of various articulated fish were found.

Mr. Larry Simpson of Oklahoma City is gratefully acknowledged for help with the identification of various fossil elements. All materials noted in this report are on deposit at the Anadarko Basin Museum of Natural History in Elk City, Oklahoma.

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OKLAHOMA EARTHQUAKES, 1986

James E. Lawson, Jr.[1] *and Kenneth V. Luza*[2]

Instrumentation

A statewide network of 11 seismograph stations was used to locate 52 earthquakes in Oklahoma for 1986 (Fig. 1). The Oklahoma Geophysical Observatory (OGO) station, TUL, located near Leonard, Oklahoma, in southern Tulsa County, operates seven seismometers, three long-period and four short-period. The seismic responses at TUL are recorded on 14 paper-drum recorders and one digital recorder. Accurate timing is assured by a microprocessor clock that is continuously locked to the National Bureau of Standards cesium-beam clocks by low-frequency radio transmissions broadcast by WWVB (Lawson, 1980). Seven semipermanent volunteer-operated seismograph stations and three radio-telemetry seismograph stations complete the Oklahoma Geological Survey's seismic network. The operation and maintenance of 10 of the stations is partially supported by the U.S. Nuclear Regulatory Commission (Luza, 1978).

Each of the seven volunteer-operated seismograph stations consists of a Geotech S-13 short-period vertical seismometer; a Sprengnether MEQ-800-B unit, including amplifier, filters, hot-stylus heat-sensitive-paper recording unit, and a clock; and a Kinemetrics time-signal-radio receiver for high-frequency WWV time signals. Each radio-telemetry system consists of one Geotech S-13 seismometer and one radio-telemetry unit. The telemetry unit amplifies the seismometer output and uses this output to frequency-modulate an audiotone. The signals are transmitted to Leonard in the 216- to 220-MHz band with 500-mW transmitters and 11-element beam antennas, giving an effective radiated forward power of 12.9 W. Transmission path lengths vary from 50 to 75 km. Seismograms from the radio-telemetry stations are recorded at the Oklahoma Geophysical Observatory.

Station OCO, which contains equipment similar to the volunteer-operated stations, is located at the Omniplex museum in Oklahoma City. Omniplex staff members change the seismic records daily as well as maintain the equipment. Oklahoma Geophysical Observatory staff help interpret the seismic data and archive the seismograms with all other Oklahoma network seismograms.

Data Reduction and Archiving

Arrival times from all visible teleseisms (phases from distant earthquakes) at TUL, RLO, BHO, VVO, SIO, and OCO are sent to the U.S. National Earthquake Information Service and the International Seismological Centre in England. P-wave and surface-wave amplitudes from TUL, plus selected arrival

[1]Oklahoma Geophysical Observatory, Leonard.
[2]Oklahoma Geological Survey.

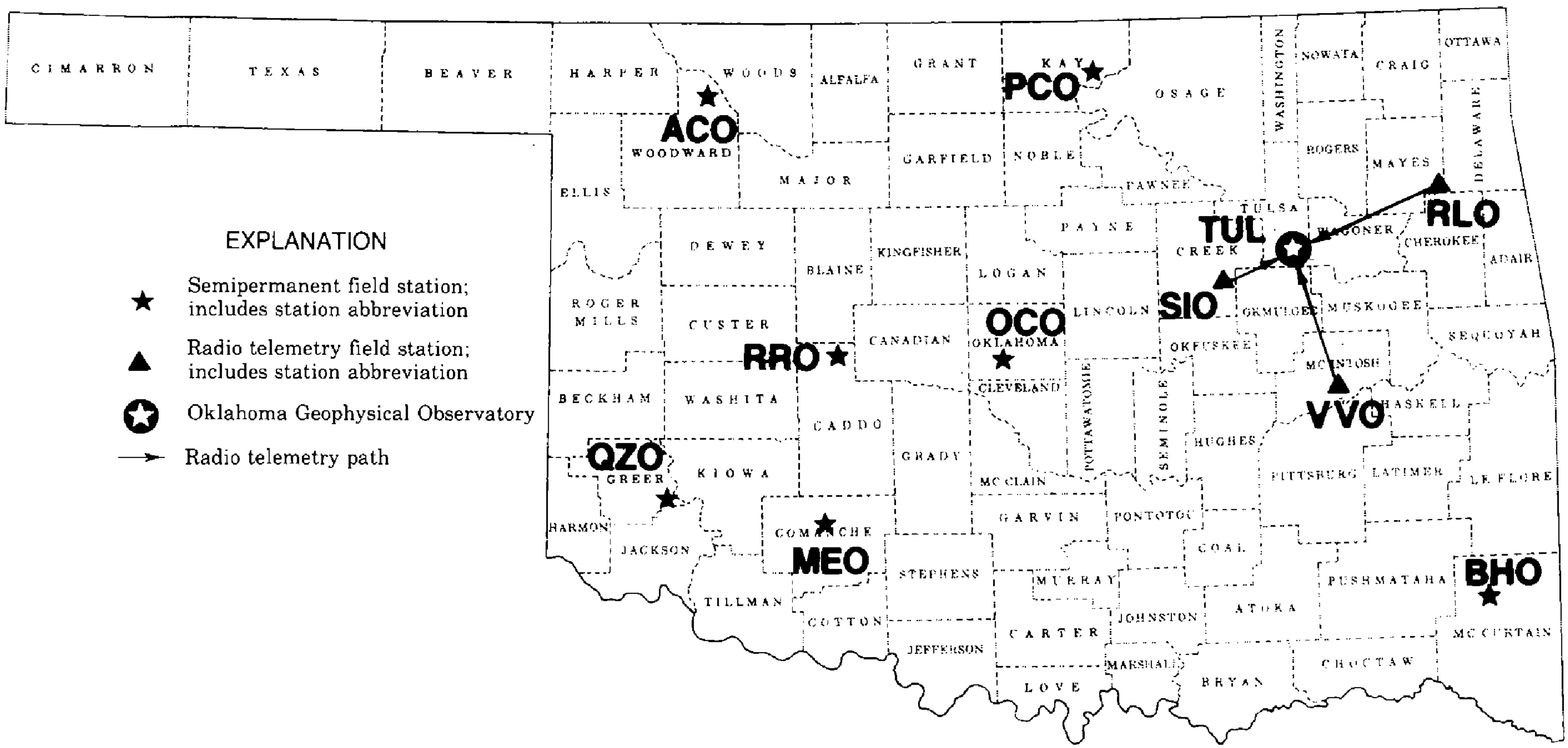

Figure 1. Active seismographs in Oklahoma.

times from ACO, QZO, and other stations, are also included. These reduced seismic data are sent to more-specialized agencies such as the USAF Technical Applications Center, which monitors underground nuclear tests worldwide.

From station TUL, at the OGO near Leonard, five short-period vertical seismograms (with differing frequency responses) are searched exhaustively for local and regional earthquake phases. Also searched are two TUL short-period horizontal seismograms; two short-period vertical seismograms from each of RLO, SIO, and OCO; and one short-period vertical seismogram from each of the seven other stations.

Fourteen to 16 daily TUL seismograms, as well as 13 daily seismograms from the remote stations, are permanently archived at the OGO.

Earthquake Distribution

All Oklahoma earthquakes recorded on seismograms from three or more stations are located. In 1986, 52 Oklahoma earthquakes were located (Fig. 2; Table 1). No earthquakes were reported felt. The felt and observed effects of earthquakes are generally given values according to the Modified Mercalli intensity scale, which assigns a Roman numeral to each of 12 levels described by effects on humans, man-made constructions, or natural features (Table 2).

Earthquake-magnitude values range from a low of 1.2 (m3Hz) in Haskell County to a high of 2.9 (m3Hz) in Coal County. Garvin and McClain Counties continue to be one of the most active areas in the state since 1979. For the third year in a row, the Canadian County area contained no locatable earthquakes. The Arkoma basin, which includes all or parts of Pontotoc, Coal, Hughes, McIntosh, Pittsburg, Latimer, and Le Flore Counties, experienced many low-magnitude earthquakes. The first known earthquakes in Texas and Delaware Counties were recorded in 1986. Except for the Texas County earthquake, western Oklahoma was conspicuously quiet in 1986.

Catalog

A desk-top computer system, including linked HP-9825T and HP-9835-A computers, hard and flexible disks, and printers, is used to calculate and catalog local earthquake epicenters. Any earthquake within Oklahoma or within about 100–200 km of Oklahoma's borders is considered a local earthquake. A catalog containing date, origin time, county, intensity, magnitude, location, focal depth, and references is printed in page-sized format. Table 1 contains 1986 Oklahoma earthquake data displayed in a modified version of the regional earthquake catalog. Each event is sequentially numbered and arranged according to date and origin time. The numbering system is compatible with the system used for the *Earthquake Map of Oklahoma* (Lawson and others, 1979) and subsequent additions (Lawson and Luza, (1980–1986).

The date and time are given in UTC. UTC refers to Coordinated Universal Time, formerly Greenwich Mean Time. The first two digits refer to the hour on a 24-hour clock. The next two digits refer to the minute, and the remaining digits are the seconds. To convert to local Central Standard Time, subtract 6 hours.

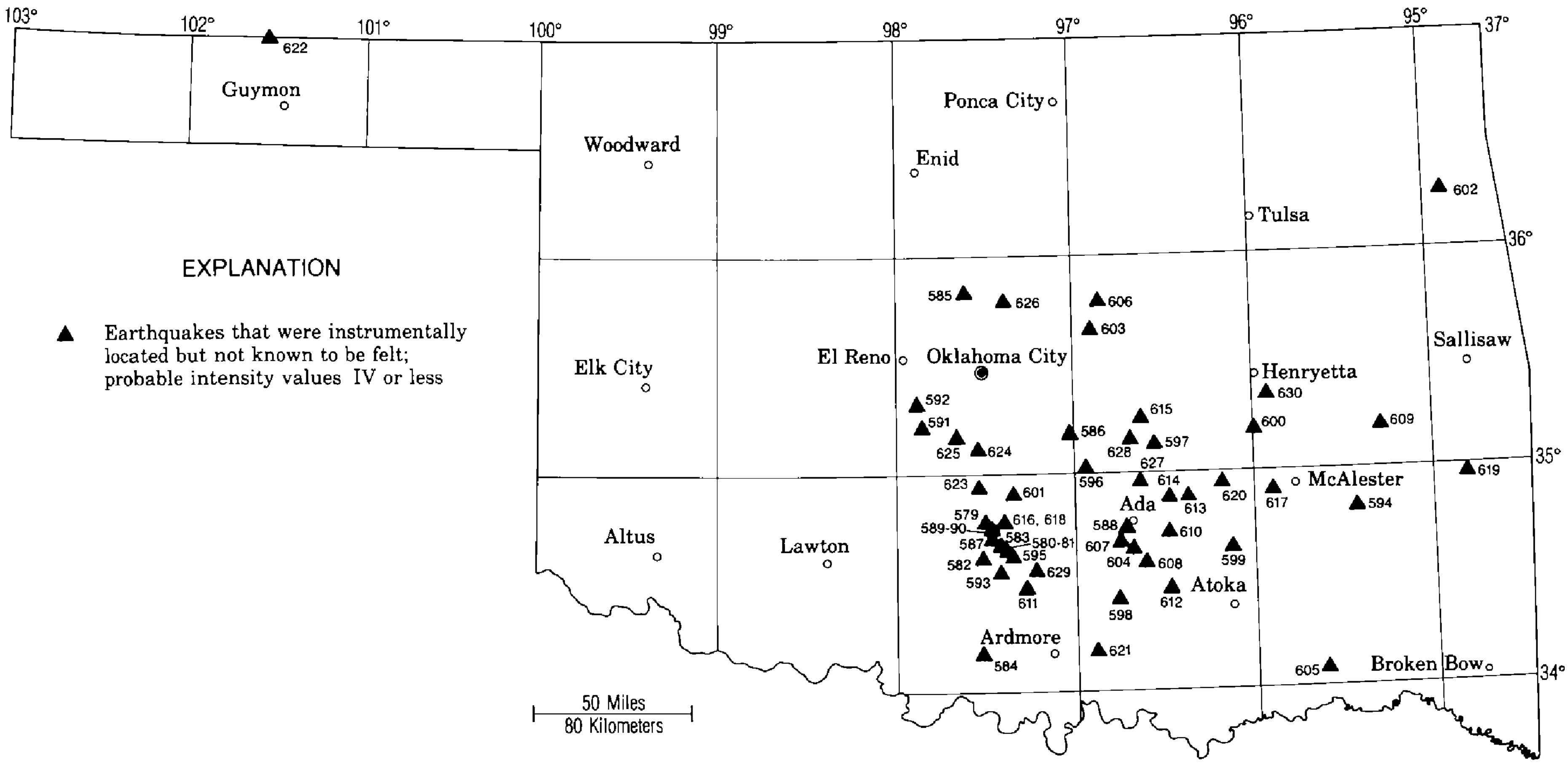

Figure 2. Distribution of Oklahoma earthquakes for 1986. Numbers correspond to event numbers in Table 1.

TABLE 1.—OKLAHOMA EARTHQUAKE CATALOG FOR 1986

Event Number	Date and Origin Time (UTC)[1]		County	Intensity MM[2]	Magnitudes 3Hz	bLg	DUR	Latitude deg N	Longitude deg W	Depth (km)[3]
579	JAN 1	013407.41	GARVIN		2.2	1.9	2.3	34.764	97.473	5.0R
580	JAN 1	022046.17	GARVIN		1.9	1.9	2.0	34.656	97.436	5.0R
581	JAN 1	064044.52	GARVIN		1.6		1.8	34.683	97.451	5.0R
582	JAN 1	080807.63	GARVIN		1.7		2.1	34.625	97.537	5.0R
583	JAN 1	094638.73	GARVIN		1.5		2.1	34.703	97.459	5.0R
584	JAN 3	061213.41	CARTER				2.2	34.197	97.554	5.0R
585	JAN 3	192434.00	LOGAN				2.2	35.851	97.646	5.0R
586	JAN 7	122510.81	POTTAWATOMIE		1.8		1.6	35.274	96.987	5.0R
587	JAN 9	034926.82	GARVIN		1.8		2.2	34.726	97.464	5.0R
588	JAN 25	223307.40	PONTOTOC		2.0		2.0	34.753	96.720	5.0R
589	JAN 26	020340.65	GARVIN		2.5	2.5	2.4	34.728	97.456	5.0R
590	JAN 26	121212.62	GARVIN				2.2	34.748	97.472	5.0R
591	JAN 27	023723.85	GRADY		2.2	2.1	2.3	35.238	97.858	5.0R
592	JAN 27	050350.38	GRADY		2.5	2.4	2.4	35.348	97.878	5.0R
593	FEB 6	105013.75	GARVIN		1.6		1.8	34.560	97.446	5.0R
594	FEB 14	060905.41	LATIMER		2.5	1.8	2.4	34.821	95.442	5.0R
595	FEB 24	235222.43	GARVIN		2.6	2.3	2.1	34.626	97.417	5.0R
596	FEB 25	052620.33	POTTAWATOMIE		1.7		1.6	35.023	96.923	5.0R
597	MAR 13	094626.55	SEMINOLE		1.6		1.6	35.117	96.546	5.0R
598	APR 5	145453.00	JOHNSTON		1.6	1.6	1.9	34.446	96.749	5.0R
599	APR 16	195208.80	COAL		2.3	2.0	2.1	34.631	96.149	5.0R
600	APR 29	235718.65	HUGHES		1.9		1.6	35.165	96.003	5.0R
601	APR 30	033610.71	McCLAIN		2.0		2.2	34.931	97.360	5.0R
602	MAY 25	102744.82	DELAWARE		2.1	1.4	2.2	36.230	94.877	5.0R
603	JUN 1	195238.19	LINCOLN		2.1	1.6	2.0	35.656	96.897	5.0R
604	JUN 2	070811.21	PONTOTOC		1.3		1.1	34.652	96.651	5.0R
605	JUN 10	074801.66	CHOCTAW		2.0	1.5	1.9	34.056	95.592	5.0R
606	JUN 15	220054.27	LINCOLN		1.3		1.6	35.767	96.859	5.0R
607	JUN 30	195551.16	PONTOTOC		2.7	2.1	2.3	34.706	96.752	5.0R
608	JUL 26	041723.83	PONTOTOC		2.6	2.3	2.3	34.591	96.620	5.0R
609	AUG 4	233606.82	HASKELL		1.2		1.7	35.165	95.296	5.0R
610	SEP 2	131959.04	PONTOTOC		2.1		2.1	34.684	96.483	5.0R
611	SEP 2	153709.90	MURRAY		1.9		1.7	34.489	97.270	5.0R
612	SEP 4	173317.41	COAL		2.9	2.6	2.5	34.477	96.503	5.0R
613	SEP 16	010516.94	HUGHES		2.5		2.3	34.884	96.370	5.0R
614	SEP 23	054927.96	PONTOTOC		2.0		1.8	34.903	96.468	5.0R
615	OCT 7	120639.12	SEMINOLE		2.2		2.5	35.257	96.580	5.0R
616	OCT 13	174244.71	GARVIN		2.6	2.3	2.0	34.750	97.421	5.0R
617	OCT 18	211216.49	PITTSBURG				1.1	34.915	95.909	5.0R
618	OCT 30	012434.80	GARVIN		2.0		1.8	34.759	97.409	5.0R
619	NOV 1	013035.93	LE FLORE		1.6		1.5	34.962	94.747	5.0R
620	NOV 2	012403.59	HUGHES		1.5		1.4	34.940	96.179	5.0R
621	NOV 2	040011.97	JOHNSTON		1.9		1.7	34.192	96.855	5.0R
622	NOV 5	133446.18	TEXAS		2.8		2.4	36.993	101.561	5.0R
623	NOV 26	205338.63	McCLAIN		2.2	1.8	1.8	34.957	97.526	5.0R
624	NOV 26	221656.53	McCLAIN		2.0	1.9	2.0	35.125	97.541	5.0R
625	NOV 27	061215.90	GRADY		1.6	1.8	2.0	35.158	97.671	5.0R
626	DEC 4	175011.83	LOGAN		2.7	2.4	2.2	35.766	97.328	5.0R
627	DEC 14	115618.54	SEMINOLE		1.7		1.6	34.959	96.642	5.0R
628	DEC 21	173258.13	SEMINOLE		2.8	2.8	2.6	35.142	96.676	5.0R
629	DEC 23	211047.62	GARVIN				1.6	34.572	97.204	5.0R
630	DEC 25	084617.38	McINTOSH		1.9	1.4	1.7	35.399	95.839	5.0R

[1]UTC refers to Coordinated Universal Time, formerly Greenwich Mean Time. The first two digits refer to the hour on a 24-hour clock. The next two digits refer to the minute, and the remaining digits are the second. To covert the local Central Standard Time, subtract 6 hours.
[2]Modified Mercalli (MM) earthquake-intensity scale (see Table 2).
[3]The hypocenter is restrained (R) at an arbitrary depth of 5.0 km, except where indicated, for purposes of computing latitude, longitude, and origin time.

TABLE 2.—MODIFIED MERCALLI (MM) EARTHQUAKE-INTENSITY SCALE (ABRIDGED) (MODIFIED FROM WOOD AND NEUMANN, 1931)

I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings. Automobiles may rock slightly.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, doors, windows disturbed. Automobiles rocked noticeably.
V	Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; unstable objects overturned. Pendulum clocks may stop.
VI	Felt by all; many frightened and run outdoors.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction. Shock noticed by person driving automobiles.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings; great in poorly built structures. Fall of chimneys, stacks, columns. Persons driving automobiles disturbed.
IX	Damage considerable even in specially designed structures; well-designed frame structures thrown out of plumb. Buildings shifted off foundations. Ground cracked conspicuously.
X	Some well-built wooden structures destroyed; ground badly cracked, rails bent. Landslides and shifting of sand and mud.
XI	Few if any (masonry) structures remain standing. Broad fissures in ground.
XII	Damage total. Waves seen on ground surfaces.

Earthquake magnitude is a measurement of energy and is based on data from seismograph records. There are several different scales used to report magnitude. Table 1 has three magnitude scales, which are mbLg (Nuttli), m3Hz (Nuttli), and MDUR (Lawson). Each magnitude scale was established to accommodate specific criteria, such as the distance from the epicenter, as well as the availability of certain seismic data.

For earthquake epicenters located 11 km to 222 km from a seismograph station, Otto Nuttli developed the m3Hz magnitude scale (Zollweg, 1974). This magnitude is derived from the following expression:

$$\text{m3Hz} = \log(A/T) - 1.63 + 0.87 \log(\Delta),$$

where A is the maximum center-to-peak vertical-ground-motion amplitude sustained for three or more cycles of Sg waves, near 3 Hz in frequency, measured in nanometers; T is the period of the Sg waves measured in seconds; and Δ is the great-circle distance from epicenter to station measured in kilometers.

In 1979 St. Louis University (Stauder and others, 1979) modified the formulas for m3Hz. This modification was used by the OGO beginning January 1, 1982. The modified formulas had the advantage of extending the distance range for measurement of m3Hz out to 400 km, but also had the disadvantage of increasing m3Hz by about 0.12 units compared to the previous formula. Their formulas were given in terms of log(*A*) but were restricted to wave periods of 0.2 sec to 0.5 sec. In order to use log(*A/T*), we assumed a period of 0.35 sec in converting the formulas for our use. The resulting equations are:

(epicenter 10 to 100 km from a seismograph)

$$\text{m3Hz} = 0.88 \log(\Delta) + \log(A/T) - 1.46$$

(epicenter 100 to 200 km from a seismograph)

$$\text{m3Hz} = 1.06 \log(\Delta) + \log(A/T) - 1.82$$

(epicenter 200 to 400 km from a seismograph)

$$\text{m3Hz} = 1.29 \log(\Delta) + \log(A/T) - 2.35$$

Otto Nuttli's (1973) earthquake magnitude, mbLg, for seismograph stations located between 55.6 km and 445 km from the epicenter, is derived from the following equation:

$$\text{mbLg} = \log(A/T) - 1.09 + 0.90 \log(\Delta).$$

Where seismograph stations are located between 445 km and 3,360 km from the epicenter, mbLg is defined as:

$$\text{mbLg} = \log(A/T) - 3.10 + 1.66 \log(\Delta),$$

where A is the maximum center-to-peak vertical-ground-motion amplitude sustained for three or more cycles of Sg waves, near 1 Hz in frequency, measured in nanometers; T is the period of Sg waves measured in seconds; and Δ is the great-circle distance from epicenter to station measured in kilometers.

The MDUR magnitude scale was developed by Lawson (1978) for earthquakes in Oklahoma and adjacent areas. It is defined as:

$$\text{MDUR} = 1.86 \log(\text{DUR}) - 1.49,$$

where DUR is the duration or difference, in seconds, between the Pg-wave arrival time and the time the final coda amplitude decreases to twice the background-noise amplitude. Before 1981, if the Pn wave was the first arrival, the interval between the earthquake-origin time and the decrease of the coda to twice the background-noise amplitude was measured instead. Beginning January 1, 1982, the interval from the beginning of the P wave (whether it was Pg, P*, or Pn) to the decrease of the coda to twice the background-noise amplitude was used.

The depth to the earthquake hypocenter is measured in kilometers. For most Oklahoma earthquakes the focal depth is unknown. In almost all Oklahoma events, the stations are several times farther from the epicenter than the likely depth of the event. This makes the locations indeterminate at depth, which usually requires that the hypocenter depth be restrained to an arbitrary 5 km for purposes of computing latitude, longitude, and origin time. All available evidence indicates that no Oklahoma hypocenters have been deeper than 15 to 20 km.

Earthquake detection and location accuracy have been greatly improved since the installation of the statewide network of seismograph stations. The frequency of earthquake events and the possible correlation of earthquakes to specific tectonic elements in Oklahoma are being studied. It is hoped that this information will provide a more complete data base that can be used to develop numerical estimates of earthquake risk, giving the approximate frequency of the earthquakes of any given size for various regions of Oklahoma. Numerical risk estimates could be used for better design of large-scale structures, such as dams, high-rise buildings, and power plants, as well as to provide the necessary information to evaluate insurance rates.

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ELEMENTS OF AN OGS CORE-DRILLING PROJECT

LeRoy A. Hemish[1]

A core-drilling rig purchased by the Oklahoma Geological Survey (OGS) in 1981 (featured on the cover of the October 1981 issue of *Oklahoma Geology Notes*) plays an important role in the Survey's designated job of collecting geologic data. Cores recovered from the Earth's crust are invaluable to the geologist in that they provide another dimension for viewing the rocks. The coring rig, in effect, gives the geologist the ability to "see" into the strata that underlie the surface of the Earth.

A typical core-drilling project consists of three major phases: (1) the preliminary phase, (2) the operational phase, and (3) the report phase. The elements of these phases are described below.

Preliminary Phase

The purpose of a drilling project is put forward by the initiator of the project. If OGS administrators tentatively agree that the project has merit, a written proposal must then be submitted to the Director of the Survey. The proposal includes such information as estimates of cost, time needed, and number of core holes needed (with estimates of their depths); a map showing the general location of proposed drilling sites; and a description of the geologic and topographic setting in the area to be studied.

If approval for the investigation is granted by the Director, the geologist in charge of the project then does preliminary land work in the field. Ownership of property at selected sites must be determined (from information available at county courthouses or through personal contacts), and the owner must be contacted to secure permission for drilling. To allay any doubts the owner might have concerning liability or property damage, a letter from the Survey Director (Fig. 1) is presented, stating the Survey's obligations resulting from drilling activities. No payment can be made by the State to property owners for the privilege of drilling on their property.

Then a source of water for use in drilling must be located, preferably as close to the drill site as possible, to avoid long-distance hauling. Selection of the drilling site must be made with care. Accessibility is an important factor. Is the route to the site too steep for the mobile equipment? In case of heavy rains will the equipment become mired and immobile? Is the site in a place where crops might be destroyed? Will the equipment be in a location safe from vandalism when left unattended?

A route must be planned which permits maximum efficiency in moving the rig between core-hole sites. Bridges along the route must be inspected beforehand to ensure that load limits will not be exceeded.

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[1]Oklahoma Geological Survey.

OKLAHOMA GEOLOGICAL SURVEY

Charles J. Mankin, Director

June 1, 1986

TO WHOM IT MAY CONCERN;

The Oklahoma Geological Survey is conducting an evaluation of the coal resources of northeastern Oklahoma. A part of this study involves collection of cores and samples from selected locations in this region. Your property has been identified by us to be an important area for the collection of such information. We are therefore requesting permission to drill one or more core holes on your property for that purpose.

No locations will be staked nor holes drilled without your prior approval. Furthermore, the holes will be plugged in accordance with State regulations and the site restored following the completion of the drilling effort. Finally, the Survey assumes all responsibility for the drilling activities including worker's liability, site security, and damages caused to third persons or property as a result of the Survey's nonfeasance of misfeasance.

I hope it will be possible for you to grant the Survey permission to conduct the desired coring operation on your property. Should you desire further information or need additional clarification on this program, please do not hesitate to contact me.

Thank you for your consideration of this request.

Sincerely yours,

Charles J. Mankin
Director

CJM:bb

Figure 1. Letter from the Director of the Oklahoma Geological Survey, requesting permission to drill on private property.

In selecting sites, knowledge of the geology of the area is fully utilized to ensure correct interpretations of the subsurface stratigraphy and to enable more-precise predictions of expected depths for target beds. That is, the drill site should be selected in a geologically favorable area—if possible, where identifiable marker beds crop out. Furthermore, sites should be selected so that existing data will be significantly supplemented, so as to raise the quantitative evaluation of natural resources to a higher degree of reliability.

Logistics of the operation must be considered. What length of drill rod should be carried? How many feet of casing will be needed? How many bags of concrete will be required for plugging holes? Where can fuel and supplies be purchased? What is the availability of lodging and dining facilities? In addition, seasonal equipment may be needed, such as tarpaulins and heaters for use in frigid weather for the protection of the crew. The ultimate success of an operation of this kind depends in large part on proper planning.

Operational Phase

The operational phase of a core-drilling project begins when the OGS drill rig (mounted on a 2.5-ton flat-bed truck) and the trailer used to transport drill rods, water, and supplies depart for the field. The trailer is towed by a four-wheel-drive vehicle, which is also utilized to haul additional supplies, such as sacks of cement and drilling-mud additives. It is further used to temporarily store and transport cores collected during the drilling operation. The truck and four-wheel-drive vehicle are driven by OGS drilling technicians. A third Survey vehicle is driven to the field by the supervising geologist. This vehicle is used as an "office-in-the-field" at the drill site. It is also used for transportation between the drill site and the place of lodging, for hauling fuel, and for emergency runs in case of equipment breakage.

The driller and his assistant are responsible for operation and maintenance of all rig equipment. A thorough knowledge of the mechanical aspects of this equipment is essential, as the two men are also responsible for all needed repair work on the rig.

When the drilling site is reached, the rig is positioned and leveled; siting of the hole is determined by the geologist, generally by pacing from section lines; the location is plotted on a topographic map; and the legal description of the site is duly recorded. Water is then hauled for circulation in the drill hole, the mast is raised, the portable slush pit is set up, the required drill bit is attached, and drilling commences (Fig. 2). Generally, a 5⅞-in.-diameter hole is drilled to a depth of about 9 ft with a three-cone-type roller rock bit. Temporary surface casing is set (4-in. pcv pipe), which permits recirculation of drilling fluids.

If continuous coring is desired, a 10-ft core barrel with a 3-in.-diameter diamond bit is attached to the bottom of the drill stem. Two-inch-diameter core is cut, which is retrieved from the outer core barrel through the hollow drill stem by means of a wire-line hoist.

At the surface, the core is forced from the inner core barrel by means of water pressure and collected in trays, where it is washed, marked, described by the geologist, cut into 2-ft lengths, and boxed (Fig. 3). The boxed cores are labeled and hauled to the OGS Core Library in Norman, where they are stored.

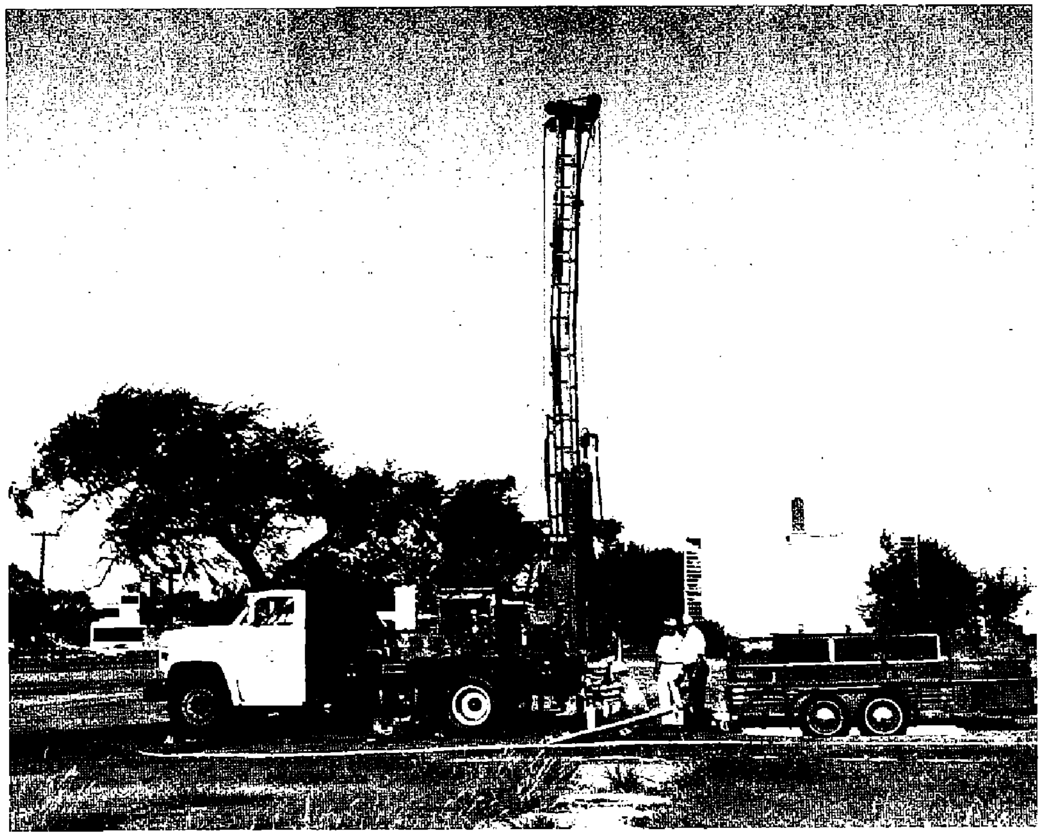

Figure 2. The Oklahoma Geological Survey drill rig and drill crew drilling a test hole in Cleveland County, Oklahoma.

If a specific segment of the core (such as a coal bed) is to be analyzed, it is removed from the tray prior to boxing and sealed in a clear, tough plastic bag (0.006 mils thick) for transport to the OGS laboratory.

Finally, the hole is plugged in accordance with state regulations and the site is restored. The rig and crew then move to the next scheduled drilling site.

Report Phase

The operational phase of a coring project ends with the completion of the last scheduled drill hole. The raw data (such as hand-written logs of the drill holes, descriptions of cores, field map data) are then taken to the OGS offices in Norman, where they are typed or otherwise put into presentable form. This is the beginning of the report phase. If requested, copies of the logs and core descriptions, as well as analytical data, are mailed to the landowners who granted the Survey permission to conduct coring operations on their property.

It then becomes the supervising geologist's responsibility to evaluate the accumulated data, to prepare maps showing where the data were gathered, to assemble cross sections for the purpose of making geologic interpretations, and to compile a report which assimilates all the information. The report is generally published by the Oklahoma Geological Survey.

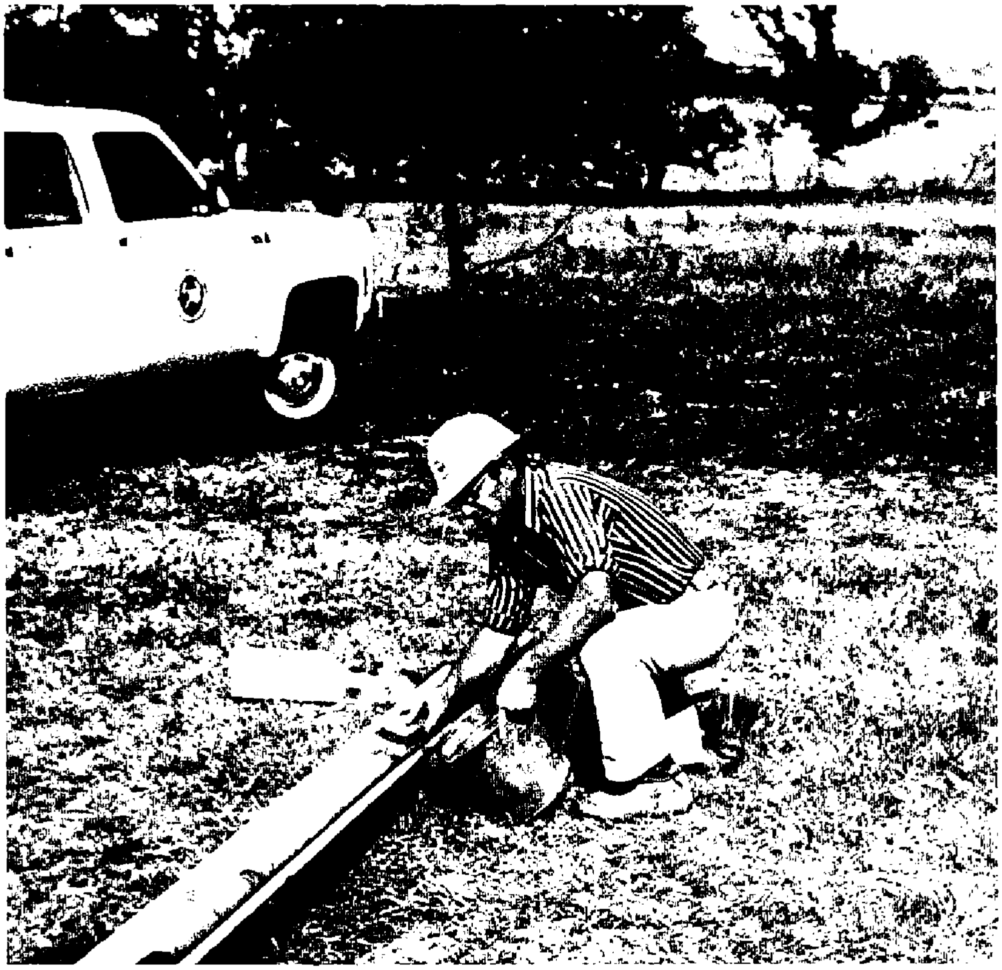

Figure 3. The author preparing a core for description and boxing during a coal-coring study in McIntosh County, Oklahoma.

Major OGS core-drilling projects have included an investigation of tar sands and heavy oil in the Arbuckle Mountains region, supervised by Margaret R. Burchfield and William E. Harrison; a geothermal-gradient study in the Arkoma basin region, involving collection of coal cores, supervised by LeRoy A. Hemish; a stratigraphic study and mapping project in Kay County, supervised by James R. Chaplin; coal-geology studies in Okfuskee, Okmulgee, McIntosh, and Muskogee Counties, supervised by LeRoy A. Hemish; and a stratigraphic study of upper Desmoinesian–lower Missourian rocks in northeastern Oklahoma, also supervised by LeRoy A. Hemish.

Future projects involve further coring for coal in the Survey's ongoing investigation of coal beds in Oklahoma, additional coring in Kay County, attempts to core to basement rock on either side of the Meers fault in the Wichita Mountains region, and to core thick shale intervals in order to study the movement of fluids through shale.

MINERAL INDUSTRY OF OKLAHOMA, 1986

The value of nonfuel mineral production in Oklahoma in 1986 was estimated at $258 million, rising slightly from the record $252 million reached in 1985. Construction materials continued to represent most of the output value; crushed stone, portland cement, and construction sand and gravel were the leading commodities produced. Increases in value of production were noted for portland cement, feldspar, gypsum, pumice, industrial sand and gravel, and crushed stone, while declines were posted for clays, lime, iodine, construction sand and gravel, and tripoli.

In 1986, the State's business conditions continued at very low levels similar to those of 1985. The construction industry, a major consumer of nonfuel minerals, continued to follow the downward pattern of activity which began in 1983. The dollar volume of construction activity for the year is expected to be at least 20% less than in 1985.

Nationally, Oklahoma ranked fourth in the production of crude gypsum. Temple-Eastex, Inc. dedicated a new $20 million gypsum-wallboard plant near Fletcher. At full production, the plant will employ about 100 workers to produce drywall, a product used in all types of construction for interior partitioning.

NONFUEL MINERAL PRODUCTION IN OKLAHOMA

Commodity	1985 Quantity[b]	1985 Value (thousands)	1986[a] Quantity[b]	1986[a] Value (thousands)
Cement:				
Masonry (thousand short tons)	43	$ 2,854	50	$ 3,400
Portland (thousand short tons)	1,589	72,583	1,700	79,600
Clays (thousand short tons)	997	2,338	1,120	2,647
Gemstones (thousand short tons)	—	2	—	W[c]
Gypsum (thousand short tons)	1,595	12,548	1,766	13,771
Sand and gravel for construction (thousand short tons)	12,600[d]	32,300[d]	10,600	26,000
Stone:				
Crushed (thousand short tons)	31,173	98,811	30,900	102,100
Dimension (thousand short tons)	11	836	19	913
Combined value of feldspar, iodine, lime, pumice, salt (1985), sand and gravel (industrial), tripoli, and withheld value	—	29,335	—	29,403
Total	—	$251,607	—	$257,834

Source: USBM Denver Regional Office of State Activities in cooperation with the Oklahoma Geological Survey.
[a]Preliminary figures.
[b]Production as measured by mine shipments, sales, or marketable production (including consumption by producers).
[c]Withheld to avoid disclosing company proprietary data, value included with "Combined value" figure.
[d]Estimated.

BOREHOLE TEMPERATURE GRADIENTS STUDIED BY OGS

Oklahoma Geological Survey Special Publication 86-2, *Temperature-Gradient Information for Several Boreholes Drilled in Oklahoma*, prepared by petroleum geologist William E. Harrison and engineering geologist Kenneth V. Luza of the Survey, is modified from a report to the U.S. Department of Energy as part of an OGS contract with DOE to study the geothermal resources of Oklahoma.

One of the main purposes of the study was to examine the relationship between borehole temperatures from geophysical logs—the principal source of geothermal-gradient information—and post-drilling equilibrated formation temperatures. A micro-thermometer constructed by OGS was used to study six industry wells in central and eastern Oklahoma. The results serve as an independent check on a previously published and widely used geothermal-gradient map of Oklahoma.

Authors' abstract:

Temperature conditions were monitored in six industry wells (called holes-of-opportunity in this report) that were drilled in central and eastern Oklahoma. Five of these wells provided useful temperature information, and two wells were used to determine the length of time needed for the borehole-fluid temperature to achieve thermal equilibrium with the formation rocks. The Ward Petroleum 1 Boardman well in Cleveland County had a final equilibrated temperature of 66°F at 776 ft about 65 days after the cessation of drilling. A temperature survey began in the TXO F-1 Henley well in Pittsburg County 107 days after drilling had stopped. The temperature measurements indicated that the fluids within the borehole probably had achieved thermal equilibrium prior to the first temperature survey.

Four wells were used to verify the validity of a geothermal-gradient map of Oklahoma (Cheung, 1978). Temperature surveys in two wells indicated a gradient lower than the predicted gradients on the geothermal-gradient map. When deep temperature data, between 5,000 and 13,000 ft, are adjusted for mud-circulation effects, the adjusted gradients approximate the gradients on the geothermal-gradient map. Two boreholes that were surveyed showed the possible influence of ground water on the temperature gradient. In one hole the temperature gradient was lowered by movement of ground water, whereas the gradient was raised in the second well.

The temperature-confirmation program appears to substantiate the geographic distribution of the high- and low-thermal-gradient regimes in Oklahoma. Some variation in site-specific gradient conditions exists, however. Therefore, the map data should serve only as a guide for gradient information. Precise temperature measurements at specific depths are needed to assess a site for a potential geothermal application.

SP 86-2 is available over the counter or postpaid from the Oklahoma Geological Survey at the address given inside the front cover of this issue. The price is $3.

AAPG ANNUAL CONVENTION
Los Angeles, June 7–10, 1987

The Pacific Section of AAPG invites you to visit what used to be a dusty, hot, dry, sleepy little town called La Ciudad de Los Angeles—now known as big and thirsty LA. LA is the center of a giant metropolitan area that embraces mountains, seashore, and desert—and lots of oil fields. The center of the city lies over the old Los Angeles City oil field, discovered about 1890, which is reluctantly still producing a few barrels of crude each day. From the heart of the city, go in any direction and you will find an oil patch. Some are old and obvious; some are hidden behind walls and landscaped gardens. But oil is there in great abundance, and where you find oil you will find oil people. LA is world headquarters for majors such as Arco, Occidental Petroleum, and Unocal, as well as a host of small companies. Petroleum geologists, paleontologists, mineralogists, and geophysicists abound in the environs, and they all look forward to participating in the 1987 AAPG Annual Convention.

Southern California is a great place to host a convention for a group of petroleum scientists because its wonders are easily accessible. You can conveniently check out the folds and faults that trap oil, the turbidite and fractured shale reservoir rocks, the major features of continental collision, and almost any geologic feature but carbonates. And here, our friends from the Permian basin are helping out with a postconvention field trip to view carbonates in west Texas. Field trips, both before and after technical sessions, will allow you to see these geologic wonders, and the odds are quite favorable for a nice, warm, sunny day.

Just to make the trip to LA a little more meaningful, various short courses and workshops which will stretch the mind and enlarge our capacity to practice geology are being offered prior to the opening session. Topics range from the old-fashioned trace fossils to the more modern computer mapping.

Not to be overshadowed is the technical program. We will have three symposia: "Knowledge-Based Geologic Information Systems," "Controls on Carbonate Platform and Basin Development," and "Antarctica." Technical papers will focus on the past with case histories and on the future by examining potential exploration frontiers and emerging new technologies. Poster sessions and oral presentations will be part of the great show.

— E. F. "Bud" Reid
General Chairman

AAPG Annual Convention Agenda

Technical Sessions

Note: Some technical sessions are held concurrently.

June 8

Depositional Models in Petroleum Exploration
Petroleum Generation, Migration, and Accumulation
Recent Advances in Development Geology
Structural Concepts I
Sedimentary Petrology
Carbonate Facies—Mostly Modern
Antarctic Symposium

June 9

Controls on Carbonate Platform and Basin Development
Knowledge-Based Geologic Information Systems
Remote Sensing
Stratigraphic Techniques
Ocean Drilling Program (ODP)
Basin Modeling
Sandstone Diagenesis, Porosity Alteration, and Reservoir Quality
Geologic Factors, Economic Trends, and Their Impact on Exploration
Clastic Depositional Models
Advances in Subsurface Techniques
Geothermal, Uranium, Oil Shale, and Tar Sands
Basin Analysis Case Histories: North America
Applications of Organic Geochemistry in Exploration

June 10

Neogene Deposition and Tectonism of California
Oil Field Case Histories and Exploration Frontier I
Best of SEG for AAPG
Utilization of Biologic Data in Paleoenvironmental Studies
Basin Analysis Case Histories: Exclusive of North America
Carbonate Facies
Oil Field Case Histories and Exploration Frontier II
Computer Applications in Geology
Structural Concepts II
Petrofacies and Provenance
Sedimentation—Modern and Ancient
Carbonate Diagenesis

Short Courses

Shelf Sands and Sandstone Reservoirs, *June 6–7*
An Introduction to Reflective Seismic Interpretation, *June 6–7*
Computer Mapping for Geologists, *June 6–7*
Organic Geochemistry in Oil Exploration, *June 7*
Sedimentary Facies Analysis Using Trace Fossils, *June 7*
Depositional Systems in Active Margin Basins, *June 7*
Sequence Stratigraphic Interpretation of Seismic, Well, and Outcrop Data, *June 7*
Remote Sensing for Oil and Gas Exploration, *June 7*

The following are AAPG Student-Chapter short courses:

Applied Petrophysics, *June 6*
Computer Applications in Petroleum Geology, *June 7*
Workshop in Interview Skills, *June 7*

Field Trips

Cajon Pass-Wrightwood-Punchbowl-Palmdale—The San Andreas Fault, *June 6*
New Concepts in the Use of Biogenic Sedimentary Structures for Paleoenvironmental Interpretation of Southern California Mesozoic and Cenozoic Strata, *June 6*
Miocene Submarine Canyon/Fan Deposits and Recent Landslides of the Palos Verdes Hills, California, *June 7*
Petroleum Geology of Coastal Southern California, *June 7*
Sedimentary Facies, Tectonic Relations, and Hydrocarbon Significance in Ridge Basin, California, *June 7*
Oil Producing Areas in Long Beach, *June 11*
Remote Sensing for Geologic Exploration—A Visit to Jet Propulsion Laboratory, Pasadena, California, *June 11*
Geologic Transect Across the Western Transverse Ranges, California, *June 11–12*
Monterey Formation, Santa Maria Basin, California, *June 11–12*
Platform/Basin Evolution, Permian (Lower to Middle Guadalupian) Depositional Sequences, Guadalupe Mountains, West Texas–New Mexico, *June 11–14*

The following are AAPG Student-Chapter field trips:

Miocene Monterey Formation—Depositional and Diagenetic Facies Along the Santa Barbara, California, Coastal Area, *June 6*
Structural Features of the Southern San Andreas Fault System, *June 10–11*

For further information about the annual meeting, contact: AAPG Convention Dept., P.O. Box 979, Tulsa, OK 74101-0979; (918) 584-2555.

CONODONTS OF THE McLISH AND TULIP CREEK FORMATIONS SUBJECT OF NEW OGS BULLETIN

Jeffrey A. Bauer of the Ohio State University is author of the recently issued Oklahoma Geological Survey Bulletin 141, *Conodonts and Conodont Biostratigraphy of the McLish and Tulip Creek Formations (Middle Ordovician) of South-Central Oklahoma.*

The two units studied by Bauer are exposed in continuous, generally well-exposed sections in the Arbuckle Mountains; these rocks are part of a thick, intracratonic succession critical to understanding of North American Middle Ordovician biostratigraphy.

Bauer's study compares the conodont succession of the McLish and Tulip Creek Formations with presently used conodont faunal and zonal schemes and fits it into accepted chronostratigraphic frameworks.

Author's abstract:

Samples from the McLish and Tulip Creek Formations of south-central Oklahoma yielded 12,890 identifiable conodont elements referable to 25 genera. The conodont fauna is dominated by *Phragmodus flexuosus*, which is divided into two distinct, biostratigraphically useful morphotypes. Species of *Cahabagnathus* and *Eoplacognathus* allow correlation of the McLish and Tulip Creek with the *Pygodus serra* Zone of the North Atlantic Province. The conodont fauna, accordingly, is representative of the upper Whiterockian Series (Chazyan). Continuity of the fauna through the McLish–Tulip Creek boundary beds indicates no significant break in sedimentation.

Samples just above the basal sandstone of the McLish yielded conodonts different from those in the remainder of the formation and in the overlying Tulip Creek. *Neomultioistodus, Paraprioniodus*, and *Scandodus*? are representatives of this lower McLish association. Conodonts of this *Neomultioistodus* association are considered reworked.

Bulletin 141 is available over the counter or postpaid from the Oklahoma Geological Survey at the address given inside the front cover of this issue. The price is $6 for paperbound copies, $10 for clothbound.

UPCOMING MEETINGS

Geology of Industrial Minerals, 23rd Annual Forum, May 11–15, 1987, North Aurora, Illinois. Information: James W. Baxter, Illinois State Geological Survey, 615 E. Peabody Dr., Champaign, IL 61820; (217) 333-5107.

Geological Society of America, 100th Annual Meeting and Geoscience Exposition, October 26–29, 1987, Phoenix, Arizona. Abstracts due June 11; preregistration due September 25. Information: GSA, Meetings Department, P.O. Box 9140, Boulder, CO 80301; (303) 447-2020.

Vincent E. McKelvey
(1916–1987)

In Memoriam

VINCENT E. McKELVEY

Former Director of the U.S. Geological Survey

Dr. Vincent E. McKelvey, 70, a world-renowned research geologist with 46 years of service in the U.S. Geological Survey, who was USGS director from 1971 to 1978, died January 23, 1987.

In his early years with the USGS, beginning in 1941, McKelvey studied and mapped the phosphate fields of the northwestern United States and then moved east to the USGS headquarters in Washington, D.C., to lead the Survey's program of uranium exploration. In subsequent years, he dealt with problems of the nation's oil and gas supplies, represented the United States at the Law of the Sea meetings, and further developed his long-term interest in deep-sea mineral deposits. McKelvey was appointed the ninth director of the USGS in 1971.

McKelvey was the author of about 125 scientific articles dealing with the geology of manganese, phosphate, uranium, mineral and fuel resources, marine resources, methods of estimating reserves, prospecting methods, stratigraphy, sedimentation, and mineral economics. He most recently had completed several reports on marine minerals, including one published by the USGS in 1986 documenting worldwide mineral resources of the ocean floors.

As an internationally recognized scientist, McKelvey received numerous awards and honors for his contributions to the geological sciences. In 1985, the USGS honored him by establishing the annual V. E. McKelvey Forum on Mineral and Energy Resources, a symposium held each year in Denver. In

1978, the U.S. Board on Geographic Names officially designated a 6,680-foot-high peak in the Thiel Mountains of Antarctica as "Mount McKelvey," in honor of the former USGS director.

Among the many honors and awards received by McKelvey were the Department of the Interior's highest award, the Distinguished Service Award (1963); the Henry Krumb Lecturer for the American Institute of Mining Engineers on subsea mineral resources (1968); the Seventh McKinstry Memorial Lecture, Harvard University (1971); the National Civil Service League Award (1972); the Rockefeller Public Service Award (1973); a special meritorious-service award from the American Association of Petroleum Geologists (1977); and, from the same association, the Human Needs Award (1978).

"Vince had a special sense of what the U.S. Geological Survey is all about," said current USGS director Dallas L. Peck. "He held firm to the principle that its role is that of an impartial fact-finding agency that makes its results available to decision-makers. He believed that the agency's continued value to the nation was predicated on its scientific excellence and its integrity.

"Throughout his career, in his professional life, and in his personal style of leading and counseling employees of the USGS, Dr. McKelvey maintained very high standards of integrity and performance of duties," Dr. Peck added. "He was a remarkable man, whose achievements in geology made him a leader in his field and whose humanity and concern influenced the lives and careers of many people. To those in the USGS and the larger geologic community who knew him and had the benefit of his counsel and example, his contributions and his memory will long endure."

— USGS

We were saddened to receive the news of Vince's death. I had the pleasure of working with him during his tenure as director of the U.S. Geological Survey and subsequently when he served as a member of the National Academy of Sciences, Board on Energy and Mineral Resources. He was a valued professional colleague and a good friend. I'll miss him.

— Charles J. Mankin

Lee C. Gerhard

GERHARD TO HEAD KANSAS GEOLOGICAL SURVEY

Lee C. Gerhard, a petroleum geologist, is the new director of the Kansas Geological Survey. Gerhard, 49, succeeds William W. Hambleton, who retired December 31. Gerhard's appointment was effective January 1.

"We are fortunate in having attracted a scientist-administrator of such wide experience and excellence of reputation," said Frances D. Horowitz, KU vice chancellor for research, graduate studies, and public service.

Gerhard said he accepted the directorship because of the Kansas Survey's reputation for leadership in geology.

A native of Albion, New York, Gerhard received his bachelor's degree in geology from Syracuse University. His Master's and Ph.D. degrees in geology are from the University of Kansas, where he taught in the geology department. He joined the Colorado School of Mines faculty in 1982 and from 1983 to 1985 was Getty professor of geological engineering there. From 1977 to 1981 he was state geologist and director of the North Dakota Geological Survey. He also served as North Dakota director of oil-and-gas regulation.

A Fellow of the Geological Society of America, Gerhard has been an exploration geologist and researcher for Sinclair Oil and Gas Co., Amerada Petroleum Co., and other petroleum companies. Since 1982 he has done independent oil-and-gas consulting through his firm, Gerhard and Associates.

Besides teaching at Kansas and the Colorado School of Mines, he has taught at the University of Southern Colorado, Fairleigh Dickinson University, and the University of North Dakota. For three years, he was affiliated with Fairleigh Dickinson's West Indies Laboratory in St. Croix, U.S. Virgin Islands.

Gerhard has been active in a number of environmental-policy groups, including the National Advisory Committee on Atmosphere and Oceans, North Dakota air and water quality control boards, and the Caribbean Conservation Association.

REVIEW: NEW AAPG GEOLOGICAL HIGHWAY MAP OF THE MIDCONTINENT REGION

***Kathy Gentry*[1]**

The American Association of Petroleum Geologists has released a revised 1986 Geological Highway Map of the Midcontinent Region—Kansas, Missouri, Oklahoma, and Arkansas. The new comprehensive map, compiled by Allan P. Bennison, is Map 1 in a series of United States Highway Maps offered by the AAPG; it replaces the old 1966 map.

Several significant improvements have been made on this new map. The cities and towns are clearly marked, as are the major highways and waterways. Overall technical correctness of the geologic map, the greatly expanded stratigraphic column, and the cross sections—combined with the more-subtle colors and readable printing—make this publication a valuable tool for the highway traveler.

Also found on the new map are a physiographic map and a pre-Pleistocene bedrock and tectonics map, along with a brief explanation of each. Added features—the sections on minerals, fossils, and places of geologic interest—direct the traveler to collecting localities and points of interest.

The AAPG, the sponsors, and those who endeavored in the compilation of the new map are to be commended for their efforts. These dedicated people evaluated, reviewed, and brought together data vital to this publication.

Charles J. Mankin, director of the Oklahoma Geological Survey, serves on the United States Geological Highway Map Series advisory committee, and Robert O. Fay of the Survey assisted in the compilation of the new Midcontinent Region map.

The new map is available for sale at the offices of the Oklahoma Geological Survey at a price of $4.50 per copy.

[1]Consulting Geologist, Midwest City, Oklahoma.

NOTES ON NEW PUBLICATIONS

Analyses of Natural Gases, 1985

Analyses and related source data for 517 natural-gas samples from 25 states and one foreign country are included in this publication by B. J. Moore and Stella Sigler. Of the total samples, 298 were collected during calendar year 1985; the remainder were collected earlier, but releases granting permission to publish were not received before 1985. All samples were obtained and analyzed as part of Bureau of Mines investigations of the occurrences of helium in natural gases of countries with free-market economies. This survey has been conducted since 1917. The analyses published in this 182-page information circular were made by mass spectrometer and chromatograph.

Order IC 9096 from: U.S. Bureau of Mines, Publication Distribution, Cochrans Mill Road, P.O. Box 18070, Pittsburgh, PA 15236. The book is available free of charge. Please enclose a self-addressed label.

A Method for Locating Abandoned Mines

The problems presented by old mine workings affect both present-day mining and land development. An automated method of locating these old mines from the surface using electrical-resistivity techniques was developed earlier under a Bureau of Mines contract. Subsequent Bureau research has refined the techniques and expanded the area of study to a variety of geologic provinces. During this research, six mining areas in the United States were investigated with the Bureau's automated resistivity method. Authors R. G. Burdick, L. E. Snyder, and W. F. Kimbrough describe the mining areas involved and the results of the resistivity investigations, which showed a high rate of success in detecting old mines. The 27-page report also describes the field measurement techniques and data-analysis procedures.

Order RI 9050 from: U.S. Bureau of Mines, Publication Distribution, Cochrans Mill Road, P.O. Box 18070, Pittsburgh, PA 15236. Single copies of this report of investigations are free. Please enclose a self-addressed label.

Land Use and Land Cover and Associated Maps for Antlers, Oklahoma/ De Queen, Arkansas; Oklahoma/Mena, Arkansas; Oklahoma

These data sets consist of one map each keyed to USGS topographic maps Antlers, De Queen, and Mena at a scale of 1:100,000 (1 in. = about 1.6 mi). These maps are coded for statistical data development. The maps show (1) land use and land cover, (2) political unit, (3) hydrological units, and (4) census county subdivision. Also included are one positive each of the cultural base for Antlers, De Queen, and Mena.

Order OF 85-0322 (Antlers), OF 85-0323 (De Queen), or OF 85-0324 (Mena) from: U.S. Geological Survey, Mid-Continent Mapping Center, 1400 Independence Road, Rolla, MO 65401.

OKLAHOMA ABSTRACTS

The Oklahoma Geological Survey thanks the American Association of Petroleum Geologists, the Geological Society of America, and the authors for permission to reprint the following abstracts of interest to Oklahoma geologists.

Evolution of Permian Evaporite Basin in Texas Panhandle

MARK W. PRESLEY, Bureau of Economic Geology, Austin, TX (present address: Valero Producing Co., 5949 Sherry Lane, Suite 1500, Dallas, TX 75225)

Permian (Leonardian to Ochoan) evaporites in the Texas Panhandle were deposited in a range of marine shelf to supratidal environments along an arid coastline. Carbonates in these strata generally were deposited in inner shelf systems and include subtidal to supratidal facies. Landward of shelf environments, evaporites were deposited in brine pans and salt flats. Brine-pan facies are laminated anhydrite and banded salt that formed in shallow, hypersaline waters such as restricted lagoons or supratidal salines. Salt-flat facies are mainly chaotic mixtures of mudstone and halite possibly formed by salt deposition on and within mud flats that bordered brine pans, or in brine-soaked mud-flat depressions. Periodically, mud flats built across the evaporite systems and were supplied with red terrestrial clastics, mainly mud and silt.

These facies occur together in at least three different types of lithogenetic units. Strata in the Clear Fork Group (Leonardian) are considered deposits of a coastal evaporite basin that was progressively filled by terrestrial clastics. These rocks exhibit regressive cycles of brine-pan, salt-flat, and mud-flat facies. In contrast, San Andres strata (Guadalupian) were deposited in a broad marine embayment with persistent brine-pan conditions, and contain cycles of inner shelf and brine-pan facies. Post-San Andres strata (late Guadalupian and Ochoan) were deposited in the inner reaches of a broad interior salt basin and are composed mainly of mud-flat, salt-flat, and halite-rich brine-pan facies.

Reprinted as published in the *Bulletin* of the American Association of Petroleum Geologists, v. 71, no. 2, p. 167.

Late Miocene Reactivation of Ancestral Rocky Mountain Structures in the Texas Panhandle: A Response to Basin and Range Extension

ROY T. BUDNIK, Bureau of Economic Geology, Austin, TX (present address: RR1, Box 440, Amenia, NY 12501)

Structural and stratigraphic evidence from the Ogallala Formation (Neogene) documents late Miocene tectonic activity within the Great Plains. Field and subsurface studies in the Texas Panhandle indicate that parts of the Amarillo uplift, a major element of the Pennsylvanian Ancestral Rocky Mountains, were elevated as much as 150 m during initial deposition of the Ogallala Formation. Reactivation of these basement structures occurred in response to Basin and Range extension and opening of the Rio Grande rift in central New Mexico and Colorado.

Reprinted as published in *Geology*, v. 15, p. 163.

Predation on Cephalopods from the Finis Shale (Pennsylvanian–Virgilian) of Texas

WILLIAM B. BOSTON, MICHAEL SIMS, and ROYAL H. MAPES, Dept. of Geological Sciences, Ohio University, Athens, OH 45701

Cephalopod specimens from the Finis Shale Member of the Graham Formation in North-Central Texas contain examples of two possible types of predation that occurs on several genera of ammonoids and coiled nautiloids. The first represents excavation of the ventral portion of the conch. This type of damage somewhat resembles the "peeling" attack utilized by arthropods preying on gastropods. Such damage occurs on 52 specimens. The possibility that this conch damage may result from post-mortem scavenging cannot be eliminated.

The second case is nearly identical to bite marks on coiled nautiloid specimens that have been attributed to the shark *Symmorium reniforme.* Evidence of this type of attack within the Finis collection includes preserved bite marks in the form of punctures from the teeth of such sharks. Although 39 of the 1284 coiled nautiloid and ammonoid specimens exhibit well-preserved bite marks, more than 50% of the juvenile and mature specimens exhibit some form of massive conch disruption including loss of the body chamber and phragmocone crushing. Massive pre-burial conch disruption as determined by the presence of encrusting organisms on exposed inner septa and early conch whorls is present on 20 specimens. Such disruption would almost certainly be fatal; resultant buoyancy loss would allow for autochthonous accumulations of cephalopod phragmocone and shell debris. Additionally, there is evidence for a minimum sized prey selection by these predators.

Reprinted as published in the Geological Society of America Northeastern Section *Abstracts with Programs, 1987,* v. 19, no. 1, p. 6.

Evidence of Predation in Midcontinent Upper Paleozoic Anoxic and Dysaerobic Marine Environments

R. H. MAPES, Ohio University, Athens, OH, 45701; M. C. HANSEN, Ohio Geological Survey, Columbus, OH 43224; and D. R. BOARDMAN, III, Texas Tech University, Lubbock, TX 79409

Many upper Paleozoic Midcontinent units containing phosphate concretions have been interpreted as anoxic and/or dysaerobic core shales that formed in moderately deep ($\pm$200 m) upwelling, marine environments. These phosphate concretions commonly formed around coprolites from organisms living in the upper oxygenated water column. Such coprolites contain remains of fish, arthropods and cephalopods.

Analysis of the cephalopods indicates orthoconic nautiloids and ammonoids are most abundant; coiled nautiloids and coleoids are rare. Cephalopod mandibles are also present. Upper and lower mandibles are often present in a single concretion; as many as four lower mandibles sometimes occur as a stack. More than 50 observed multiple (3 or more) mandible occurrences involve nearly identical-sized mandibles. Such data suggest the predator was size selective in choosing its prey. Broken cephalopod conch material is rarely preserved with the mandible occurrences, suggesting some predators had specialized attack methods, that separated shell pieces from the edible body. When ammonoid conchs are recovered in phosphate concretions, the body chamber is almost always missing. This evidence also suggests specialized modes of predation. Predator damage to the conch undoubtedly resulted in some cephalopods becoming negatively buoyant, allowing the phragmocone to sink directly where the cephalopod lived and died, rather than floating away.

Reprinted as published in the Geological Society of America Northeastern Section *Abstracts with Programs, 1987,* v. 19, no. 1, p. 28.

Multiple Coalification Paths? Evidence from Thermogravimetry and H/C and O/C Ratios

OTTO C. KOPP, Dept. of Geological Sciences, University of Tennessee, Knoxville, TN 37996-1410; and LAWRENCE A. HARRIS, Metals and Ceramics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37830

In previous study of samples from the Exxon coal library, we observed a break in the curve relating the temperature at which volatiles are first released during heating (called the inital volatilization temperature, IVT) and coal parameters such as percent volatile matter (or fixed carbon).

When IVT's are plotted against H/C ratios for each coal, the points plotted for most sub-bituminous coals fall distinctly below the points for high-volatile, medium-volatile, and low-volatile bituminous coals. If their O/C ratios are considered, some sub-bituminous coals have O/C ratios quite different from high-volatile and medium-volatile bituminous coals. It appears that unless substantial amounts of oxygen were removed by some process(es) sub-bituminous coals such as these might never reach the high-volatile or medium-volatile ranks. This information raises a question whether some high-ranked coals might have by-passed some of the intermediate ranks if they had high O/C ratios relative to their H/C ratios during coalification.

The high O/C ratios remaining in some of the samples may have been determined by: the chemical nature of the original plant material; by conditions prevalent during peatification and early diagenesis; and/or by unusual conditions during coalification at greater depth. From the limited available data, it appears that if a coal's O/C ratio remained greater than ca. 0.15 while its H/C ratio decreased to a value below 0.8, then it might have remained in the sub-bituminous rank.

Reprinted as published in the Geological Society of America Northeastern Section *Abstracts with Programs, 1987,* v. 19, no. 1, p. 24.