OREGON GEOLOGY

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ALSO:

From the State Geologist

—Vicki S. McConnell

Like the ancient critters shown in these pages, *Oregon Geology* falls to the inexorable march of time. This will be our final issue in this print-based format. Stay tuned for articles on Oregon's fascinating and varied geology in blog and other media outlets. Meanwhile, in this issue enjoy some recent findings from Oregon's fossil hunters.

I want to take this opportunity to offer recognition and thanks to everyone who has contributed to *Oregon Geology* throughout its lifespan starting in 1979. The issues contain a treasure trove of factual and historical information about Oregon's lands, landforms, and geoscientists. Both *Oregon Geology* and the earlier published *Ore Bin* are frequently the starting point for me when gathering information for everything from Legislative testimony to classroom presentations. I know I am not the only one, as we still sell hardcopy publications in the Nature of the Northwest Information Center and the online resource gets a fair number of hits. That tells me that although we cannot continue with *Oregon Geology* in its current format we should continue to offer a venue to distribute geologic and geoscientific information outside of our more formal publications. Suggestions are welcome—just go to our website to submit or give me a call.

DOGAMI continues to evolve and change as well. We are constantly responding to environmental changes such as new statewide policies, calls for smaller government, and different demands for our mission and information. Since the last publication of *Oregon Geology* five years ago we have closed the Grants Pass Field Office, moved the Nature of the Northwest Information Center, and turned our lidar data collection program into a nationally recognized success story. As I gaze into the cloudy crystal ball of our future I see much more collaboration with new state programs such as the Regional Solutions Program (http://www.oregon.gov/Gov/ERT/pages/index.aspx) and perhaps some new opportunities to collaborate with our federal partners. We hope we can evolve quickly enough and wisely enough to not become extinct ourselves! I know how important our work and information is and I firmly believe that all Oregonians do as well.

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Main DOGAMI Office: 800 NE Oregon Street, Suite 965, Portland, OR 97232, phone (971) 673-1555, fax (971) 673-1562
Internet: http://www.oregongeology.org

Baker City Field Office:
Baker County Courthouse, 1995 3rd Street, Baker City, Oregon 97814
phone (541) 523-3133
Jason D. McClaughry, Eastern Oregon Regional Geologist

Coastal Field Office:
313 SW Second Street, Suite D, Newport, Oregon 97365
phone (541) 574-6642, fax (541) 265-5241
Jonathan C. Allan, Coastal Geomorphologist

Mineral Land Regulation and Reclamation Program
229 Broadalbin Street SW, Albany, Oregon 97321-2246
phone (541) 967-2039, fax (541) 967-2075
Gary W. Lynch, Assistant Director

The Nature of the Northwest Information Center
800 NE Oregon Street, Suite 965, Portland, OR 97232
phone (971) 673-2331, fax (971) 673-1562
Internet: http://www.naturenw.org
Donald J. Haines, Manager

Cover: Ground squirrel (*Spermophilus columbianus*) palate (dorsal view), Airport Lane site, La Grande, Oregon. **See p. 3 for story.**

Late Pleistocene Airport Lane fossil site, La Grande, northeast Oregon

by Jay Van Tassell[1], John Rinehart[1], and Laura Mahrt[1]

[1]Science Department, Badgley Hall, Eastern Oregon University, One University Boulevard, La Grande, OR 97850, email: jvantass@eou.edu

*Abstract: Fossils found in January 2010 at a depth of 5 m below the surface of the eroded distal margin of the late Pleistocene La Grande Airport terrace include: 1) a right tibia and two tusks from a juvenile male Columbian mammoth (*Mammuthus columbi*), 2) seven articulated vertebrae (T-13 to L-5), an articulated left radius/ulna and carpals, and the proximal part of a left calcaneus from a large male bison similar to the* Bison antiquus antiquus *fossils from Ayer Pond on Orcas Island in Washington and from Woodburn High School in Oregon, 3) the proximal end of the left femur of a male or very large female giant short-faced bear (*Arctodus simus simus*) similar to those of the Potter Creek Cave fauna in California, 4) the partial skeleton and jaws of Columbian ground squirrels (*Spermophilus columbianus*), which indicate colder and wetter conditions at the site than at present, 5) diatoms (*Aulacoseira*;* Navicula*;* Nitzchia*; and* Rossithidium*); sponge spicules (*Ephydatia fluviatilis*); and grass (*Poaceae*), juniper (*Juniperus*), and pondweed (*Potamatogen*) pollen that suggest deposition in shallow streams and adjacent floodplains, and 6) western hemlock (*Tsuga heterophylla*) pollen, which suggests that western hemlock was abundant in the nearby hills during the late Pleistocene. Fragments of the bison vertebrae yielded an AMS radiocarbon date of 12,950 ± 50 ^{14}C years (15,260 calendar years) BP. The bison, mammoth, and bear found at the Airport Lane fossil site may have been drowned in a spring flood or a jökulhaup released when an ice dam burst. Another hypothesis is that they were killed and butchered by late Pleistocene hunters, but no artifacts or other signs of human activity were found at the site.*

INTRODUCTION

An earth scraper operator removing 5 m of sediment from the top of a hill in a potato farmer's field near the La Grande Airport in the Grande Ronde Valley of northeastern Oregon in January 2010 spotted a patch of white in the gray silty fine-grained sand behind him (Figure 1). When he got off the earth scraper to investigate, he discovered a broken mammoth tibia. Over the next two weeks two mammoth tusks and numerous fragments of bones were found (Figure 2). An archaeologist from the United States Natural Resources Conservation Service was called in on January 23, 2010, to investigate the site. She found no signs of prehistoric human activity. The partial skeleton of a ground squirrel was discovered near the mammoth tusks while the tusks were being removed for transport. Only the tip of one tusk and half of the other survived the trip. After removing the sediment from the fossils and piecing the fragments of the bones found at the site back together, it became clear that the finds also included giant bison and short-faced bear fossils (Figure 3, Table 1). Van Tassell and others (2011) provided detailed measurements of the fossils from the Airport Lane site and how they compare with fossils from other Pleistocene locales.

GEOLOGY OF THE AIRPORT LANE FOSSIL SITE

The Airport Lane fossil site is located on the late Pleistocene Airport terrace mapped by Ferns and others (2002). This terrace is an erosional remnant of a large Pleistocene outwash fan that includes the terraces that flank the city of La Grande on its south, west, and north sides (Figure 3). Prior to the discovery of the Airport Lane fossils, Pleistocene fossils found in the La Grande terrace deposits included 1) an 11,030 ± 800 ^{14}C year-old ground sloth (*Mylodon harlani*) skull and other bones found along Foothill Road south of La Grande (Quaintance, 1966, 1969); 2) molars and other bones from a 15,280 ± 180 ^{14}C year-old Columbian mammoth (*Mammuthus columbi*) discovered on the site of Eastern Oregon University (Van Tassell and others, 2001); and 3) the humerus of a Columbian mammoth (*M. columbi*) found at the Old Hospital site on the northwest side of La Grande. The Airport Lane fossil site is the first locality in the Grande Ronde Valley to yield more than one type of late Pleistocene mammal.

MAMMOTH (*MAMMUTHUS COLUMBI*)

The mammoth fossils found at the Airport Lane site include a right tibia and two tusks (Figures 2 and 3). The dimensions of the tibia (Table 2), measured according to the specifications of von den Driesch (1976), are smaller than those of adult *Mammuthus primigenius* and *Mammuthus columbi*, except for the smallest breadth of the diaphysis, which falls between values reported for juvenile and adult *M. primigenius* reported by

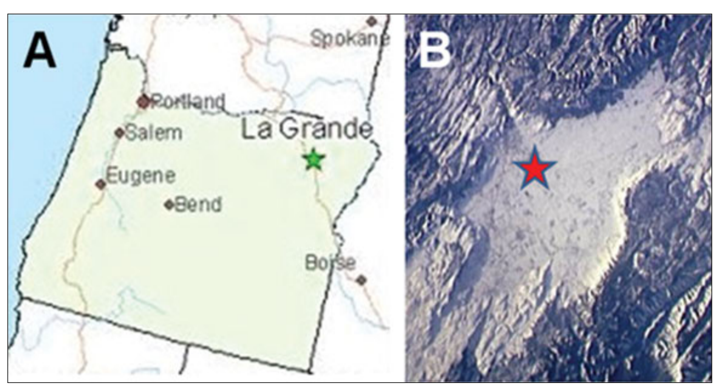

Figure 1. The Airport Lane fossil site: (A) Location of La Grande, Oregon, and (B) location of the Airport Lane fossil site in the Grande Ronde Valley shown on an image captured by an astronaut on the Space shuttle.

Figure 2. Mammoth (*Mammuthus columbi*) tusks from the Airport Lane site: (A) Mammoth tusk being excavated, (B) mammoth tusks coated in plaster, and (C) portions of the tusks that survived transport. The tusk tip in photo C (top) is from the left tusk, and the other piece is the anterior half of the right tusk. Note the silty fine sand inside the right tusk (bottom). Photo A is by April Van Tassell.

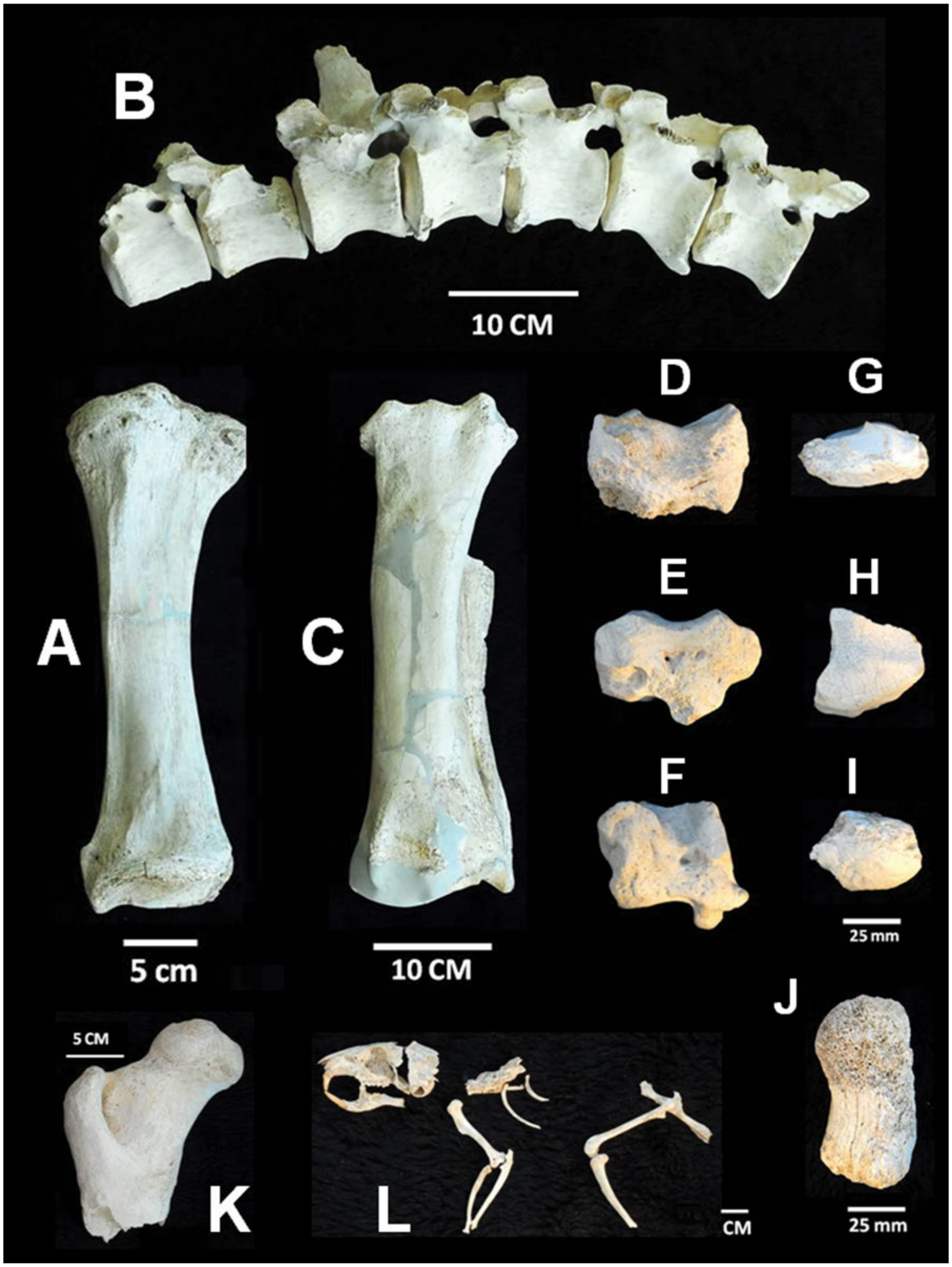

Figure 3. Airport Lane mammoth (*Mammuthus columbi*), giant bison (*Bison* cf. *B. antiquus antiquus*), short-faced bear *(Arctodus simus simus),* and ground squirrel *(Spermophilus columbianus)* fossils: (A) Mammoth right tibia, posterior view, (B) bison thoracic and lumbar vertebrae (T-13 to L-5), left lateral view, (C) bison left radius/ulna, anterior (cranial) view, (D) bison radial carpal, lateral view, (E) bison intermediate carpal, lateral view, (F) bison ulnar carpal, lateral view, (G) bison second/third carpal, lateral view, (H) bison fourth carpal, proximal view, (I) bison accessory carpal, lateral view, (J) part of bison left calcaneal tuber (the proximal part of the calcaneus), lateral view, (K) proximal end of bear left femur, proximal view, and (L) partial squirrel skeleton, left lateral view.

Table 1. Fossils from the Airport Lane Locality

Kingdom	PROTOCTISTA
Phylum	BACILLARIOPHYTA (**diatoms**)
Class	Bacillariophyceae
Order	Achnanthales
Family	Achnanthaceae
Genus	*Rossithidium* Bukhtiyarova & Round 1996
Order	Bacillariales
Family	Bacillariaceae
Genus	*Nitzchia* Hassell 1845
Order	Naviculales
Family	Naviculaceae
Genus	*Navicula* Bory de Saint-Vincent 1822
Class	Coscinodiscophyceae
Order	Aulacoseirales
Family	Aulacoseiraceae
Genus	*Aulacoseira* Thwaites 1848
Kingdom	PLANTAE (**plants**)
Division	Coniferophyta (**conifers**)
Class	Pinopsida
Order	Pinales
Family	Cupressaceae (**cypress family**)
Genus	*Juniperus* (**juniper**)
Family	Pinaceae (**pine family**)
Genus	*Tsuga*
Species	Tsuga *heterophylla* (**western hemlock**)
Division	Magnoliophyta (**flowering plants**)
Class	Liliopsida (**monocotyledens**)
Subclass	Alismatidae
Order	Najadales
Family	Potamogenaceae
Genus	*Potamogeton* (**pondweed**)
Subclass	Commelinidae
Order	Cyperales
Family	Poaceae (**true grasses**)
Kingdom	ANIMALIA
Phylum	Porifera (**sponges**)
Class	Demospongiae
Order	Haplosclerida
Suborder	Spongillina
Family	Spongillidae
Genus	*Ephydatia*
Species	*Ephydatia fluviatilis* (Linnaeus, 1759)
Phylum	Chordata
Subphylum	Vertebrata
Class	Mammalia
Order	Proboscidea
Family	Elephantidae
Genus	*Mammuthus* Brookes, 1828 (**mammoths**)
Species	*Mammuthus columbi* (Falconer, 1857)
Order	Perissodactyla
Family	Bovidae
Genus	Bison Smith, 1827 (bison)
Species	*Bison* cf. *B. antiquus antiquus* Leidy, 1852
Order	Carnivora
Family	Ursidae (**bears**)
Genus	*Arctodus* Leidy 1854
Species	*Arctodus simus* (Cope, 1879)
Order	Rodentia
Suborder	Sciuromorpha
Family	Sciuridae (**squirrel family**)
Subfamily	Sciurinae
Tribe	Marmotini
Subtribe	Spermophilina
Genus	*Spermophilus* F. Cuvier, 1825
Species	*Spermophilus columbianus* (Ord, 1915)

Table 2. Airport Lane Mammal Fossil Dimensions

Mammuthus columbianus			
Tibia:	Greatest length		577 mm
	Greatest breadth of proximal epiphysis		216
	Depth of proximal epiphysis		156
	Smallest breadth of diaphysis		75
	Greatest breadth of distal epiphysis		149
	Depth of distal epiphysis		130
Tusks:	Straight-line (chord) length (base to tip)		
		Right tusk	126 cm
		Left tusk	108
	Maximum length measured along chord (base to tip)		
		Right tusk	143 cm
		Left tusk	123
	Index of curvature [(maximum length-chord length)/chord length]		
		Right tusk	0.135
		Left tusk	0.185
	Diameter of tusk at base		
		Right tusk	10.36 cm
		Left tusk	~10.25
Bison* cf. *B. antiquus antiquus			
Radius:	Greatest length (RD2)		386 mm
	Greatest breadth of proximal end (RD3)		129
	Greatest breadth of proximal articular surface (RD4)		114
	Greatest depth of proximal end (RD9)		66
	Least transverse width of shaft		73
	Least anteroposterior width of shaft		48
Vertebrae:			
	Length of centrum (PL):		
		L-1	78 mm
		L-2	77
		L-3	76
		L-4	81
		L-5	90
	Breadth of cranial articular surface (BFcr):		
		L-1	63 mm
		L-2	—
		L-3	62
		L-4	60
		L-5	60
	Height of cranial articular surface (HFcr):		
		L-1	61 mm
		L-2	58
		L-3	63
		L-4	61
		L-5	60
	Breadth of caudal surface (BFcd):		
		L-1	87 mm
		L-2	85
		L-3	66
		L-4	71
		L-5	—
	Height of caudal articular surface (HFcd):		
		L-1	58 mm
		L-2	52
		L-3	60
		L-4	64
		L-5	58
Arctodus simus simus			
Femur:	Greatest breadth of proximal end (BP)		128.9 mm
	Maximum caput diameter		66.5
	Smallest breadth of diaphysis (SD)		<56.8
Spermophilus columbianus			
Skull:	Palatilar length		24.2 mm
	Zygomatic breadth		~28.4
	Nasal length:		
		Left	11.5
		Right	10.5

Lister (2009). These results suggest that the Airport Lane tibia came from a juvenile mammoth. This was confirmed by an x-ray radiograph of the tibia that shows that the epiphyseal plate is present (Figure 4).

According to Lister (2009), epiphyseal fusion of the proximal end of male *M. primigenius* tibiae takes place at a dental age of ~28 years. The timing of fusion to dental stage is the same in *Mammuthus primigenius* and *Mammuthus columbi* according to Haynes (1991), but Lister (2009) advanced the hypothesis that dental ages of Columbian mammoths may underestimate true ages at an unknown rate. The presence of the epiphyseal plate in the Airport Lane mammoth tibia suggests an age less than 28 years or somewhat greater if Columbian mammoths had a slower rate of epiphyseal fusion than *M. primigenius.* The two mammoth tusks uncovered at the Airport Lane site were in a position that suggests that they may came from the same mammoth (Figure 2). The tip of the right tusk was missing and the end of the left tusk was badly shattered. Both tusks were hollow and filled with sediment. The right Airport Lane mammoth tusk is larger than the left (Table 2). This may indicate that the tusks came from an animal with two different-sized tusks or it may be an indication that the tusks came from two different mammoths. The index of curvature of the Airport Lane tusks is smaller than *M. primigenius* values and falls within the range of the index of curvature of *M. columbi* tusks. This suggests that the Airport Lane mammoths belong to the species *M. columbi* like the other mammoths previously found in the late Pleistocene La Grande alluvial fan terrace deposits.

Figure 4. X-ray radiograph of the proximal end of the mammoth tibia. Note the prominent epiphyseal plate (arrow).

The diameter of the base of the Airport Lane mammoth tusks falls in the lower range of *M. columbi* from Hot Springs, South Dakota, and the relationship between the chord length and the maximum length measured along the curve of each tusk falls close to the trend of these parameters for the Hot Springs *M. columbi* (Table 2). The Hot Springs assemblage is primarily young adult males (Lister and Agenbroad, 1994). It is likely that the Airport Lane mammoth was also male.

GIANT BISON (*BISON* CF. *B. ANTIQUUS ANTIQUUS*)

The bison fossils at the Airport Lane fossil site include a whole left ulnar carpal and fragments of the left radial carpal, left intermediate carpal, second/third carpal, and the accessory carpal (Figure 3). The proximal (dorsal) surfaces of the first, second, and third carpals match the distal end of the left radius. This suggests that the radius and carpals were articulated before being struck by the earth scraper and are from the same animal.

The left radius/ulna was measured following the specifications of Miller (1971). All of the measurements (Table 2) fall in the range of *Bison latifrons* and are larger than those of *Bison antiquus antiquus* and *Bison antiquus occidentalis* found in areas outside of the Pacific Northwest. The greatest length, least anteroposterior diameter of the diaphysis, and the least transverse width of the diaphysis are similar to those of *B. latifrons* males.

The bison vertebrae found at the Airport Lane fossil site (Figure 3) include two thoracic vertebrae (T-13 and T-14) and all the lumbar vertebrae (L-1 to L-5). The right sides of the vertebrae were sheared off by the earth scraper. This indicates that the bison skeleton was lying on its left side. Measurements of the L-5 vertebra (Table 2) made according to the specifications of Miller (1971) and von den Driesch (1976) fall within or are larger than the range of measurements for bison L-5 radii from the Costeau Pit of California, which Miller (1971) tentatively identified as *B. latifrons*. The dimensions of the fifth lumbar vertebra from the Airport Lane fossil site are greater than those of the fifth lumbar vertebra of male *B. antiquus* from Rancho La Brea, California, reported by Miller (1971).

Fragments of the *Bison* vertebrae from the Airport Lane fossil site were sent to Beta Analytic Inc., Miami, Florida, for AMS (accelerator mass spectrometry) radiocarbon dating. The results (Beta–302403) are:

Conventional radiocarbon age: **12,950 ± 50 ^{14}C years BP (before 1950)**

Calibrated age: **15,260 BP = 13,310 BC**

Part of the calcaneal tuber from the proximal end of the left calcaneus of a bison was also found at the Airport Lane fossil site (Figure 3). This is the only part of the rear leg that was recovered at the site.

The bison radius and L-5 vertebra found at the Airport Lane fossil site are similar in size to those of *B. latifrons* radii but to date only *B. antiquus* fossils have been reported in Oregon. These include the head of a *B. antiquus* recovered near Medford in 1938 (Orr and Orr, 2009) and the skeletal remains of another *B. antiquus* found in ~12,200-year-old Missoula Flood deposits on the campus of Woodburn High School in 2009 (Ellingson, 2009). Only a few *B. antiquus* fossils have been found in eastern Washington and Oregon. They include a *B. antiquus* from Walla Walla, Washington (McDonald, 1981) and the skull and horns of a *B. antiquus occidentalis* found on Lick Creek in Wallowa County in 1924 (Orr and Orr, 2009).

The sites nearest to the Airport Lane site where *B. latifrons* fossils have been found are the American Falls Reservoir and other sites in southeast Idaho and the MacArthur site in Shasta County in northern California (McDonald, 1981). The age of the Airport Lane bison is very young compared to the ages of *B. latifrons* specimens from Costeau Pit, California (42 ka), the American Falls Reservoir site, Idaho (>32-21 ka), and Rancho La Brea (in the earlier part of 30–13 ka) cited by McDonald (1981). *B. latifrons* is thought to have gone extinct at the height of the late Wisconsin glaciations with little or no influence of human hunting (McDonald, 1981). The AMS radiocarbon date for the Airport Lane fossil site bison places it very close to or after the time *Bison latifrons* is thought to have disappeared.

Is the Airport Lane bison the first *B. latifrons* to be discovered in Oregon or is it a large *B. antiquus*? The application of the system of measurements of bison bones used by Todd (1987, 1992) at bison kill sites such as the Horner II, Wyoming, and Lipscomb, Texas, sites indicates a possible answer. Comparison of the ratio of the greatest length (RD 2) of the Airport Lane bison radius vs. the greatest breadth of the proximal end (RD 3) and the ratio of the greatest breadth of the proximal articular surface (RD 4) of the Airport Lane bison radius vs. the greatest depth of the proximal end (RD 9) with values from other bison fossil sites (Table 2, Figure 5) suggests that the bison from the Airport Lane fossil site was part of a population of large and long-legged group of early *B. antiquus* in the Pacific Northwest that includes the bison found at the Ayer Pond site on Orcas Island, Washington (Kenady and others, 2011) and at the Woodburn site in Oregon (Ellingson, 2009). The large size of the Airport Lane bison could also be a result of it being part of a small population

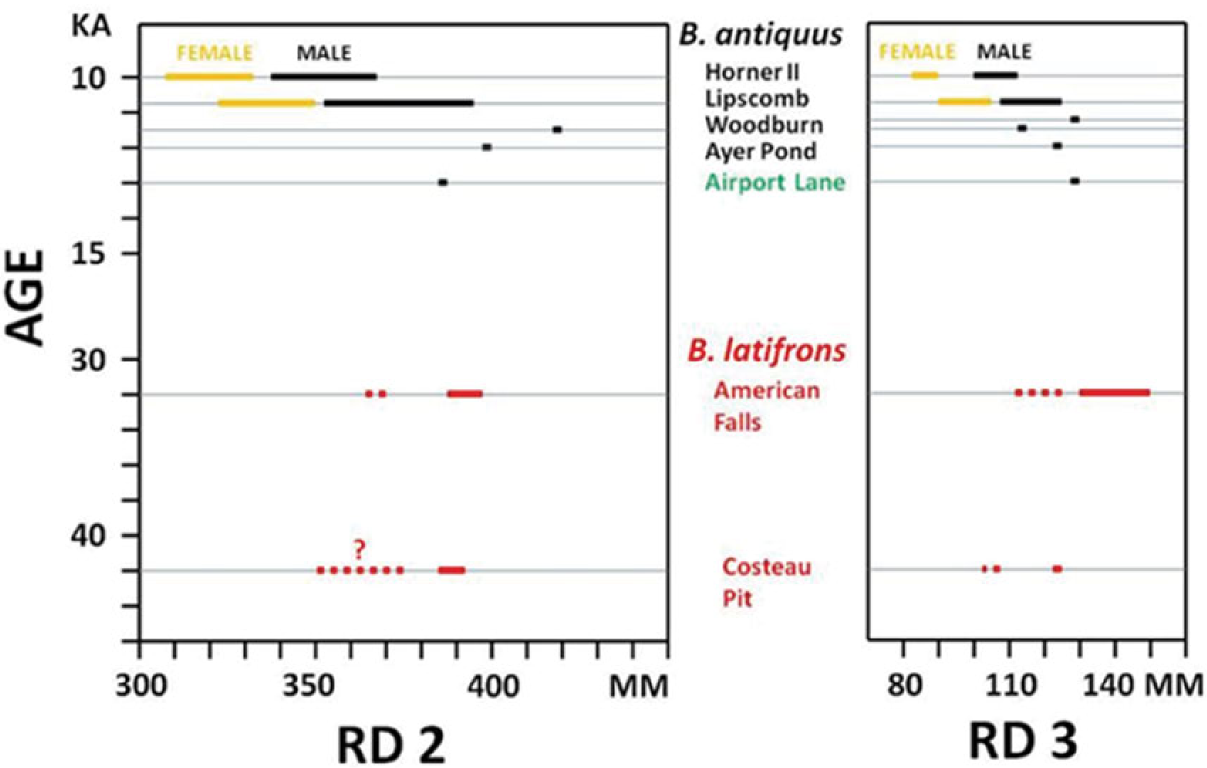

Figure 5. Variations in the sizes of the greatest length of the proximal end (RD 2) and the greatest breadth of the proximal end (RD 3) for fossil bison radii from selected sites. The graphs suggest that the Airport Lane bison may be part of a group of long-legged early *B. antiquus antiquus* including the bison at Ayer Pond, Washington, and Woodburn, Oregon. Measurements of the Horner II bison are from Todd (1987), the Lipscomb measurements from Todd (1992), the Woodburn measurements from D. B. Ellingson (written communication, 2012), the Ayer Pond measurements from M. C. Wilson (written communication, 2012), the American Falls are from Stevens (1978), and the Costeau Pit measurements are from Miller (1971).

of *B. antiquus* isolated in the Grande Ronde Valley during the late Wisconsin glaciations that adapted to the vegetation and environmental conditions in the Grande Ronde Valley at this time by becoming larger. Finding a bison skull with horn cores at the Airport Lane fossil site would help confirm to which species the Airport Lane fossil site bison belongs. Until horn cores are found, the Airport Lane fossil site bison is classified as *Bison* cf. *B. antiquus antiquus*.

SHORT-FACED BEAR (*ARCTODUS SIMUS SIMUS*)

A single bear fossil, the proximal end of the left femur of a short-faced bear, has been found at the Airport Lane fossil site (Figure 3). Only two other sites in Oregon, the Rancholabrean Fossil Lake locale (Orr and Orr, 2009) and the late Pleistocene Drews Gap locale in Lake County (Packard and Allison, 1980) have yielded short-faced bear fossils.

The Airport Lane femur is slender like most bear femurs and has an overall shape that is very similar to the short-faced bear femur illustrated by Richards and Turnbull (1995; their Figure 14 A,B,C). The presence of the capitular epiphysis and the fused trochanter epiphysis suggest that the Airport Lane short-faced bear was a mature individual.

Measurements made using the guidelines of von den Driesch (1976) show that the length of the proximal end and the maximum caput diameter of the Airport Lane bear femur both fall in the range of the femurs of *Arctodus simus simus* found at the Rancholabrean Potter Creek Cave site in Shasta County, California, and are much smaller than those of the larger giant short-faced bear *Arctodus simus yukonensis* (Table 2). The Airport Lane femur has dimensions that fall in the upper part of the range of the short-faced bear femurs from the Potter Creek Cave fauna, which is approximately the same age as the bison from the Airport Lane site. This may indicate that the Airport Lane short-faced bear is a male, but since the Potter Creek Cave short-faced bears are predominantly females (Kurtén, 1967), it is possible that the Airport Lane short-faced bear femur is from a large female.

COLUMBIAN GROUND SQUIRREL (*SPERMOPHILUS COLUMBIANUS*)

One of the workers at the Airport Lane site dug up a clot of soil near the mammoth tusks that contained the skull and partial skeleton of a ground squirrel, plus the femur of a second ground squirrel (Figure 3). A mandible of a third ground squirrel was found on the bulldozed surface approximately 7 m to the southeast. These ground squirrel fossils came from a horizon 5 m below the late Pleistocene terrace surface, well below the depth (~1.5 m) that these rodents normally burrow. This suggests that they may be the same age or slightly younger than the other late Pleistocene fossils at the Airport Lane site but are not modern ground squirrels.

The ground squirrel fossils include a cranium, two mandibles, a left humerus, a right humerus, four articulated vertebrae, a left pelvis, three ribs, a right radius, a right ulna, a right femur, two left femurs, and a right and a left tibia. The skull was complete when it was removed from the soil matrix, but the posterior portion of the skull fell apart shortly afterward (Figure 6). Because of this, measurement of the greatest length of the skull was impossible. Other measurements of the skull (Table 2) show that the Airport Lane *Spermophilus* has dimensions that most closely match *Spermophilus columbianus*. This identification is confirmed by the nearly parallel upper tooth rows of the palate, which is a diagnostic feature of *S. columbianus* according to Hall (1981) and Elliott and Flinders (1991).

Columbian ground squirrels (*S. columbianus*) live today in the Rocky Mountain region of western Montana, Idaho, northeastern Washington, southeastern British Columbia, and western Alberta. They are also found on the plains of eastern Washington and in the Blue and Wallowa Mountains of eastern Oregon (Elliott and Flinders, 1991). They are typically found on the edges of alpine or subalpine meadows and grasslands and on mounds within meadows where flooding occurs in the upper part of the Ponderosa Pine zone to the lower part of the Subalpine Fir zone. Colonies of Columbian ground squirrels are found along the margins of the Grande Ronde Valley, including the Ladd Canyon

Figure 6. Ground squirrel (*Spermophilus columbianus*) palate (dorsal view) showing left and right I, P^4, P^3, M^1, M^2, and M^3.

area 8 km southwest of the Airport Lane fossil site (Betts, 1976; Verts and Carraway, 1998). The presence of *S. columbianus* at the Airport Lane site indicates wetter and colder conditions on the floor of the Grande Ronde Valley during the late Pleistocene than at present.

S. columbianus fossils have been previously described only at the late Pleistocene (Rancholabrean) Wasden Site (Owl Cave) in Idaho (Guilday, 1969; Kurtén and Andersen, 1980). This is the first time they have been found in Oregon.

MICROFOSSILS

The grayish-brown silty fine sand inside and surrounding the mammoth tusks at the Airport Lane fossil site contains rare freshwater diatoms, sponge spicules, and pollen grains (Figure 7).

The diatoms in the sediments at the Airport Lane fossil site include *Aulacoseira*, *Navicula*, *Nitzchia*, and *Rossithidium* (previously known as *Achnanthes*). *Aulacoseira* is a freshwater planktic diatom, *Navicula* and *Nitzchia* are freshwater motile diatoms, and *Rossithidium* is a freshwater attached diatom. *Nitzchia* is an indicator of water with a high content of dissolved ions (Bradbury, 1988). All of these diatoms have been reported in the Columbia River (U.S. Department of the Interior, 1966) and, with the exception of *Rossithidium*, in the sediments of the Grande Ronde Valley (Van Tassell and others, 2001).

The sponge spicules in the Airport Lane fossil site sediments belong to the species *Ephydatia fluviatilis.* This species of sponge is common in the sediments of the Grande Ronde Valley (Van Tassell and others, 2001). *Ephydatia fluviatilis* is an indicator of water temperatures of 12˚–14˚C, water depths less than 1.5 m, and high ion concentrations (Bright, 1982).

Pollen grains identified in the Airport Lane fossil site sediments include grass (*Poaceae*), juniper (*Juniperus*), western hemlock (*Tsuga heterophylla*), and pondweed (*Potamogeton*). Western hemlock has been found in 4,400-year old lake sediments in the Wallowa Mountains to the east of the Grande Ronde Valley (Beck, 1996). The only known modern stand of western hemlock in eastern Oregon is a small refugial population at an elevation of 1,951 m in the Indian Creek drainage on the east side of the Grande Ronde Valley (Oregon Plant Atlas, 2011).

The diatoms and sponge spicules in the silty fine sands within and around the mammoth tusks at the Airport Lane fossil site suggest deposition in shallow streams and adjacent floodplain environments at the distal margin of the late Pleistocene La Grande outwash fan. Pondweed (*Potamogeton*) grew along the banks of the creeks and lakes in the area. Juniper trees (*Juniperus*) may have dotted the landscape. Grasses and pondweed provided a food source for mammoths, bison, and other herbivores. Stands of western hemlock were probably much more extensive on the slopes surrounding the Grande Ronde Valley than at present. The Airport Lane site is ~18 m above the present-day elevation of Catherine Creek, ~0.8 km to the southeast of the site. This suggests that the creek has cut down at least 18 m since the Airport Lane fossils were buried in the outwash fan sediments.

TAPHONOMY

One possible explanation for why the mammoth, bison, and bear ended up entombed in the silty fine-grained sands at the Airport Lane site ~15,260 years ago is that they drowned in a flood and were washed to the distal margins of the late Pleistocene La Grande outwash fan. This may have occurred during the spring as rivers were swollen with melt waters from the glaciers in the nearby mountains. Bilderback (1999) and Geraghty (1999) have mapped a Pleistocene ice-dammed lake in the headwaters of the rivers in the Elkhorn Mountains. It is possible that an ice dam may have burst and produced a jökulhaup. It is likely that the ground squirrels burrowed into these flood deposits some time after the flood.

This hypothesis does not answer the question of why the fossils of the large animals at the Airport Lane fossil site consist only of tusks, articulated vertebrae, and leg bones. Where are the rest of the skeletons? Are they still in the ground or were they washed away? Another possibility is suggested by Agenbroad's (1978) study of the early Holocene Hudson-Meng bison kill site in Nebraska, where butchering of the bison left behind

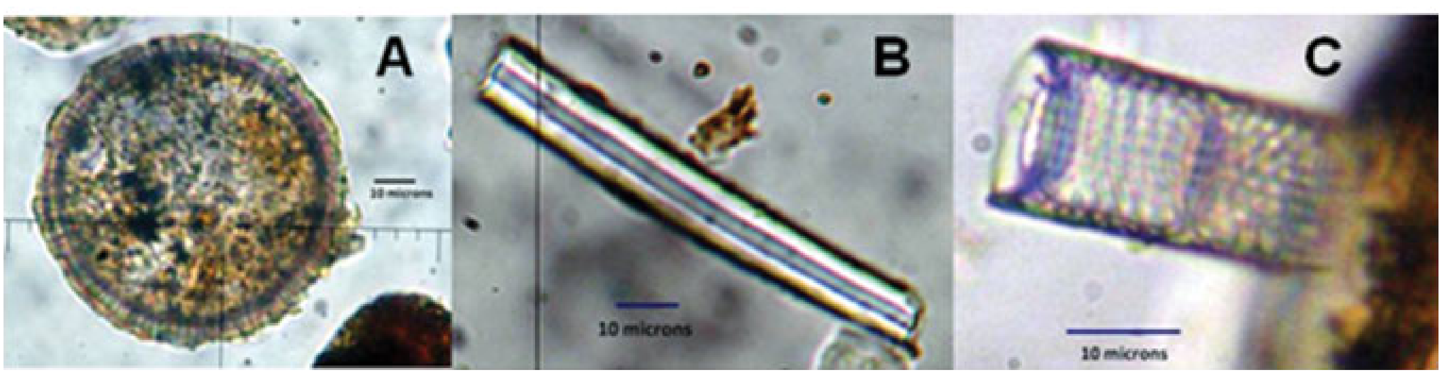

Figure 7. Microfossils found in the sediment inside and surrounding the Airport Lane mammoth tusks: (A) Western hemlock (*Tsuga heterophylla*) pollen, (B) sponge (*Ephydatia fluviatilis*) spicule, and (C) planktic diatom (*Aulacoseira*).

numerous articulated vertebrae and limb elements, including abundant femurs, tibiae, radii, and calcanei. These are the types of bones found at the Airport Lane site. Although no tools, butchering marks, or other evidence of human activity have been found, butchering of the animals at the site would explain why these particular skeletal elements are present and others are missing. Further investigation of the Airport Lane site is needed to determine whether this is an artifact of the way the bones were uncovered by the earth scraper or if this is a true reflection of the nature of the bones at the site.

CONCLUSIONS

The Airport Lane fossil site is located on an erosional remnant of the distal margin of a late Pleistocene outwash fan. Diatoms and sponge spicules in the silty fine sands at the site suggest deposition in a shallow stream and adjacent areas. Vegetation in the area included grasses, juniper, and pondweed. Mountain hemlock grew on the hills surrounding the valley. The creeks in the area have cut down ~ 18 m since the late Pleistocene.

The Airport Lane mammal fossils include 1) the tusks and tibia of a juvenile male Columbian mammoth (*Mammuthus columbi*); 2) seven articulated vertebrae, an articulated radius/ulna and carpals, and the proximal end of a calcaneus from a large male bison that is similar in size to *Bison latifrons* but is probably a large *Bison antiquus* related to early *Bison antiquus* found at Woodburn High School in western Oregon and on Orcas Island, Washington; 3) the proximal end of the femur of a male (or very large female?) giant short-faced bear (*Arctodus simus simus*) most closely related to the species at Potters Cave, California; and 4) a partial skeleton and other bones from several Columbian ground squirrels (*Spermophilus columbianus*), a species which is found today in the colder and wetter areas on the margins of the Grande Ronde Valley and not at the Airport Lane fossil site. AMS radiocarbon dating of fragments of the bison vertebrae gave a date of 12,950 ± 50 ^{14}C years (~15,260 calendar years BP).

It is not known how the bison, mammoth, and bear found at the Airport Lane fossil site died. They may have drowned in a spring flood or a jökulhaup released when an ice dam high in the mountains burst or they may have been killed and butchered by late Pleistocene hunters. Further investigation at the site may help clarify this mystery.

ACKNOWLEDGMENTS

We are grateful to Bill Orr, who first suggested that the curvature of the tusks indicated that they were from a mammoth. Dr. Mark Omann x-rayed the mammoth tibia and identified the epiphyseal plate. Mike Wilson identified the bison carpal bones and hinted that the vertebrae might be from a bison, not a short-faced bear as we originally thought. Dave Ellingson provided measurements of the radius from the Woodburn High School bison. We are grateful to Greg McDonald for identifying the bear femur. Blaine Schubert also helped us identify the bear fossils.

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Oregon Outback Dig at Fossil Lake!

For two weeks in mid-May, 2013, an intrepid group of fossil hunters from the School of Geosciences at the University of Louisiana, Lafayette, collected creatures that lived during the Ice Age in the high desert of the Oregon outback. The field paleontology course, directed by James E. Martin and Cathy Bishop, consisted of seven students who braved the arid, windy conditions punctuated with periods of rain and even light snow. Students collected numerous fossil vertebrates and invertebrates from Fossil Lake, a dry lake bed. The Oregon outback and fossil hunting were new experiences for the Louisiana students, and Fossil Lake did not disappoint—despite extremes in temperature that ranged from freezing to the 70s, they hiked and crawled to find exquisitely preserved fossils from a rare mammoth tooth to several partial bird skulls, and many mammals including horse, camel, fox, gopher, and vole. Fossil Lake is the most significant Ice Age site in the Pacific Northwest, and the Louisiana students found important specimens that will contribute to a continuing study of the area by Martin. The specimens collected are federal property having been collected under permit from the Bureau of Land Management and will be preserved for the public in the Geology Museum at the University of Louisiana.

(from http://geos.louisiana.edu/content/fossil-lake.pdf; photo credits: J. E. Martin)

A fossil bighorn sheep (Bovidae, *Ovis canadensis)* and geochronology of the Pleistocene Fossil Lake area, northern Lake County, Oregon

by James E. Martin[1]

[1]University of Louisiana, Geology Museum, School of Geosciences, Hamilton Hall, Lafayette, LA 70504, email: jxm2118@louisiana.edu

Abstract: The Fossil Lake area of central Oregon has been known as one of the most prolific fossiliferous areas in the American West since the 1870s. The site ranges in age from the Irvingtonian into the Rancholabrean North American Land Mammal Age (NALMA), representing deposits equivalent in part to the ice ages of the Pleistocene Epoch. Extensive trenching and radiometric dating resulted in the composite section and geochronology of the Fossil Lake Formation herein. The Rancholabrean portion of the stratigraphic succession has produced asssemblages that normally are associated with relatively arid conditions. From this portion of the section, dated between 47 and 26.6 ka, the first confirmed bighorn sheep from Fossil Lake was discovered. The skull cap and horn cores are of moderate size and indicate a male specimen of Ovis canadensis*. This specimen complements other bighorn sheep from Oregon near Adel, Fort Rock Cave, and the Paisley caves. Paleofaunal associations indicate that this bighorn sheep existed in relatively arid environments during the late Pleistocene.*

INTRODUCTION

Fossil Lake (Figure 1) is the most prolific fossiliferous area for Quaternary fossil vertebrates in the Pacific Northwest. Thousands of specimens have been collected from Fossil Lake since its discovery in 1876. Surprisingly, until recently no definitive evidence of the presence of bighorn sheep had been documented from Fossil Lake (e.g., Elftman, 1931). In 2012, however, a cranium of a bighorn sheep (Figure 2) was discovered by Leroy Foster during a field paleontology class at Fossil Lake. Other late Pleistocene specimens have also been found in Oregon. A similarly preserved cranial specimen of only slightly larger size was described by Thoms and Smith (1973) from the South Warner Valley near Adel in southern Lake County, Oregon. The Adel specimen was identified as *Ovis catclawensis*, then considered an extinct Pleistocene species, larger than the living species. However, on the basis of later research, this taxon is now considered at best a temporal subspecies of *Ovis canadensis* (Harris and Mundel, 1974) or a synonym of *Ovis canadensis* (Wang, 1988). Most workers do agree that the living bighorn sheep are smaller than their Pleistocene counterparts (Harris and Mundel, 1974; Lyman, 2009). Undescribed Pleistocene bighorn sheep specimens from Oregon and currently housed at the University of Oregon have been recovered from the Fort Rock Cave (Stratum 3) and from the Paisley Caves, in northern and central Lake County, respectively. From the latter, a radiocarbon date of 12,380 ± 70 (BETA-238087) was derived for a mountain sheep jaw (Hockett and Jenkins, 2013; Jenkins and others, 2013) with a butcher-cut recovered in Unit 5/5D, Level 30. Within the same excavation unit (5/5) but in quadrant B less than 75 cm away, 5 cm lower, and in the same stratum, a human coprolite was recovered and dated at 12,275 ± 55 (OxA-16498) and 12,400 ± 60 (BETA-213424). Two other human coprolites were found nearby, one to the northwest some 2 m and one to the south-

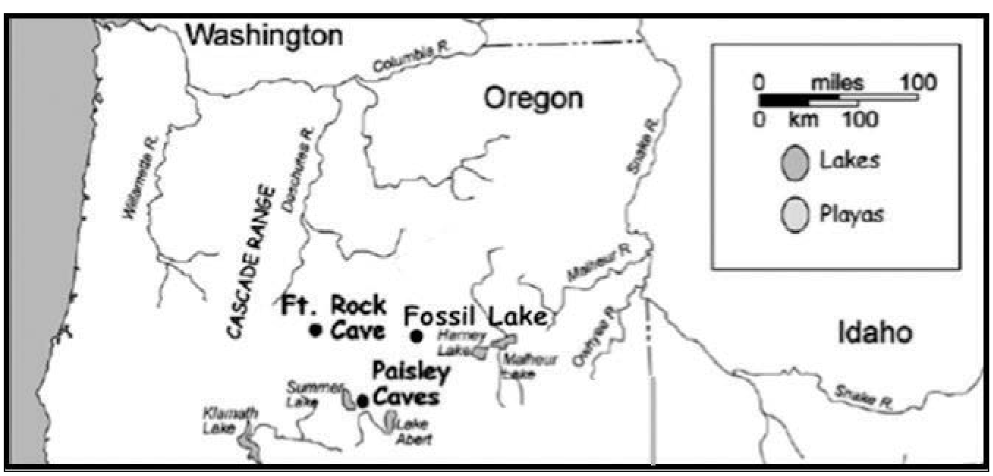

Figure 1. Map showing the location of Fossil Lake site in Lake County, Oregon.

Figure 2. Late Pleistocene bighorn sheep discovery by Leroy Foster at Fossil Lake, Oregon.

east less than a meter away, in the same stratum at elevations of 1,366.81 and 1,365.86, respectively. These coprolites were dated at 12,345 ± 55 (OxA-16497) & 12,290 ± 60 (BETA-213426) and 12,260 ± 60 (BETA-216474) & 12,140 ± 70 (OxA-16495), respectively (D. Jenkins, per. comm., August 20, 2013), substantiating the late Pleistocene date of occurrence. These sheep specimens are considered *Ovis canadensis*, as are the various Holocene specimens described from the Pacific Northwest (e.g., Lyman, 2009).

LITHOSTRATIGRAPHY AND AGE OF SPECIMEN

In 1977 the author was engaged to determine the extent and importance of the Fossil Lake area for the Bureau of Land Management. Most of the vertebrate-producing areas were delineated at that time, as well as a preliminary composite stratigraphic section of the Fossil Lake Formation of Smith (1926). Previously, Fossil Lake had been considered Pleistocene in age and equivalent to the Rancho La Brea tar pit assemblage of southern California (e.g., Kurten and Anderson, 1980). However, the most important indicator of the Rancholabrean NALMA, the occurrence of *Bison*, had never been reported among the thousands of specimens that had been collected over nearly a hundred years. In 1989 the author began yearly expeditions to collect from discrete stratigraphic levels. In addition, the stratigraphic section of the Fossil Lake Formation was refined (after extensive trenching; the lithostratigraphic results were summarized by Martin and others (2005). Eighteen lithostratigraphic units representing at least nine rhythmic graded bedded sequences were defined (Figure 3), and geochemical matching of interbedded tephras provided a geochronological framework, extending from approximately 646 to 10 ka (Martin and others, 2005). As can be seen from Figure 3, the upper part of the section extends from a major unconformity at the base of Unit 5 to Unit 18. This portion of the section represents the later part of the Rancholabrean NALMA. A few undescribed postcranial specimens of ?*Bison* have been recovered from this uppermost portion of the section, corresponding with the absolute dates.

Following the formulation of the general lithostratigraphic framework and tephra dates, efforts were directed to refinement of the geochronology of the upper portion of the Fossil Lake section, by using radiocarbon dating techniques. The tephra and radiocarbon dates are presented together for the first time (Figure 3). Unit 8 produced a geochemically compared tephra date of 47 ± 20 ka (Marble Bluff bed; Berger and Busacca, 1995; Negrini and others, 2000) and Unit 14 produced a date of 23.2 ± 0.3 ka (Trego Hot Springs tephra; Benson and others, 1997), suggesting that radiocarbon analyses were possible. Therefore, a series of samples from the upper portion of the section were submitted for AMS radiocarbon dating. First, two bone samples from Unit 14, from just above and below the Trego Hot Springs tephra were analyzed to check the accuracy of the procedure and of the original geochemical comparison. The bone date from below the tephra was 26,560 ± 160 rcbp (radiocarbon years before present), whereas that from above the tephra was 15,480 ± 70 rcbp. These dates bracket the geochemical date of 23.2 ± 0.3 ka and correlate well with stratigraphic position.

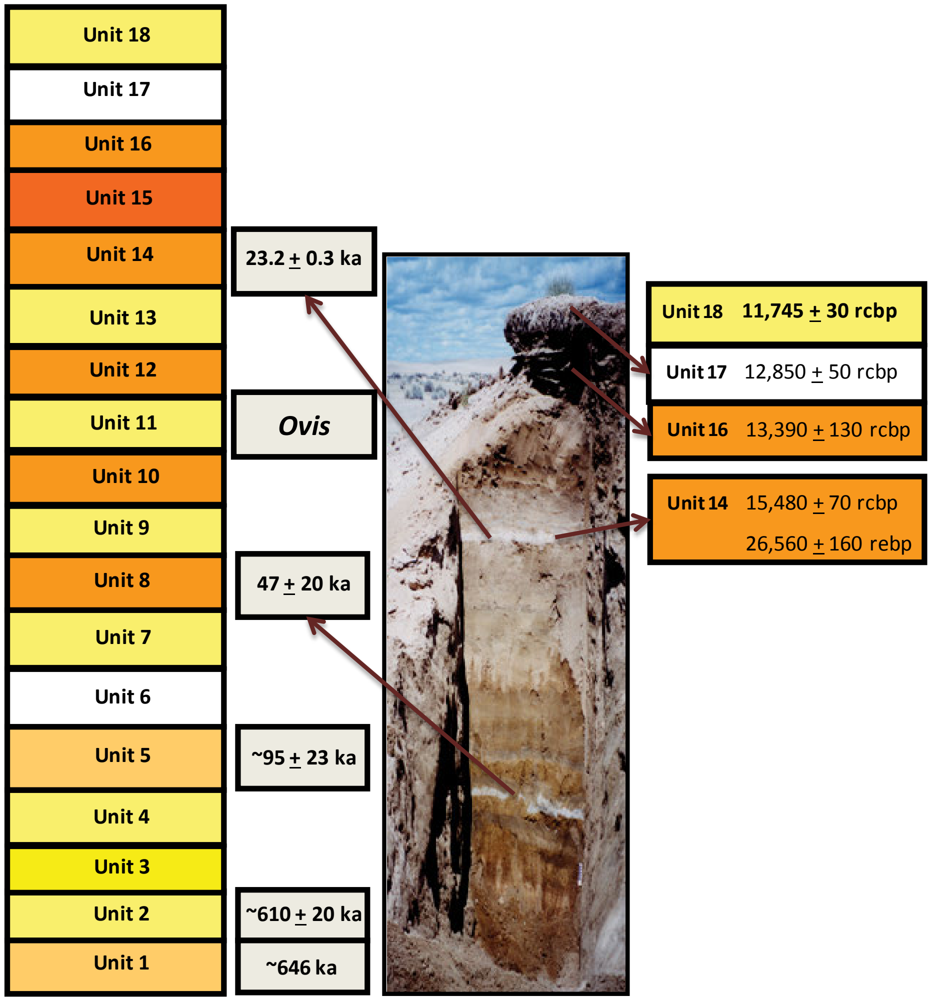

Figure 3. Lithostratigraphy and geochronology of the Fossil Lake Formation.

Unit 16, a brown siltstone overlying a ferruginous, cross-bedded sandstone, produced a radiocarbon date of 13,390 ± 130 rcbp derived from salmonid elements (Martin, 2010). Unit 16 is superposed by a white claystone (Unit 17), representing a widespread lacustrine event. This unit is characterized by salmonid elements, specimens of which produced two dates: an initial date of 10,140 ± 130 rcbp by Geochron Laboratories and a second date of 12,850 ± 50 rcbp by the PaleoResearch Institute (Martin, 2010). The latter laboratory dated the uppermost exposed unit at Fossil Lake (Unit 18), which resulted in a date of 11,745 ± 30 rcbp (Martin, 2010). Finally, a date of 6,050 ± 50 rcbp was produced from a lagomorph found in a burrow intruded into Unit 17. These dates appear to confine the upper portion of the Fossil Lake section to the late Rancholabrean NALMA.

Within this interval from Unit 11, the cranium of a bighorn sheep was discovered. Unit 11 is bracketed by the tephra date of 47 ± 20 ka from Unit 8 and the radiocarbon date of 26,560 ± 160 rcbp from Unit 14 (Figure 3). Relative stratigraphic position suggests the bighorn sheep lived closer to the latter date, approximately 30,000 to 35,000 years ago.

SYSTEMATIC PALEONTOLOGY

Class Mammalia Linnaeus, 1758
Order Artiodactyla Owen, 1848
Family Bovidae Gray, 1821
Genus *Ovis* Linnaeus, 1758
Species *Ovis canadensis* Shaw, 1804

Referred specimen—SDSM 86931, cranium with horn cores from Unit 11, Fossil Lake Formation (Martin and others, 2005).

Discussion—The well-preserved cranium (Figures 2 and 4) from Fossil Lake consists of the skull cap and horn cores. The horn cores are large (Table 1) and indicate the specimen represents a male of the species. The frontal and parietal bones are relatively well preserved, and allow measurements of the interorbital, interhorn core, and interfrontal foramina distances (Table 1). All measurements are relatively large compared to Recent specimens and in the size range of those from the Great Basin (compare with measurements by Stokes and Condie, 1961) and only slightly smaller than the specimen from south-

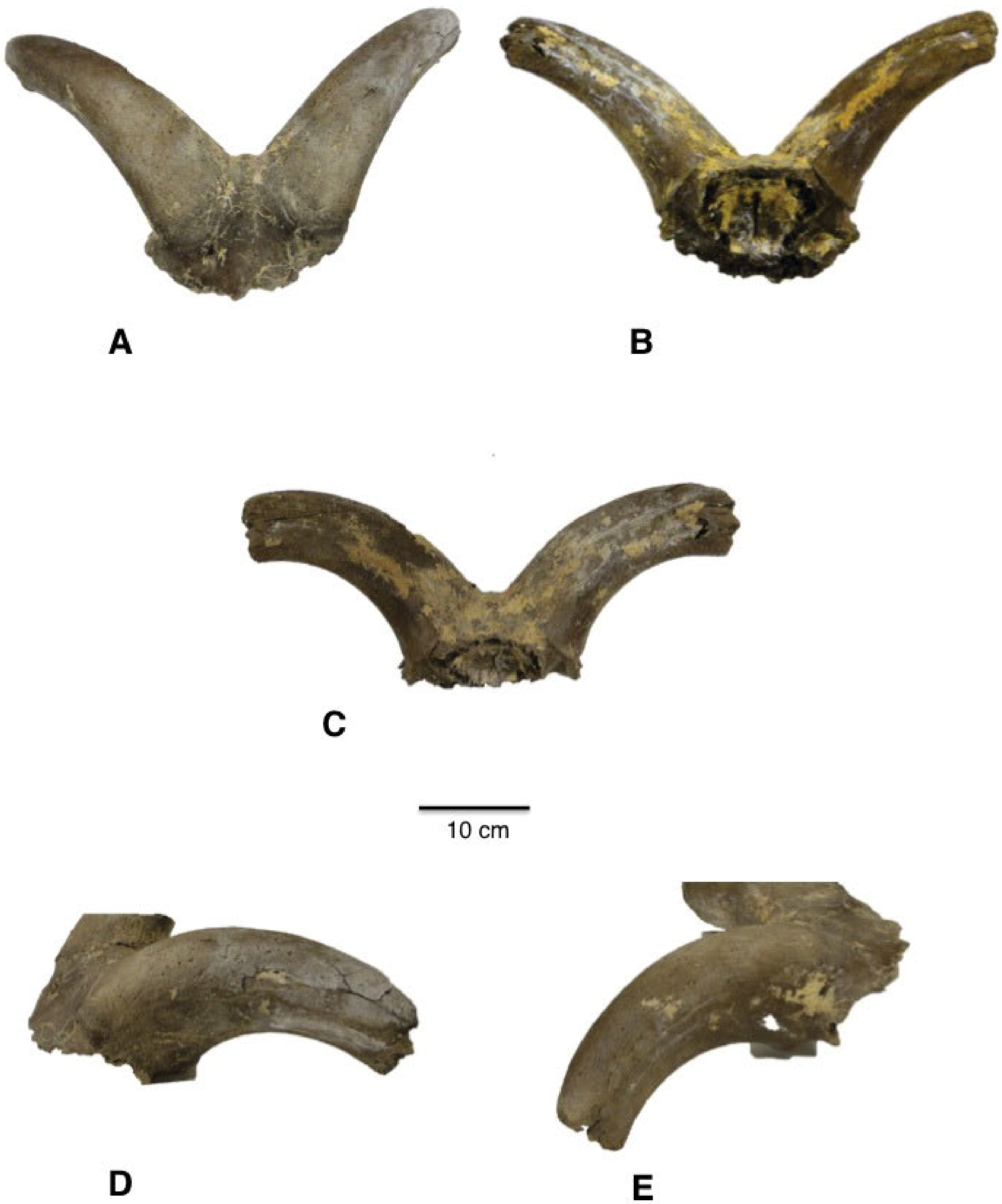

Figure 4. *Ovis canadensis* cranium from Fossil Lake, Oregon. A, dorsal view; B, ventral view; C, posterior view; D, left lateral view; E, right lateral view.

ern Lake County near Adel (Thoms and Smith, 1973). Overall, size and morphology indicate a small (possibly younger) male of *Ovis canadensis*.

On the basis of the change from mesic- to more xeric-adapted faunal elements, a general drying trend occurred during the deposition of the Fossil Lake Formation. Large camels (*Camelops*) and horses (*Equus*) are two of the most common large mammal fossils found at Fossil Lake and persist to just below Unit 17, dated at 12,850 ± 50 rcbp. The equid fossils are common elements in the lower portion of the lithostratigraphic section at Fossil Lake but become relatively rare in the upper portion of the section. The converse is true of large camel fossils, which become more common than horse fossils in the upper part of the section. Another important faunal component, *Bison*, is confined to only the uppermost portion of the Fossil Lake succession. The bighorn sheep specimen from Fossil Lake was found in Unit 11, where horse and jackrabbit specimens have also been found. *Lepus* sp. cf. *L. californicus*, the jackrabbit, is the most abundant mammal fossil found in Unit 11, suggesting that a relatively arid paleoenvironment of xeric shrub-steppe habitats surrounded the ephemeral lakes when the bighorn sheep was entombed.

Table 1. Measurements of *Ovis canadensis* specimen from Fossil Lake, Oregon.

Interorbital distance	17.5 cm
Distance between anterior frontal foramina	7.0 cm
Minimum distance between proximal ends of horn cores	2.3 cm
Maximum distance between distal ends of horn cores	39.0 cm
Maximum length along dorsal curvature of left horn core	26.5 cm
Maximum length along dorsal curvature of right horn core	27.0 cm
Minimum length along ventral curvature of left horn core	17.2 cm
Minimum length along ventral curvature of right horn core	17.0 cm
Maximum circumference of proximal left horn core	32.0 cm
Maximum circumference of proximal right horn core	31.5 cm
Maximum proximal diameter of left horn core	10.0 cm
Maximum proximal diameter of right horn core	10.0 cm
Minimum distal diameter of left horn core	6.0 cm
Minimum distal diameter of right horn core	5.0 cm

SUMMARY

Cranial size and morphology of the first specimen of the bighorn sheep, *Ovis*, recovered from the Pleistocene Fossil Lake area in northern Lake County, Oregon, indicates the specimen represents a relatively small male of *Ovis canadensis*. Extensive dating of the exposed section of the Fossil Lake Formation at Fossil Lake indicates that ephemeral lakes extended from 646 ka to approximately 10 ka. Eighteen stratigraphic units representing nine rhythmically deposited, graded bedded sequences have been recognized in the section. The upper 14 units were deposited during the late Pleistocene (Rancholabrean NALMA). The bighorn sheep cranium was discovered in Unit 11, which is bracketed by radiometric dates of 47 ± 20 to 26,560 + 160 rcbp, indicating the specimen was deposited approximately 30,000 to 35,000 years ago. From other paleofaunal evidence the paleoenvironments during deposition of the bighorn sheep cranium around the ephemeral lakes were xeric shrub-steppe habitats.

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I sincerely thank the Lakeview District of the Bureau of Land Management for support of my research at Fossil Lake. Tom Rasmussen, Todd Forbes, and William Cannon, in particular, have provided funding that has allowed research to continue. William Cannon, district archaeologist, initiated the project and guided its development. I thank the various members of field paleontology classes for their efforts over the years, particularly Leroy Foster of Pierre, South Dakota, who found the bighorn specimen. Dennis L. Jenkins, Museum of Natural and Cultural History, University of Oregon, reviewed the final draft and made valuable comments for which I am most appreciative.

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Follow the saga of BERNIE on blog and at OMSI

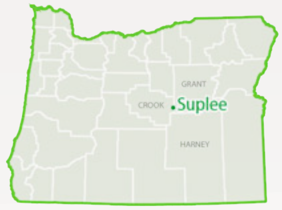
In 2011 Gloria and Greg Carr, out fossil hunting for ammonites near Suplee, Oregon, came across a fossil bone in a road cut. That bone led to another, and then another. Was it an entire critter? The Carrs sought out the landowners, ranchers Gene and Miriam Bernard*, to ask permission to excavate the fossils with the stipulation that the fossils would be donated to the University of Oregon Condon collection.

Recognizing the scope of the site, the Carrs contacted the North American Research Group (NARG), a consortium of groups, clubs, and organizations with interests in paleontology, paleobotany and geology, to help with the excavation. They also sought permission from the Crook County Road Commission to excavate in the road right-of-way.

On Memorial Day 2012, 22 NARG members excavated the site and brought out more than 1,000 pounds of material. The University of Oregon agreed to loan the to the Oregon Museum of Science and Industry (OMSI) in Portland, where the fossils are being prepared and displayed in the Paleontology Lab. Here staff and volunteers work on the rocks in a setting open to the public.

So far, limbs, shoulder bones, ribs, part of a skull, and part of a jaw have been prepared. Two species of critters appear to be present, with multiple individuals of one species—ichthosaur, thalattosaur, pleisosaur, archosaur? It's too early to tell the whole story.

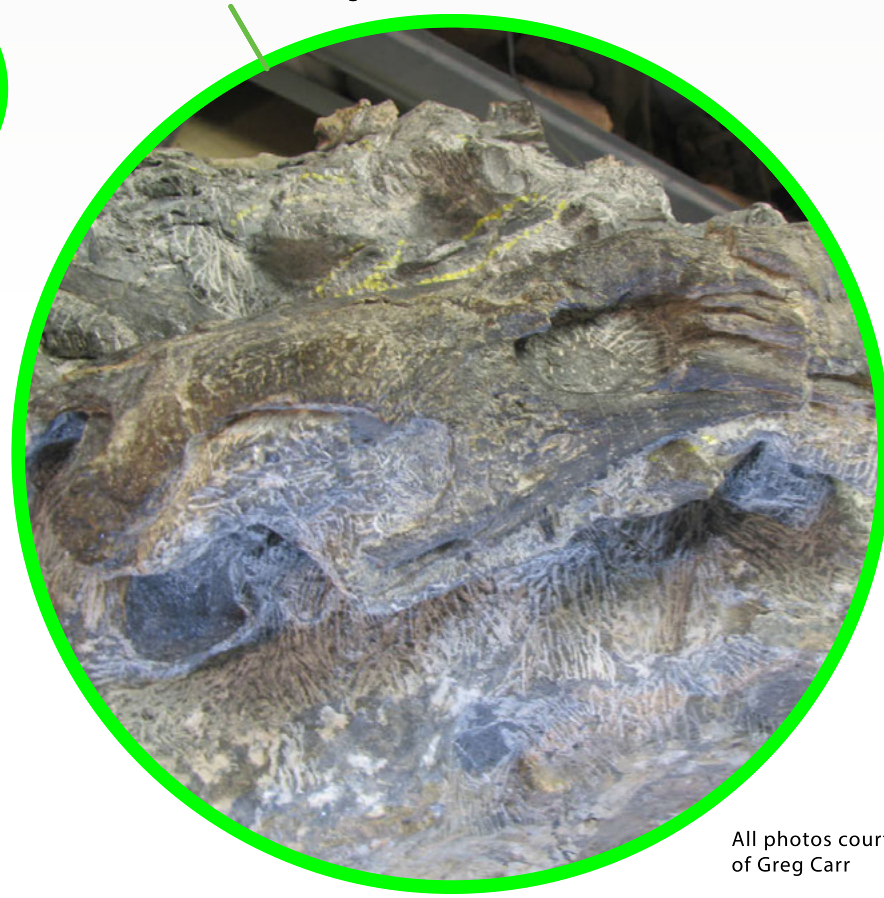
*Bernie was named after Bernard.



GEOLOGY

The fossil-rich site occurs in a well-cemented sandstone lens in shale of the Jurassic Izee terrane exposed in a large erosional inlier. The coarse sand at the site indicates a shallow or nearshore environment. Ammonites, gastropods, nautiloids, brachiopods, belemnites and bivalves are present in addition to the bones.

SKULL in rock block.
Skull is 14 inches long.



All photos courtesy of Greg Carr

LEARN MORE

Bernie the Ichthyosaur Blog, by Greg Carr. Learn more about the dig, the paleoenvironment, and how the specimens are prepared. See photos of the specimens as they are uncovered and follow the discussion of how the specimens are classified.

7th Fossil Preparation Symposium Presentation, April 2014, by Greg Carr. The presentation covers finding, recovering, and to-date preparation of Bernie (and friends).

NARG

OMSI Science Labs

University of Oregon Condon Collection

Fossil Collecting in Oregon

Geomyid rodents from the Pleistocene Fossil Lake area, Lake County, Oregon

by Randolph J. Moses[*1,2] and James E. Martin[3,4]*

*[1]Corresponding author: ARCADIS U.S., Inc., 189 N. Cedar St., Buffalo, Wyoming 82834, email: moses.wyogeo@gmail.com
[2]Research Associate, Museum of Geology, South Dakota School of Mines and Technology, 501 E. St. Joseph St., Rapid City, South Dakota 57701
[3]J. E. Martin Geoscientific Consultation, 21051 Doral Ct., Sturgis, South Dakota 57785
[4]Research Professor and Curator of Paleontology; University of Louisiana, Geology Museum; School of Geosciences; Lafayette, Louisiana 70504

Abstract: Thomomys*, a pocket gopher genus restricted to western North America, is one of the most common fossil mammals from the lower portion of the late Pleistocene Fossil Lake sedimentary succession, south-central Oregon. The 234 gopher specimens used in this study were recovered and collected with precise stratigraphic control. Five stratigraphic units ranging from 95 to 646 ka on the basis of tephra geochronology contain gopher fossils. Investigation of specimens collected from these units indicates at least two species of* Thomomys*. The morphology of p4, length and width of p4, m1, and m2, as well as jaw depth of specimens from successive stratigraphic layers were compared. The existence of two different p4 morphologies indicates that at least two separate species are represented: one morphology similar to extant* Thomomys talpoides *and one more plesiomorphic morphology similar to that of* Thomomys townsendii.

Thomomys talpoides *is the modern geomyid taxon that inhabits the Fossil Lake area and also occurs at the several of the lowest stratigraphic levels in the Fossil Lake deposits. The appearance of* Thomomys talpoides *at Fossil Lake represents the first unequivocal occurrence of* T. talpoides *in the Irvingtonian of Oregon.* T. talpoides *normally is not found (or is rare) in the same unit as* T. townsendii, *suggesting environmental control. Other taxa occurring in units with* T. talpoides *suggest arid (or xeric) conditions, whereas those associated with* T. townsendii *indicate a more mesic environment of deposition.*

INTRODUCTION

The Fossil Lake area is an extremely fossiliferous Pleistocene region in south-central Oregon (Figure 1). The stratigraphy and tephrochronology were documented by Martin and others (2005), who found 18 lithostratigraphic units arranged in nine successive, rhythmic, fining-upward packages (Figure 2). Each package is represented by a coarse basal sand or gravel, grading upward into lacustrine clays. Sediments represent successive lake fillings with sedimentary influences from regional and local volcanism. Paleontological research at Fossil Lake has identified many rodent genera including hundreds of specimens (with numerous associated or articulated skeletons) of *Thomomys*, from stratigraphic Units 1–5 (Figure 2). Many of the associated and articulated specimens of *Thomomys* have been excavated and recovered from filled burrows; none cross stratigraphic boundaries. These specimens were collected over two decades by expeditions from the Museum of Geology, South Dakota School of Mines and Technology (SDSM). Several lithostratigraphic packages at Fossil Lake contain tephras that provided radiometric chronology on the basis of geochemical correlation. The stratigraphically lowest tephra (A) was matched to Rye Patch Dam tephra with a date of 646 ka (Figure 2) (Martin and others, 2005) and occurs within the basal yellow claystone unit (Unit 1). Superjacent, a gray-brown basaltic sandstone (Unit 2)

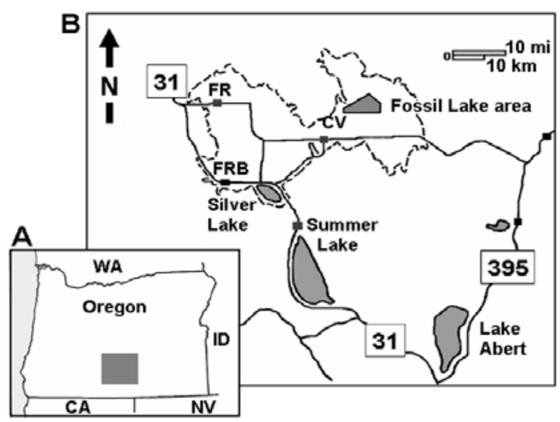


Figure 1. (A) Oregon map with shaded area indicating the Fossil Lake region in B. (B) Map of northern Lake County, Oregon, showing locations of modern lakes of the region (shaded) and the maximum extent of the Pleistocene Fort Rock Lake (dashed line). Fossil Lake is within the Christmas Valley Basin. CV = Christmas Valley, FRB = Fort Rock Basin, FR = town of Fort Rock, CA = California, ID = Idaho, NV = Nevada, WA = Washington. From Martin and others (2005).

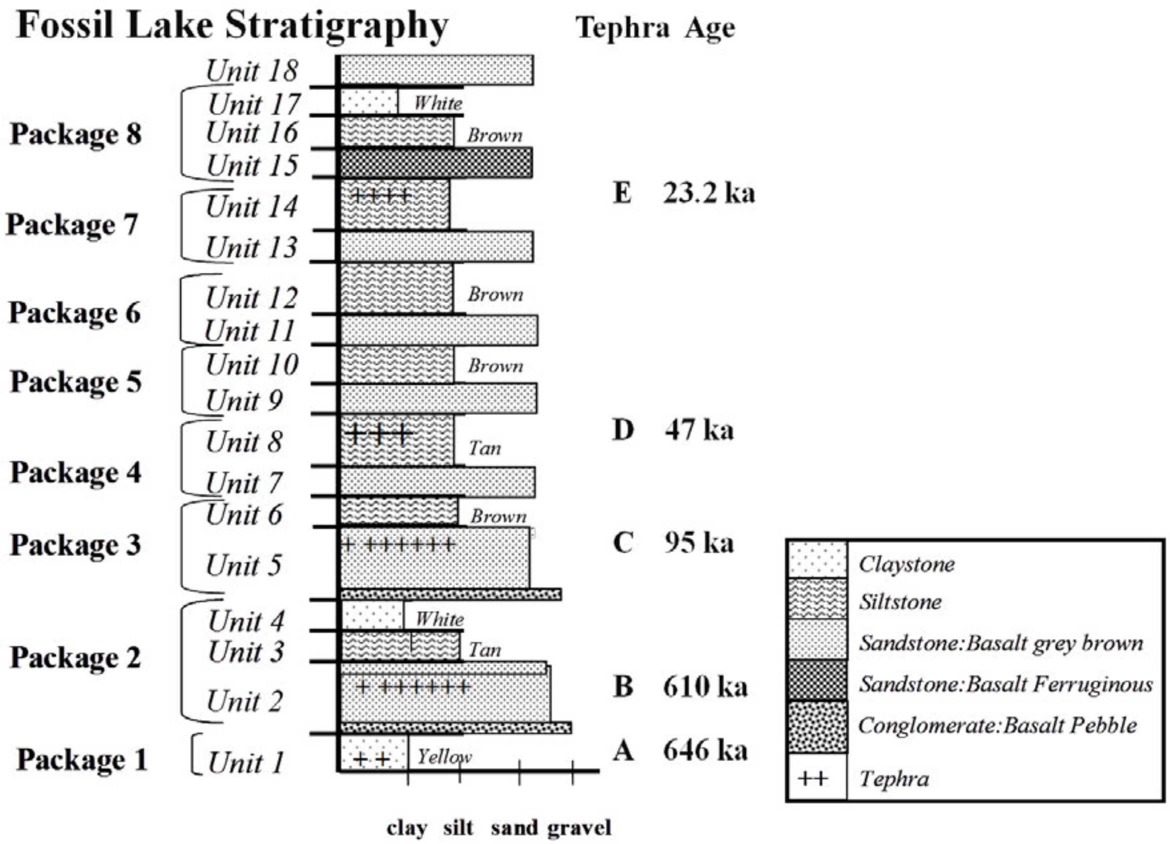


Figure 2. Lithostratigraphy and tephrochronology of Fossil Lake, Oregon. Units are grouped into depositional packages. Dates from tephras are labeled A–E. From Martin and others (2005).

bears the second tephra (B). Tephra B has been matched to the Dibekulewe ash with a date of 610 ka (Martin and others, 2005). Both tephras A and B indicate deposition during the Irvingtonian North American Land Mammal Age (NALMA) as defined on the bases of mammal occurrence correlated with absolute dates (see Bell and others, 2004), indicating earlier deposition than previously thought (e.g., Allison, 1966). The gray-brown basalt sandstone grades into a tan “transitional” layer (Unit 3) that in turn grades into a white claystone (Unit 4). The upper contact of the white claystone layer is marked by a distinct unconformity. Superjacent, a basalt gravel and sandstone (Unit 5) grade into a brown siltstone (Unit 6). Unit 5 contains a tephra layer (C) that has been matched to the Tulelake Sample T64 tephra and dated to ~95 ka (Martin and others, 2005). This much younger date indicates a depositional hiatus (lacuna of Wheeler, 1964) during which the late Irvingtonian and early Rancholabrean NALMAs as currently defined and correlated are missing (Bell and others, 2004; Martin and others, 2005). Tephra D within stratigraphic Unit 8 of Fossil Lake has been matched to the Marble Bluff bed (Mount St. Helens set C), which has been dated at ~47 ka (Martin and others, 2005).

PREVIOUS TAXONOMIC INTERPRETATIONS

E. D. Cope (1883, 1889) was the first to recognize pocket gophers at Fossil Lake (Elftman, 1931) and identified several species including *T. clusius*, *T. talpoides*, and *T. bulbivorus*. Hay (1912) identified a new species, *Thomomys scudderi*, based on a single specimen from Fossil Lake. Bailey (1915) conducted a biological survey and revised modern pocket gophers of the genus *Thomomys* as part of a technical revision of the family Geomyidae, which was originally prepared by C. H. Merriam. Elftman (1931) in his description of the fossil mammals of Fossil Lake decided that only a single species, *Thomomys townsendii*, existed at Fossil Lake and considered *T. scudderi* as a junior synonym. Davis (1937) reviewed modern *Thomomys townsendii*, reexamined the Fossil Lake gophers, and decided that although the specimens resembled *T. townsendii* enough distinction warranted a new species, *Thomomys vetus*, which he regarded as a close relative of *T. townsendii*. Moreover, Davis (1937) also resurrected *Thomomys scudderi* Hay (1912), which he considered more closely related to the *Thomomys bottae* group. Although Davis admitted that pocket gophers are normally allopatric, he explained the sympatry of two species at Fossil Lake as the result of complementary ranges. A change of habitat would result in the withdrawal of one species and the invasion of the area by another (Davis, 1937). Both Elftman and Davis were under the impression that all fossil mammals at Fossil Lake were of the same relative age, what is now considered the Rancholabrean NALMA, a perception that persisted until Martin and others (2005) established that the lower stratigraphic units at Fossil Lake contained paleofauna and tephras with dates consistent with Irvingtonian NALMA. Elftman (1931) and Davis (1937) concurred that only *Thomomys quadratus* is currently extant at Fossil Lake. However, Goldman (1939) considered *T. quadratus* (and *T. clusius*, described from Fossil Lake by Cope, 1883) as subspecies of *Thomomys talpoides*. Molecular data (e.g., Patton and Smith, 1994) indicate nine extant species, including all those previously described from Fossil Lake. Verts and Carroway (1999, 2003) reviewed both Recent *Thomomys talpoides* and *T. townsendii*. Of these, *T. talpoides* currently occurs in the Fossil Lake area, and *T. townsendii* occurs just to the east in Malheur and Harney counties, Oregon. Moreover, *T. talpoides* commonly occupies alkaline soils and appears to burrow through deep soils associated with Pleistocene lakes. The distribution of the species is relict and therefore disjunct, with separate populations occurring in southern Idaho, northeastern California, and northern Nevada as well as Oregon (Verts and Carraway, 1998). *T. townsendii*'s current range is restricted to deep lacustrine or fluviatile soils (Rogers, 1991). Other species of *Thomomys* (*T. mazama*, *T. bulbivorus*, and *T. bottae*) occurring in Oregon are principally associated with the Cascade Range to the west. Little recent research has concerned the species of *Thomomys* at Fossil Lake, although Verts and Carroway (2003) considered *Thomomys vetus* closely related to *T. townsendii*. Therefore, the following species have been recognized at Fossil Lake: *Thomomys talpoides*, *T. townsendii*, *T. bulbivorus*, *T. scudderi*, and *T. vetus*.

Species of *Thomomys* are well adapted for a fossorial mode of life in a variety of conditions and use both teeth and long claws to dig burrow systems that can be tens of meters in length and extend to depths of two meters (Jones and others, 1983). Pocket gophers are exceedingly territorial and nearly contiguously allopatric. However, *Thomomys* species are rarely found sympatrically but consist of morphologically divergent species (Thaeler, 1968). Species of *Thomomys* are among the most morphologically variable of mammals with intraspecific variation as great as interspecific variation (Dalquest and Scheffer, 1944; Verts and Carraway, 1999). Therefore, determination of species can be difficult (Verts and Carraway, 1998). *Thomomys* has rootless, ever-growing teeth that can complicate species identification (Chomko, 1990). The occlusal face of the anterior loph of the lower p4 is normally triangular but may have a concavity (scallop) on the anteromedial surface (Figure 3), a condition that is diagnostic of *T. talpoides* (Chomko, 1990; Verts and Carraway, 1999).

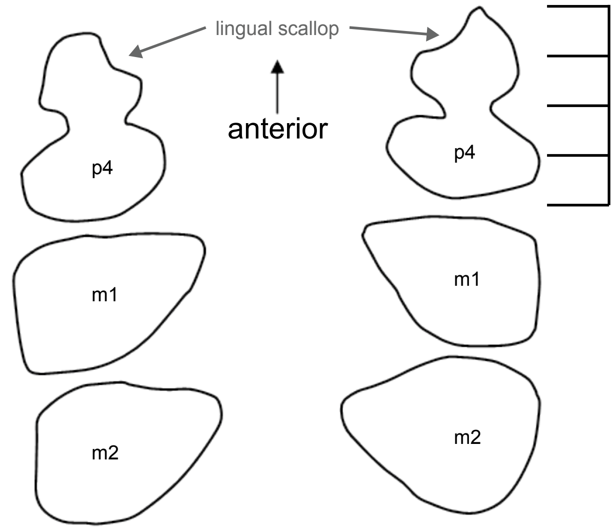


Figure 3. Diagrammatic sketch of the occlusal surface of the lower dentition (p4–m2) of *Thomomys talpoides*. Note the lingual scallop on the anterior loph of p4. Scale bar in millimeters.

Davis (1938) discussed geographic and morphological variations among the geomyids and noted that pocket gophers, especially males, tend to increase in size with age and are consistently larger than most females. Vaughan (1967, p. 149) noted that pocket gophers display "considerable individual variation due to age, sex and type of habitat." Smith and Patton (1984) went further in stating that males and females must generally be treated separately (in statistical analyses) as the result of pronounced sexual dimorphism, and female gophers consistently vary less than males. The maximum size attained seems to be directly related to the type of soil these animals inhabit (Dalquest and Scheffer, 1944; Verts and Carraway, 1999). However, correlation also appears between size of the animal and factors such as altitude and nutrient availability. Examples provided by Davis (1938) demonstrate that at high elevations where the soil is usually rocky, or at lower elevations where the same general environment occurs, the gophers tend to be small. In these environments, skulls of males and females are nearly indistinguishable. However, rocky soil does not appear to have been a factor in this study as all lithologies at Fossil Lake are poorly consolidated, relatively fine-grained lacustrine sediments. In environments containing well-developed deep soils, individuals possess well-developed features, and the size of both sexes had generally increased (Davis, 1938).

PROCEDURE

To determine the species composition of the sample and to evaluate patterns of morphological change in *Thomomys* from Fossil Lake, 206 fossil dentaries of *Thomomys* at the Museum of Geology, South Dakota School Mines and Technology (SDSM) and 7 fossil dentaries of *Thomomys* at the University of Louisiana Geology Museum (ULGM) were examined (Table 1). In addition, similar measurements were taken for 15 Recent *Thomomys* specimens (identified as *Thomomys talpoides*) collected from Fossil Lake (Table 1). The maximum length and width of lower p4 through m2, and maximum jaw depth (Figure 4) were measured by using digital calipers (± 0.001 mm) and a microscope. Each measurement was made in triplicate and an average value was computed. Data were normalized using natural logarithm transformation to aid in analyses. In cases when both left and right dentaries from one individual were available, each was treated as a unique specimen. The morphology of the p4, m1, m2, and dentaries were compared as well as cranial material when available. Locality and stratigraphic information were cataloged for each specimen. Except unit 6, which is used here to designate Recent specimens, stratigraphic unit numbers correspond to the nomenclature of Martin and others (2005). Broken or repaired teeth and dentaries were excluded from the measurements, and individual teeth (teeth not in alveoli) were avoided unless positively associated with dentaries. In addition, six partial crania (JEM 0778, JEM 0913-1, JEM 1130-026, JEM 10-60, JEM 0633-63, and ULGM V2575) were studied in attempt to determine the taxonomic affinity of the fossil specimens from Fossil Lake. All specimens labeled with "JEM" are housed at the Museum of Geology, South Dakota School of Mines and Technology; formal specimen numbers have not been assigned to some specimens at this time. Specimens labeled with "ULGM" are housed at the University of Louisiana Geology Museum. Specimens labeled with "UWBM" are housed at the University of Washington Burke Museum.

Table 1. Specimens of *Thomomys* from Fossil Lake, Oregon, and associated data. The 228 specimens listed include 206 fossil dentaries of *Thomomys* at South Dakota School Mines and Technology (SDSM), 7 fossil dentaries of *Thomomys* at University of Louisiana Geology Museum (ULGM), and 15 Recent *Thomomys* dentaries (identified as *Thomomys talpoides*). Stratigraphic unit numbers correspond to the nomenclature of Martin and others (2005). Morphology types are 1, diamond/round; 2, scalloped; unk, unknown. Measurements are in millimeters: p4L, maximum length of p4; p4W, maximum width of p4; Ln p4 Area, natural logarithm of p4 area (L × W); m1L, maximum length of m1; m1W, maximum width of m1; Ln m1 Area, natural logarithm of m1 area (L × W); m2L, maximum length of m2; m2W, maximum width of m2; Ln m2 Area, natural logarithm of m2 area (L × W); JD, jaw depth; Ln JD, natural logarithm of JD. Year is year collected. Field number (JEM) is that of J. E. Martin. All specimen numbers are informal numbers assigned at SDSM except where noted with ULGM. Also see Figure 4.

Strat. Unit	p4 Morphology	Taxon	Description	p4L	p4W	Ln p4 Area	m1L	m1W	Ln m1 Area	m2L	m2W	Ln m2 Area	JD	Ln JD	Year	Field Number (JEM)	Specimen Number
1	2	*T. talpoides*	L. Dent.	2.18	1.61	1.26	1.32	1.96	0.95	1.43	1.97	1.04	7.60	2.03	2005	0518-34	86922
1	2	*T. talpoides*	R. Dent.	2.24	1.65	1.31	1.43	1.99	1.04	1.41	2.00	1.04			2005	0518-34	86922
1	2	*T. talpoides*	L. Dent.	2.00	1.49		1.33	1.78		1.37	1.74	0.87			1977	7759	
1	unk	*Thomomys* sp.	L. Dent.	2.17	1.50	1.18	1.41	1.87	0.97	1.37	1.85	0.93			1994	9435	34148
2	1	*T. townsendii*	R. Dent.	2.47	1.80	1.50	1.30	2.05	1.09	1.42	2.09	1.09	9.33	2.23	1990	9023	18990
2	1	*T. townsendii*	L. Dent.	2.60	1.83	1.56									2001		68612
2	1	*T. townsendii*	R. Dent.	2.76	1.90	1.66	1.64	2.20	1.28	1.91	2.37	1.51	10.88	2.39	2005	0510-96	
2	1	*T. townsendii*	L. Dent.	2.29	1.67	1.34	1.32	2.06	1.00	1.54	2.08	1.16	7.40	2.00	1991		24666
2	1	*T. townsendii*	L. Dent.	2.51	1.91	1.57	1.44	2.09	1.10	1.55	2.08	1.17			1991		24667
2	1	*T. townsendii*	L. Dent.	2.67	1.78	1.56	1.58	2.34	1.31	1.61	2.36	1.33	8.79	2.17	1991		24668
2	1	*T. townsendii*	L. Dent.	2.52	2.08	1.66	1.65	2.31	1.34						1995		39546
2	1	*T. townsendii*	R. Dent.	2.50	1.87	1.54	1.39	1.98	1.01	1.57	2.21	1.24	7.22	1.98			61785
2	1	*T. townsendii*	L. Dent.	2.56	1.88	1.57	1.39	2.12	1.08	1.61	2.22	1.27	8.04	2.08			62129
2	1	*T. townsendii*	R. Dent.	2.38	1.67	1.38	1.37	2.11	1.06	1.49	2.14	1.16	7.09	1.96	2001		67067
2	1	*T. townsendii*	L. Dent.	2.13	1.72	1.30	1.46	2.12	1.13	1.44	1.95	1.03	5.95	1.78	2002		70533
2	1	*T. townsendii*	L. Dent.	2.21	1.87	1.42	1.56	2.25	1.26	1.69	2.32	1.37			2000		66035
2	1	*T. townsendii*	R. Dent.	2.68	2.04	1.70	1.73	2.32	1.39						1990	9081	19425
2	1	*T. townsendii*	L. Dent.	2.28	1.74		1.37	1.92		1.47	2.13	1.14	10.30	2.33	1977	7760	
2	1	*T. townsendii*	R. Dent.	2.35	1.82	1.46	1.29	1.85	0.87	1.45	2.00	1.06	9.57	2.26	1996	9623	43821
2	1	*T. townsendii*	L. Dent.	2.30	1.72	1.37	1.41	2.09	1.08	1.54	2.20	1.22	8.28	2.11	1996	9637	44260
2	1	*T. townsendii*	R. Dent.	2.68	1.84	1.60									1996	9655	44921
2	1	*T. townsendii*	R. Dent.	2.43	1.73	1.44	1.45	1.96	1.04	1.58	2.05	1.18	8.34	2.12	2006	0630-35	
2	1	*T. townsendii*	L. Dent.	2.59	1.97	1.63	1.64	2.17	1.27	1.73	2.28	1.37	10.54	2.36	2006	0633-64	
2	1	*T. townsendii*	R. Dent.	2.64	1.86	1.59	1.36	1.93	0.97	1.49	2.02	1.10	9.56	2.26	2006	0633-65	
2	1	*T. townsendii*	L. Dent.	2.34	1.76	1.41	1.51	2.11	1.16	1.62	2.09	1.22			2008	0821-54	
2	1	*T. townsendii*	R. Dent.	2.61	1.95	1.63	1.55	2.11	1.18							977	48193
2	2	*T. talpoides*	L. Dent.	2.91	2.09	1.81	1.65	2.35	1.36						1990	9025	19059
2	2	*T. talpoides*	L. Dent.	2.71	1.90	1.64										9354	28337
2	2	*T. talpoides*	L. Dent.	2.40	1.76	1.44	1.62	2.03	1.19	1.61	2.04	1.19	8.24	2.11			50840
2	2	*T. talpoides*	R. Dent.	2.25	1.65	1.31	1.43	1.92	1.01	1.46	1.95	1.05			2001		67433
2	2	*T. talpoides*	L. Dent.	2.22	1.74	1.35	1.37	2.24	1.12	1.61	2.19	1.26			2009	0919-71	
2	2	*T. talpoides*	R. Dent.	2.21	1.53	1.22	1.30	1.80	0.85	1.33	1.78	0.86			2008	0821-55	
2	2	*T. talpoides*	R. Dent.	2.13	1.60	1.22	1.59	2.08	1.19				7.52	2.02	2008	0826-65	

(table continued on next page)

(Geomyid rodents, continued)

Table 1 (continued). Specimens of *Thomomys* from Fossil Lake, Oregon, and associated data.

Strat. Unit	p4 Morphology	Taxon	Description	P4L	P4W	Ln P4 Area	M1L	M1W	Ln M1 Area	M2L	M2W	Ln M2 Area	JD	LnJD	Year	Field Number (JEM)	Specimen Number
2	2	*T. talpoides*	R. Dent.	2.27	1.51	1.23	1.36	1.88	0.93	1.48	1.90	1.04			2008	0860-35	86924
2	2	*T. talpoides*	R. Dent.	2.45	1.74	1.45	1.17	2.20	0.94	1.65	2.15	1.27	8.40	2.13	2010	1058-27	
2	2	*T. talpoides*	L. Dent.	2.46	1.53	1.33	1.35	2.02	1.00	1.39	1.83	0.93			2011	1130-29	
2	2	*T. talpoides*	L. Dent.	2.01	1.63	1.18	1.23	1.79	0.79	1.36	1.73	0.85			1993	9354	28336
2	2	*T. talpoides*	R. Dent.	2.35	1.61	1.33	1.47	2.06	1.11	1.68	2.07	1.25	7.46	2.01	1990	9025	19058
2	2	*T. talpoides*	R. Dent.	2.35	1.73	1.40	1.48	2.20	1.18	1.51	2.15	1.18	6.30	1.84	2013		ULGM V2401
2	2	*T. talpoides*	R. Dent.	2.46	1.70	1.43	1.52	2.20	1.21	1.50	2.15	1.17			2013		ULGM V3399
2	unk	*Thomomys* sp.	L. Dent.	2.15	2.18	1.54	1.25	2.07	0.95	1.41	2.05	1.06	8.65	2.16	2007	0746-43	
2	unk	*Thomomys* sp.	L. Dent.	2.29	1.61	1.30	1.59	2.07	1.19	1.71	2.04	1.25			1990		19058
2	unk	*Thomomys* sp.	L. Dent.	2.14	1.54	1.19	1.30	2.19	1.05	1.46	2.10	1.12			1992		27020
2	unk	*Thomomys* sp.	L. Dent.	2.44	1.62	1.37									1995		38367
2	unk	*Thomomys* sp.	L. Dent.										9.68	2.27	2000		66116
2	unk	*Thomomys* sp.	L. Dent.				1.58	2.36	1.32	1.79	2.40	1.46			2001		67002
2	unk	*Thomomys* sp.	L. Dent.							1.78	2.37	1.44			2001		67068
2	unk	*Thomomys* sp.	L. Dent.	2.42	1.80	1.47	1.37	2.12	1.06	1.48	2.11	1.13	8.36	2.12	2011	1130-30	
3	1	*T. townsendii*	R. Dent.	2.39	1.67	1.38	1.34	2.19	1.08	1.46	2.27	1.20	7.50	2.01	2001		68669
3	1	*T. townsendii*	L. Dent.	2.62	1.91	1.61	1.57	2.07	1.18	1.63	2.33	1.33	10.50	2.35	1990	9057	19241
3	1	*T. townsendii*	R. Dent.	2.72	1.85	1.61	1.50	1.95	1.07				9.28	2.23	2006	0627-15	
3	1	*T. townsendii*	R. Dent.												2010	1060	86923
3	1	*T. townsendii*	R. Dent.	2.88	1.89	1.70	1.57	2.20	1.24	1.62	2.28	1.30	9.81	2.28	2009	0913-1	
3	1	*T. townsendii*	L. Dent.	2.65	1.85	1.59	1.60	2.11	1.22	1.73	2.41	1.43	9.42	2.24	2009	0913-1	
3	1	*T. townsendii*	R. Dent.	2.45	1.72	1.44	1.40			1.43	2.15	1.12	6.70	1.90	2013		ULGM V3455
4	1	*T. townsendii*	L. Dent.	2.47	2.02	1.61											16041
4	1	*T. townsendii*	R. Dent.	2.54	1.94	1.59	1.57	2.12	1.20								16041
4	1	*T. townsendii*	R. Dent.	2.47	1.78	1.48	1.42	2.06	1.07				9.40	2.24	1992	9218	25496
4	1	*T. townsendii*	L. Dent.	2.29	1.64	1.32	1.32	1.87	0.91				8.21	2.10	1992	9218	25497
4	1	*T. townsendii*	R. Dent.	2.47	1.80	1.49	1.52	2.02	1.12	1.46	2.13	1.13			1995	9565	36760
4	1	*T. townsendii*	R. Dent.	2.41	1.81	1.48										969	42890
4	1	*T. townsendii*	R. Dent.	2.10	1.62	1.22	1.27	1.87	0.86	1.36	1.83	0.91			2000		66136
4	1	*T. townsendii*	L. Dent.	2.23	1.89	1.44	1.34	2.08	1.03	1.51	2.05	1.13	7.83	2.06	2000		66431
4	1	*T. townsendii*	R. Dent.	2.21	1.86	1.41	1.35	2.08	1.03	1.56	2.08	1.18	7.95	2.07	2000		66431
4	1	*T. townsendii*	R. Dent.	2.79	2.00	1.72	1.75	2.15	1.33	1.79	2.12	1.33	8.81	2.18	2005	0548-1	
4	1	*T. townsendii*	L. Dent.	2.69	1.95	1.66	1.50	2.13	1.16	1.73	2.21	1.34	8.67	2.16	2005	0548-1	
4	1	*T. townsendii*	L. Dent.	2.09	1.71	1.27	1.31	2.00	0.96	1.55	2.06	1.16	8.43	2.13	2005	0558-14	
4	1	*T. townsendii*	R. Dent.	2.80	2.13	1.78	1.66	2.38	1.38	1.71	2.42	1.42	11.57	2.45	2006	0636-39	
4	1	*T. townsendii*	L. Dent.	2.73	2.03	1.71	1.62	2.28	1.31	1.73	2.32	1.39	11.30	2.42	2006	0636-39	
4	1	*T. townsendii*	R. Dent.	2.37	1.74	1.41	1.46	2.02	1.08	1.52	2.08	1.15			2006	0636-40	
4	1	*T. townsendii*	R. Dent.	2.63	2.07	1.69	1.54	2.19	1.21	1.73	2.19	1.33			2006	0636-45	
4	1	*T. townsendii*	R. Dent.	2.55	1.87	1.56	1.52	2.05	1.14				9.05	2.20	2010	1042-32	
4	1	*T. townsendii*	L. Dent.	2.94	2.02	1.78									2010	1024-16	
4	1	*T. townsendii*	L/R Dent.	broken			1.41	2.32	1.19						1991		24778
4	1	*T. townsendii*	L. Dent.				1.36	1.75	0.87						1990	9018	31421
4	1	*T. townsendii*	L. Dent.	2.43	2.02	1.59	1.21	2.11	0.94						1994		35057
4	1	*T. townsendii*	R. Dent.	2.47	1.71		1.52	1.99	1.11	1.61	2.12	1.23	8.44	2.13		992	60546
4	1	*T. townsendii*	L. Dent.	2.63	1.92		1.63	2.22	1.29	1.69	2.34	1.37	9.08	2.21		996	60704
4	1	*T. townsendii*	L. Dent.	3.35	1.76	1.77	1.48	2.37	1.25	1.62	2.32	1.32	8.08	2.09		JLG 6/1980	15460
4	1	*T. townsendii*	L. Dent.	2.48	1.87	1.54	1.60	2.18	1.25	1.68	2.19	1.30	8.86	2.18	1977	7760	
4	1	*T. townsendii*	L. Dent.	2.34	1.81	1.44	1.41	2.09	1.08				8.53			969	42888
4	1	*T. townsendii*	R. Dent.	2.25	1.51	1.22	1.41	1.86	0.97	1.54	1.97	1.11				969	42887
4	1	*T. townsendii*	L. Dent.	2.44	1.87	1.52	1.33	2.18	1.06	1.54	2.16	1.20	7.56	2.02			15434
4	1	*T. townsendii*	L. Dent.	2.83	2.04	1.75	1.65	2.36	1.36								15448
4	1	*T. townsendii*	L. Dent.	2.59	2.00	1.64	1.43	1.96	1.03				8.39	2.13		7763	15456
4	1	*T. townsendii*	R. Dent.	2.60	2.18	1.73	1.41	1.94	1.01	1.64	2.09	1.23	9.19	2.22			15998
4	1	*T. townsendii*	R. Dent.				1.50	2.25	1.21								16040
4	1	*T. townsendii*	L. Dent.	2.74	1.92	1.66	1.50	2.17	1.18	1.60	2.13	1.23					16042
4	1	*T. townsendii*	L. Dent.	2.63	1.91	1.61	1.53	2.30	1.26				8.99	2.20	1991	9145-6	24200
4	1	*T. townsendii*	L. Dent.	2.27	1.83	1.42	1.36	2.28	1.13	1.54	2.18	1.21	8.11	2.09	1991		24267
4	1	*T. townsendii*	R. Dent.	2.67	2.13	1.74	1.62	2.21	1.28	1.70	2.38	1.40	8.29	2.12			35771
4	1	*T. townsendii*	R. Dent.	2.64	1.97	1.65	1.53	2.35	1.28	1.60	2.59	1.42			1993		35973
4	1	*T. townsendii*	R. Dent.	2.35	1.83	1.46	1.46	2.11	1.13				6.81	1.92	1993		36004
4	1	*T. townsendii*	R. Dent.	2.67	2.07	1.71	1.50	2.29	1.23				8.28	2.11	1993		45371
4	1	*T. townsendii*	R. Dent.	2.30	1.77	1.40	1.35	1.96	0.97	1.41	1.92	1.00	7.40	2.00			51348
4	1	*T. townsendii*	R. Dent.	2.66	1.85	1.59	1.58	2.07	1.19	1.59	2.18	1.24	9.07	2.20			60703
4	1	*T. townsendii*	L. Dent.	2.36	1.82	1.46	1.45	2.14	1.13	1.58	2.10	1.20			2000		64932
4	1	*T. townsendii*	L. Dent.	2.44	1.73	1.44	1.46	1.77	0.95	1.41	1.84	0.95	6.58	1.88	2000	2000-58	66432

(table continued on next page)

Table 1 (continued). Specimens of *Thomomys* from Fossil Lake, Oregon, and associated data.

Strat. Unit	p4 Morphology	Taxon	Description	P4L	P4W	Ln P4 Area	M1L	M1W	Ln M1 Area	M2L	M2W	Ln M2 Area	JD	LnJD	Year	Field Number (JEM)	Specimen Number
4	1	*T. townsendii*	L. Dent.	2.46	1.73	1.45	1.28	1.68	0.77	1.67	2.25	1.32	7.13	1.96	2001		69613
4	1	*T. townsendii*	R. Dent.	2.30	1.76	1.40	1.53	2.07	1.15	1.56	2.30	1.28	7.37	2.00	2001		69613
4	1	*T. townsendii*	R. Dent.	2.54	1.76	1.50									2001		69807
4	1	*T. townsendii*	L. Dent.	2.49	2.01	1.61	1.40	2.27	1.16		2.22		8.77	2.17	2006	0636-44	
4	1	*T. townsendii*	R. Dent.	2.87	2.01	1.75	1.68	2.23	1.32	1.74	2.21	1.35	10.59	2.36	2006	0636-48	
4	1	*T. townsendii*	R. Dent.	2.87	2.08	1.79	1.68	1.68	1.03	2.22	1.71	1.33	10.86	2.39	2006	0640-20	
4	1	*T. townsendii*	L. Dent.	2.26	1.78	1.40	1.47	2.05	1.11	1.58	2.05	1.17	8.66	2.16	2007	778	
4	1	*T. townsendii*	R. Dent.				1.40	2.06	1.06	1.55	2.08	1.17	8.73	2.17	2007	778	
4	1	*T. townsendii*	R. Dent.	2.47	1.88	1.54	1.63	2.28	1.31	1.63	2.30	1.32	10.16	2.32	2011	1107-13	
4	1	*T. townsendii*	R. Dent.	2.48	1.73	1.46	1.59	2.04	1.18	1.57	2.16	1.22	8.07	2.09	2011	1114-1	
4	1	*T. townsendii*	L. Dent.	2.49	1.71	1.45	1.43	1.97	1.03	1.50	2.03	1.11	7.95	2.07	2011	1114-1	
4	1	*T. townsendii*	R. Dent.	2.32	1.83	1.45	1.53	2.10	1.17						2010	1024-17	
4	1	*T. townsendii*	L. Dent.	2.89	2.21	1.86	1.75	2.27	1.38	1.76	2.29	1.40			2010	1049-14	
4	1	*T. townsendii*	L. Dent.	2.76	1.89	1.65									2010	1067-26	
4	1	*T. townsendii*	L. Dent.				1.50	2.15	1.17						1991		24780
4	1	*T. townsendii*	L. Dent.				1.76	2.19	1.35						1995		36608
4	1	*T. townsendii*	R. Dent.														16028
4	1	*T. townsendii*	L. Dent.	2.51	1.92	1.57	1.52	2.17	1.19				9.47	2.25	1992	9218	25489
4	1	*T. townsendii*	R. Dent.	2.49	1.94	1.58	1.45	2.27	1.19				9.11	2.21	1992	9218	25489
4	1	*T. townsendii*	R. Dent.	2.77	1.90	1.66									1992	9218	25498
4	1	*T. townsendii*	R. Dent.	2.50	1.81	1.51	1.49	2.17	1.18	1.63	2.21	1.28	8.76			973	47290
4	1	*T. townsendii*	L. Dent.	2.78	1.96	1.70											16029
4	1	*T. townsendii*	L. Dent.	2.70	1.91	1.64	1.46	2.22	1.18	1.69	2.23	1.33					16040
4	1	*T. townsendii*	L. Dent.	2.47	2.02	1.61	1.58	2.38	1.33	1.69	2.41	1.41	9.42	2.24	1990	9011	18868
4	1	*T. townsendii*	R. Dent.	2.40	1.86	1.50	1.49	2.12	1.15	1.63	2.20	1.28	10.53	2.35	1993	9319-3	31438
4	1	*T. townsendii*	L. Dent.	2.69	1.95	1.66									2006	0636-41	
4	1	*T. townsendii*	L. Dent.				1.24	1.98	0.90	1.59	1.94	1.13			2006	0636-42	
4	1	*T. townsendii*	R. Dent.	2.43	1.88	1.52	1.47	1.94	1.05	1.57	1.99	1.14			2006	0636-42	
4	1	*T. townsendii*	R. Dent.				1.44	2.17	1.14	1.54	2.21	1.23			2006	0636-44	
4	1	*T. townsendii*	R. Dent.	2.62	2.06	1.69	1.53	2.27	1.24	1.68	2.33	1.36	11.21	2.42	2006	0640-19	
4	1	*T. townsendii*	R. Dent.	2.51	1.74	1.47	1.52	2.18	1.20	1.66	2.30	1.34	9.32	2.23	2011	1137-16	
4	1	*T. townsendii*	R. Dent.	2.49	1.93	1.57	1.46	2.20	1.17	1.55	2.20	1.23	9.93	2.30	2011	1153-21	
4	1	*T. townsendii*	R. Dent.	2.83	2.10	1.78	1.53	2.31	1.26	1.84	2.31	1.45	11.96	2.48	2011	1176-08	
4	1	*T. townsendii*	L. Dent.				1.48	2.11		1.62	2.22	1.28	8.92	2.19	2010	1024-15	
4	1	*T. townsendii*	R. Dent.	2.54	1.81	1.53									2010	1042-33	
4	1	*T. townsendii*	L. Dent.	2.82	2.04	1.75	1.75	2.20	1.35	1.89	2.31	1.47			1994		34355
4	1	*T. townsendii*	L. Dent.	2.84	2.05	1.76	1.58	2.30	1.29	1.68	2.42	1.40	10.68	2.37	1977	7762	
4	1	*T. townsendii*	R. Dent.	2.40	1.71	1.41	1.46	2.02	1.08	1.52	2.26	1.23	8.93			973	47291
4	2	*T. talpoides*	L. Dent.	2.56	1.93	1.60	1.38	2.19	1.11	1.68	2.22	1.32	7.10	1.96			56527
4	2	*T. talpoides*	R. Dent.	2.49	1.96	1.59	1.48	2.24	1.20	1.62	2.38	1.35	7.11	1.96			56527
4	unk	*Thomomys* sp.	L. Dent.				1.53	2.11	1.17						1990		18871
4	unk	*Thomomys* sp.	R. Dent.				1.38	1.95	0.99						1990		19148
4	unk	*Thomomys* sp.	R. Dent.				1.25	2.27	1.04						1990		19337
4	unk	*Thomomys* sp.	L. Dent.				1.47	2.18	1.16						1991		24198
4	unk	*Thomomys* sp.	L. Dent.				1.67	2.35	1.37						1991		24199
4	unk	*Thomomys* sp.	L. Dent.	1.75	1.48	0.95	1.21	2.07	0.92	1.43	1.96	1.03			1991		24506
4	unk	*Thomomys* sp.	L. Dent.				1.58	2.23	1.26						1991		24513
4	unk	*Thomomys* sp.	L. Dent.	2.11	1.66	1.25	1.35	2.01	1.00	1.40	2.14	1.10			1991		24514
4	unk	*Thomomys* sp.	L. Dent.				1.71	2.20	1.32						1991		24778
4	unk	*Thomomys* sp.	L. Dent.				1.48	2.19	1.18						1992		25489
4	unk	*Thomomys* sp.	R. Dent.				1.56	2.24	1.25						1992		25489
4	unk	*Thomomys* sp.	R. Dent.	2.86	1.92	1.70									1992		25498
4	unk	*Thomomys* sp.	R. Dent.				1.37	2.09	1.05						1992		25499
4	unk	*Thomomys* sp.	R. Dent.	2.79	1.99	1.71	1.57	2.33	1.30	1.63	2.42	1.37			1992		25526
4	unk	*Thomomys* sp.	L. Dent.	2.64	2.03	1.68	1.69	2.41	1.40	1.76	2.48	1.47			1992		25526
4	unk	*Thomomys* sp.	L. Dent.				1.32	2.12	1.03						1992		26434
4	unk	*Thomomys* sp.	L. Dent.				1.29	2.01	0.95						1992		26435
4	unk	*Thomomys* sp.	R. Dent.				1.30	2.12	1.01						1992		26436
4	unk	*Thomomys* sp.	R. Dent.				1.43	1.97	1.04						1992		26588
4	unk	*Thomomys* sp.	L. Dent.				1.49	2.19	1.18						1990		31422
4	unk	*Thomomys* sp.	R. Dent.	2.20	1.79	1.37	1.51	2.11	1.16	1.49	2.13	1.15	10.12	2.31	1993	9319-3	31437
4	unk	*Thomomys* sp.	R. Dent.	2.29	1.51	1.24	1.44	1.88	1.00	1.43	1.92	1.01			1994		34082
4	unk	*Thomomys* sp.	R. Dent.	2.48	1.74	1.46	1.42	2.17	1.13	1.59	2.14	1.22			1994		34709
4	unk	*Thomomys* sp.	L. Dent.	2.54	1.87	1.56	1.39	2.19	1.11						1994		34710
4	unk	*Thomomys* sp.	L. Dent.	2.64	1.80	1.56	1.67	2.08	1.25	1.59	2.17	1.24			1994		34711
4	unk	*Thomomys* sp.	R. Dent.	2.14	1.79	1.34									1994		34712
4	unk	*Thomomys* sp.	R. Dent.	2.57	1.78	1.52	1.62	2.02	1.19	1.69	2.31	1.36			1994		35070
4	unk	*Thomomys* sp.	L. Dent.	2.47	1.79	1.49	1.46	2.25	1.19	1.68	2.31	1.36			1994		35070

(table continued on next page)

Table 1 (continued). Specimens of *Thomomys* from Fossil Lake, Oregon, and associated data.

Strat. Unit	p4 Morphology	Taxon	Description	P4L	P4W	Ln P4 Area	M1L	M1W	Ln M1 Area	M2L	M2W	Ln M2 Area	JD	LnJD	Year	Field Number (JEM)	Specimen Number
4	unk	*Thomomys* sp.	(2) M1				1.31	1.91	0.92						1993		36003
4	unk	*Thomomys* sp.	R. Dent.				1.38	2.04	1.04						1993		36003
4	unk	*Thomomys* sp.	R. Dent.				1.23	1.91	0.85						1995		36609
4	unk	*Thomomys* sp.	L. Dent.	1.90	1.48	1.03	1.31	1.97	0.95						1995		36648
4	unk	*Thomomys* sp.	R. Dent.				1.61	1.98	1.16						1995		36696
4	unk	*Thomomys* sp.	L. Dent.	2.85	1.92	1.70	1.63	2.20	1.28	1.72	2.22	1.34			1995		37204
4	unk	*Thomomys* sp.	L. Dent.				1.42	2.12	1.10						1995		39034
4	unk	*Thomomys* sp.	R. Dent.	2.02	1.56	1.15	1.27	1.95	0.91	1.33	1.90	0.93			1993		51312
4	unk	*Thomomys* sp.	R. Dent.				1.49	2.07	1.13	1.58	2.18	1.24					60705
4	unk	*Thomomys* sp.	R. Dent.										6.90	1.93	2001		69599
4	unk	*Thomomys* sp.	R. Dent.				1.50	2.30	1.24	1.64	2.40	1.37	9.26	2.23	1977	7762	
4	unk	*Thomomys* sp.	L. Dent.				1.50	2.15	1.17	1.66	2.15	1.27			1977	7762	
4	unk	*Thomomys* sp.	R. Dent.				1.39	2.16	1.10	1.69	2.34	1.37	7.74	2.05			15460
4	unk	*Thomomys* sp.	L. Dent.				1.57	2.28	1.27	1.69	2.43	1.41				973	47292
4	unk	*Thomomys* sp.	R. Dent.				1.45	2.35	1.23	1.70	2.25	1.34			2013		ULGM V2576
5	1	*T. townsendii*	R. Dent.	2.39	1.84	1.48	1.44	2.15	1.13				7.37	2.00	2000		66248
5	1	*T. townsendii*	L. Dent.	2.31	1.77	1.40	1.38	2.08	1.06	1.42	2.13	1.10	9.24	2.22	2010	1046-81	
5	1	*T. townsendii*	L. Dent.	2.53	1.88	1.56	1.48	2.19	1.17	1.60	2.32	1.31	10.60	2.36	2010	1026-75	
5	1	*T. townsendii*	L. Dent.	2.41	1.85	1.50	1.47	2.19	1.17	1.67	2.21	1.31			2010	1029-11	
5	1	*T. townsendii*	R. Dent.	2.74	1.92	1.66	1.50	2.25	1.22	1.59	2.30	1.30	8.09	2.09			62039
5	1	*T. townsendii*	R. Dent.	2.51	1.74	1.47	1.34	2.06	1.02				7.44	2.01	2001		68694
5	1	*T. townsendii*	L. Dent.	2.42	1.66	1.39	1.40	1.96	1.01	1.43	1.95	1.03	6.58	1.88	2001		68695
5	1	*T. townsendii*	L. Dent.	2.75	2.02	1.72	1.56	2.21	1.24	1.71	2.31	1.37			2003	0352-129	77785
5	1	*T. townsendii*	R. Dent.	2.99	2.09	1.84	1.67	2.42	1.39	1.78	2.34	1.43			2003	0352-130	77786
5	1	*T. townsendii*	R. Dent.	2.53	2.03	1.64	1.69	2.42	1.41	1.85	2.68	1.60	10.70	2.37	2005	0517-093	
5	1	*T. townsendii*	L. Dent.	2.74	1.98	1.69	1.54	2.23	1.24	1.65	2.16	1.27	11.35	2.43	2011	1134-11	
5	1	*T. townsendii*	L. Dent.	2.37	1.83	1.47	1.40	2.18	1.11	1.48	2.22	1.19			2011	1155-47	
5	1	*T. townsendii*	R. Dent.	2.57	1.90	1.59	1.51	2.21	1.20	1.54	2.27	1.25			2011	1155-48	
5	1	*T. townsendii*	R. Dent.	2.93	1.94	1.74									2010	1026-76	
5	1	*T. townsendii*	R. Dent.	2.76	2.05	1.73	1.59	2.28	1.29								51788
5	1	*T. townsendii*	R. Dent.	2.59	1.92	1.61	1.41	2.00	1.04	1.58	2.08	1.19			2010	1046-82	
5	1	*T. townsendii*	R. Dent.	2.45	1.89	1.53	1.57	2.18	1.23	1.58	2.16	1.23			2000		65186
5	1	*T. townsendii*	L. Dent.	2.46	1.96	1.57	1.44	2.34	1.22	1.65	2.31	1.34	10.70	2.37	2007	0753-63	
5	1	*T. townsendii*	L. Dent.	2.60	1.75	1.52	1.50	2.35	1.26	1.48	2.35	1.25	6.10	1.81	2013		ULGM V2139
5	1	*T. townsendii*	L. Dent.	2.50	1.95	1.58	1.52	2.34	1.27				7.20	1.97	2013		ULGM V2140
5	2	*T. talpoides*	L. Dent.	2.08	1.43	1.09							9.26	2.23	1991	9123-51	23716
5	2	*T. talpoides*	L. Dent.				1.08	1.53		1.17	1.53	0.58	5.24	1.66	2010	1026-78	
5	unk	*Thomomys* sp.	L. Dent.	2.57	1.91	1.59									1992		27241
5	unk	*Thomomys* sp.	L. Dent.				1.58	2.30	1.29	1.74	2.39	1.43			1992		28040
5	unk	*Thomomys* sp.	R. Dent.	2.63	1.82	1.57	1.65	2.13	1.26	1.68	2.30	1.35			1994		34420
5	unk	*Thomomys* sp.	R. Dent.	2.87	2.07	1.78	1.84	2.32	1.45	1.82	2.45	1.49			1994		34552
5	unk	*Thomomys* sp.	L. Dent.												1996	9625	43868
5	unk	*Thomomys* sp.	L. Dent.				1.27	2.03	0.95	1.48	2.08	1.12	6.88	1.93			62041
5	unk	*Thomomys* sp.	R. Dent.										7.50	2.01			62042
5	unk	*Thomomys* sp.	R. Dent.										8.36	2.12			62043
5	unk	*Thomomys* sp.	L. Dent.				1.43	2.04	1.07	1.30	2.16	1.03	5.82	1.76	2002		70342
5	unk	*Thomomys* sp.	L. Dent.					2.50			2.50		7.30	1.99	2013		ULGM V2141
6	2	*T. talpoides*	Dentary	1.81	1.41	0.94	1.59	1.99	1.15	1.16	1.76	0.71					Recent
6	2	*T. talpoides*	Dentary	2.00	1.37	1.01	1.46	2.16	1.15	1.44	1.91	1.01					Recent
6	2	*T. talpoides*	Dentary	1.94	1.47	1.05	1.32	1.88	0.91	1.29	1.75	0.81					Recent
6	2	*T. talpoides*	Dentary	1.92	1.50	1.06	1.41	2.02	1.05	1.48	2.00	1.09					Recent
6	2	*T. talpoides*	Dentary	1.99	1.49	1.09	1.47	1.78	0.96	1.60	1.87	1.10					Recent
6	2	*T. talpoides*	Dentary	2.00	1.57	1.14	1.46	1.97	1.06	1.60	2.24	1.28					Recent
6	2	*T. talpoides*	Dentary	2.12	1.64	1.25	1.56	1.90	1.09	1.50	1.92	1.06					Recent
6	2	*T. talpoides*	Dentary	2.44	1.72	1.43	1.41	2.22	1.14	1.61	2.14	1.24					Recent
6	2	*T. talpoides*	Dentary	2.07	1.56	1.17	1.42	2.22	1.15	1.69	2.23	1.33					Recent
6	2	*T. talpoides*	Dentary	2.16	1.62	1.25	1.47	2.15	1.15	1.74	2.36	1.41					Recent
6	2	*T. talpoides*	Dentary	1.82	1.46	0.98	1.55	1.70	0.97								Recent
6	2	*T. talpoides*	Dentary	2.12	1.58	1.21	1.59	2.05	1.18								Recent
6	2	*T. talpoides*	Dentary	2.07	1.58	1.18	1.58	2.04	1.17								Recent
6	unk	*T. talpoides*	Dentary				1.44	2.13	1.12								Recent
6	unk	*T. talpoides*	Dentary				1.21	1.73	0.74	1.35	1.75	0.86					Recent

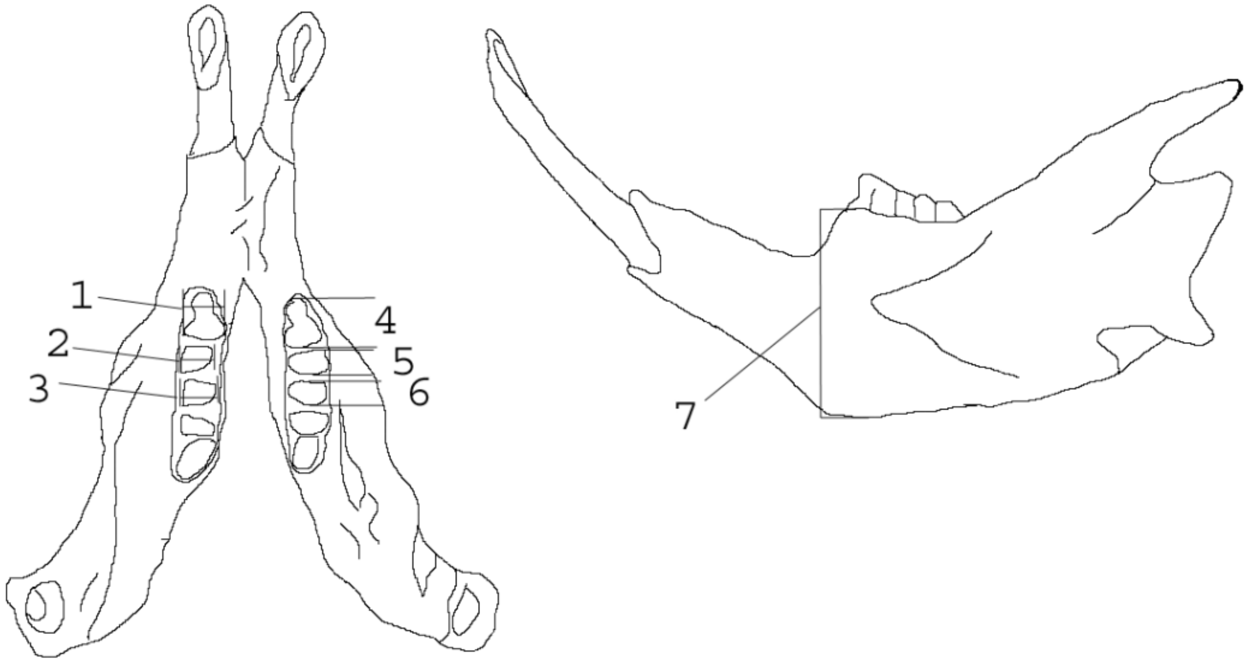


Figure 4. Diagrammatic representation of the lower jaw of *Thomomys* and measurements recorded (see Table 1). (1) p4W, maximum width of p4; (2) m1W, maximum width of m1; (3) m2W, maximum width of m2; (4) p4L, maximum length of p4; (5) m1L, maximum length of m1; (6) m2L, maximum length of m2; (7) JD, jaw depth.

RESULTS

Initial field observations of fossil specimens of *Thomomys* from the Fossil Lake area indicate two morphotypes, suggesting the possibility of two species of *Thomomys*. Specimens appear to have a high degree of variation in size. Some are relatively small and gracile, whereas others are very large and robust. Differences appear to be independent of ontogenetic stage, but may be the related to sexual dimorphism. Recent *Thomomys talpoides* from the same study area exhibit a lingual scallop on the anterior loph of the p4 (Figure 4) and are overall small and gracile; only a relatively small percentage of the fossil specimens from Fossil Lake exhibit this morphology of p4. The purpose of this work is to use dental dimensions and morphology of p4 to determine whether multiple populations existed and whether these populations represent separate species. In addition, attempts are made to determine the taxonomic identities of the fossil forms.

From Fossil Lake, 234 *Thomomys* specimens (fossil and Recent) were analyzed. Specimens were collected with precise stratigraphic data from five stratigraphic units. Although Units 1–5 are represented, most specimens were obtained from Unit 4 (white claystone layer). The sample sizes for each unit are: Unit 1, n = 4; Unit 2, n = 46; Unit 3, n = 9; Unit 4, n = 128; Unit 5, n = 32; Recent, n = 15.

p4

During investigation of the p4 of *Thomomys* specimens from Fossil Lake, two distinct p4 morphologies (morphotypes) were observed (Figure 5). In morphotype 1 the anterior loph of the p4 is slightly diamond-shaped or round in occlusal aspect. In morphotype 2, the anterior loph of the p4 is distinctly scalloped in occlusal aspect as characteristic in living *T. talpoides* (Chomko, 1990; Verts and Carraway, 1999) (Figure 3). Furthermore, several additional specimens exhibit p4 anterior loph morphologies in which the scallop is poorly developed (incipient) and appears to be "pre-scallop" in form. Specimens with incipient scallop morphology (Type 2) occur at the lowest stratigraphic levels (1 and 2). For statistical analyses, these specimens have been included with morphotype 2 (scalloped).

Type 1 (diamond/round) p4 morphology is dominant in all stratigraphic levels, except the Unit 1 and Recent samples. Type 2 morphotype (scallop) is absent from Unit 3 and is rare from Units 1, 4, and 5 (Figure 6). Unit 2 contains populations of both Type 1 and 2 morphologies, but the Type 1 morphotype is more common. All Recent specimens from Fossil Lake exhibit Type 2 (scallop) p4 morphology. Interestingly, modern Type 2 specimens are smaller than nearly all Type 2 specimens in lower stratigraphic units (Figure 7).

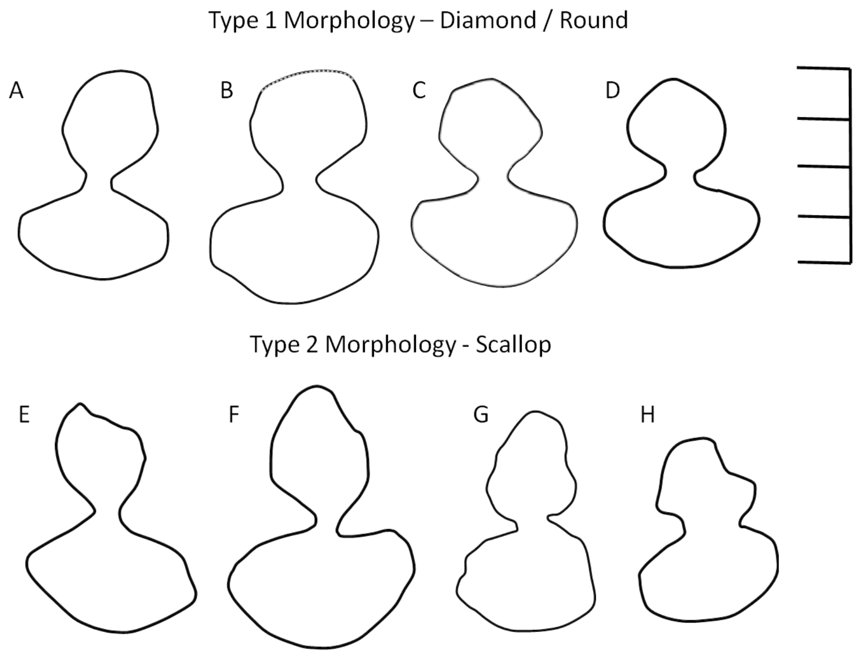


Figure 5. Lower p4 of *Thomomys* specimens from Fossil Lake, Oregon. Top row: Type 1 (diamond/round) morphology. (A) SDSM 18990, stratigraphic Unit 2; (B) SDMS 19241, stratigraphic Unit 3 (dotted line indicates inferred margin); (C) SDSM 36760, stratigraphic Unit 4; (D) SDSM 24200, stratigraphic Unit 4. Bottom row: Type 2 (scallop) morphology. (E) UWBM 56218 (incipient), stratigraphic Unit 1; (F) JEM 0518 (incipient), stratigraphic Unit 1; (G) JEM 0860 (incipient), stratigraphic Unit 2; (H) Recent *T. talpoides*. Scale bar in millimeters.

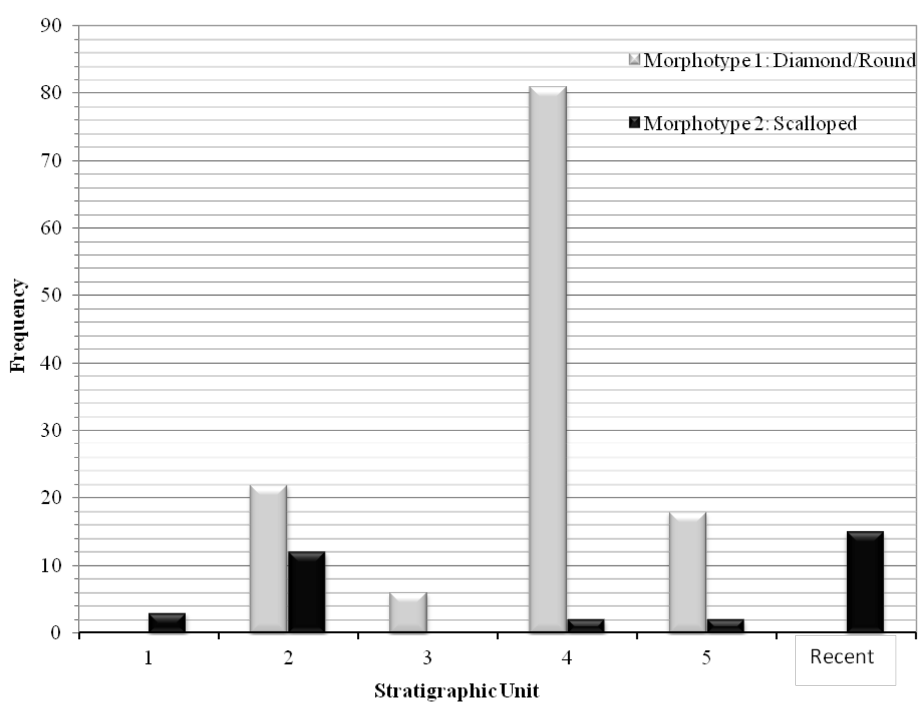


Figure 6. Histogram showing the stratigraphic distribution of lower p4 morphotypes of *Thomomys* specimens from Fossil Lake, Oregon.

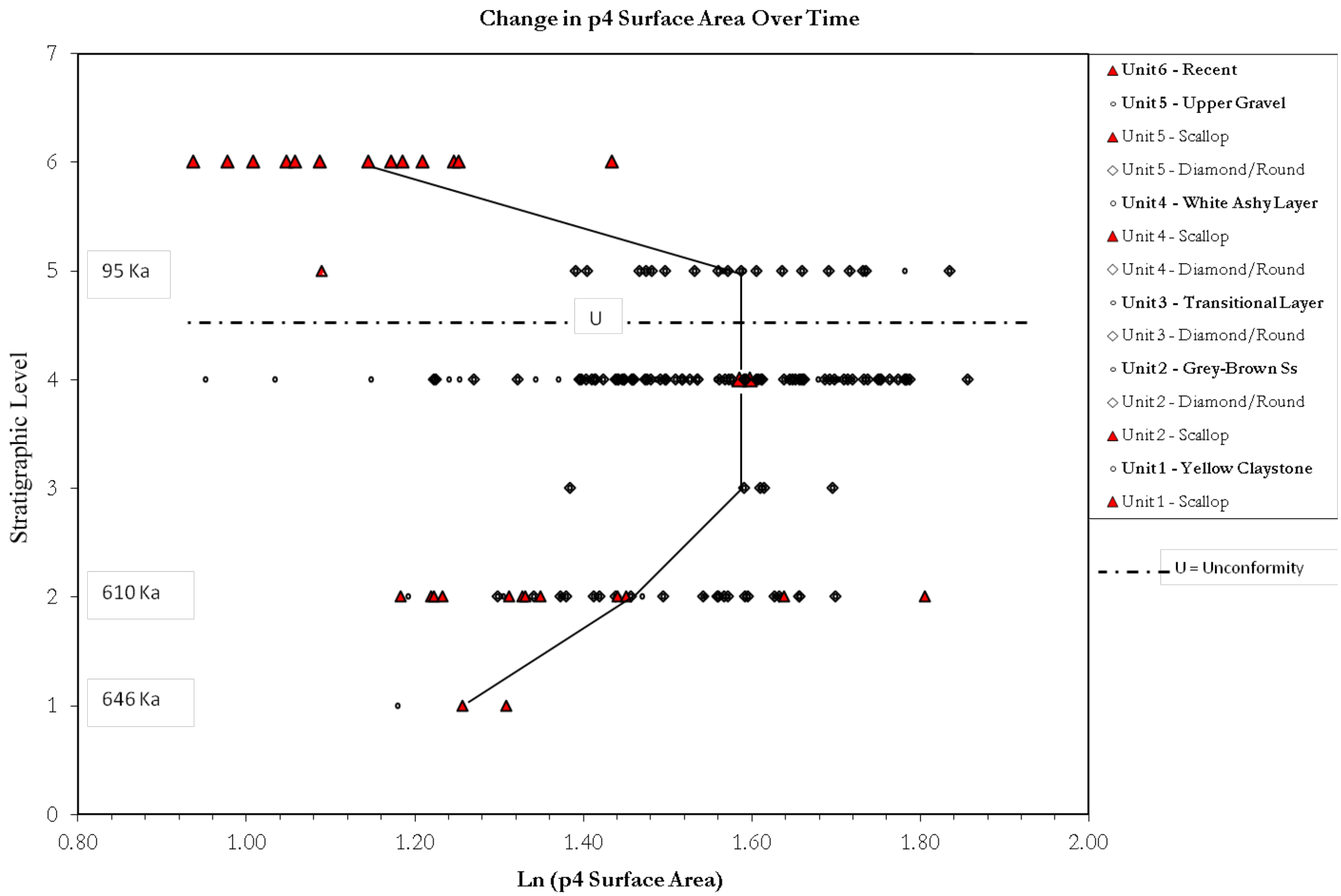


Figure 7. Natural log (ln) of the p4 surface area (length × width) for *Thomomys* specimens from each stratigraphic level of occurrence at Fossil Lake, Oregon. Line shows trend in size between units. Geochronology from associated tephras is shown (Martin and others, 2005).

Comparisons between stratigraphic units using ANOVA (single-factor) statistical analysis indicate that the modern sample is significantly different than all other samples, except stratigraphic Unit 1 (Table 2). Interestingly, all specimens from Recent and Unit 1 exhibit Type 2 (scallop) morphology. In addition, ANOVA tests indicate that significant difference exists between Unit 1 and Units 2–5. Unit 2 is significantly different than all other stratigraphic units, and Units 3–5 are not significantly different.

Figure 8 and Table 2 demonstrate the high variability in *Thomomys* at Fossil Lake. Type 2 morphology specimens do not exhibit any discernible trends and show greater range in size/shape. Recent specimens (all Type 2) are much less variable in size/shape. If assessed as a population over time, the majority of Type 1 specimens group well together in a cluster of larger size and variable shape, when compared to Type 2 specimens. Unit 4 Type 1 specimens also exhibit greater range in size/shape. In part, higher variability may be the result of a larger sample size. Nevertheless, the variability remains greater than other units. Unit 2 Type 1 specimens exhibit rather restricted size variability, but a high degree shape variability. Unit 1 has too small of a sample size to draw conclusions regarding variability. However, Unit 1 Type 2 specimens fall reasonably within the size/shape variability of Recent specimens and are within the size/shape variability of Unit 4 Type 1 specimens.

Maximum body size in pocket gophers is directly related to environmental conditions such as climate, in that a more arid climate produces less abundant and less nutritious food sources that in turn reduce body size (Dalquest and Scheffer, 1944; Davis, 1939; Rogers, 1991; Smith and Patton, 1984; Verts and Carraway, 1999). Finally, trends in size (as indicated by tooth size) can be observed over time (Figure 7). Size appears to increase from Unit 1 through Unit 3, then decrease dramatically in Recent specimens and is statistically significant according to analyses (Table 2).

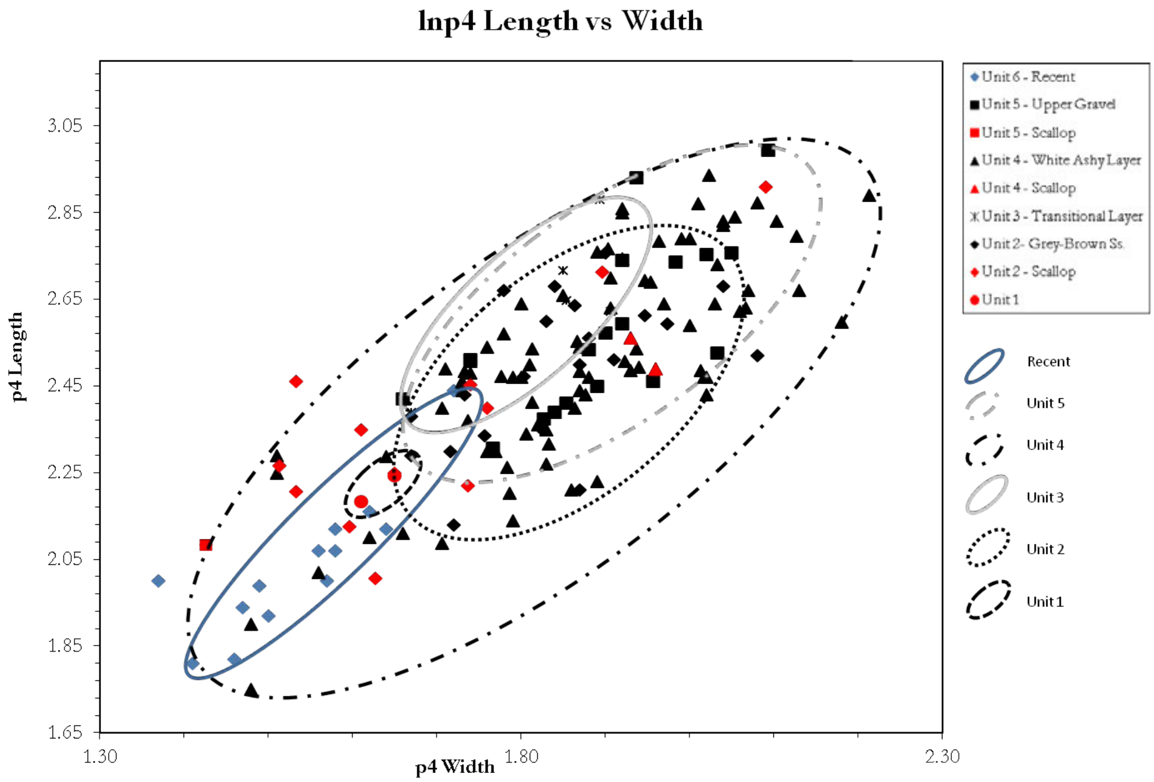


Figure 8. Natural log (ln) of the p4 (length × width) for *Thomomys* specimens from Fossil Lake, Oregon. Elongation of the fields from bottom-left to top-right indicates size variability. Broadening in the fields from top-left to bottom-right indicates shape variability.

Table 2. Analysis of variance (ANOVA, single-factor) comparison for *Thomomys* specimens between stratigraphic units at Fossil Lake, Oregon. P-values (significance) presented in matrix. Values below 0.05 indicate significant difference. Shaded cells are not significantly different according to P-value.

ANOVA comparison of natural log (ln) of the p4 (length × width)							
Stratigraphic Unit	**Recent**	**5**	**4**	**3**	**2**	**1**	**Variance**
Recent	—						0.0184
5	<0.001	—					0.0259
4	<0.001	0.440	—				0.0302
3	<0.001	0.939	0.635	—			0.0135
2	<0.001	0.007	0.009	0.095	—		0.0246
1	0.188	0.002	0.005	0.004	0.031	—	0.004
ANOVA comparison of natural log (ln) of the m1 surface area (length × width)							
Stratigraphic Unit	**Recent**	**5**	**4**	**3**	**2**	**1**	**Variance**
Recent	—						0.0153
5	0.007	—					0.0179
4	0.053	0.103	—				0.0182
3	0.141	0.615	0.747	—			0.0062
2	0.371	0.037	0.236	0.457	—		0.0225
1	0.303	0.018	0.057	0.016	0.186	—	0.0026

M1, M2, and Jaw Depth

The lower m1 of *Thomomys* specimens from Fossil Lake, although typical of *Thomomys* species, did not provide significant insight regarding the populations when analyzed for each stratigraphic level (Figures 9–11). As was seen with p4, m1, m2, and jaw depth of *Thomomys* from Fossil Lake exhibit a large range in size. Significant overlap occurs between Type 1 and Type 2 specimens within and across stratigraphic levels, and no significant trends were observed.

PATTERNS OF CHANGE

As stated before, pocket gopher growth is strongly controlled by environmental conditions. Because a strong correlation exists between gopher size and the environment, shifts in a population (as seen in Figure 7) may be used to interpret changes in the environment. Additionally, because all of the specimens are from the same area and variables such as elevation and soil type are relatively constant, environmental shifts may be attributed solely to climatic shifts.

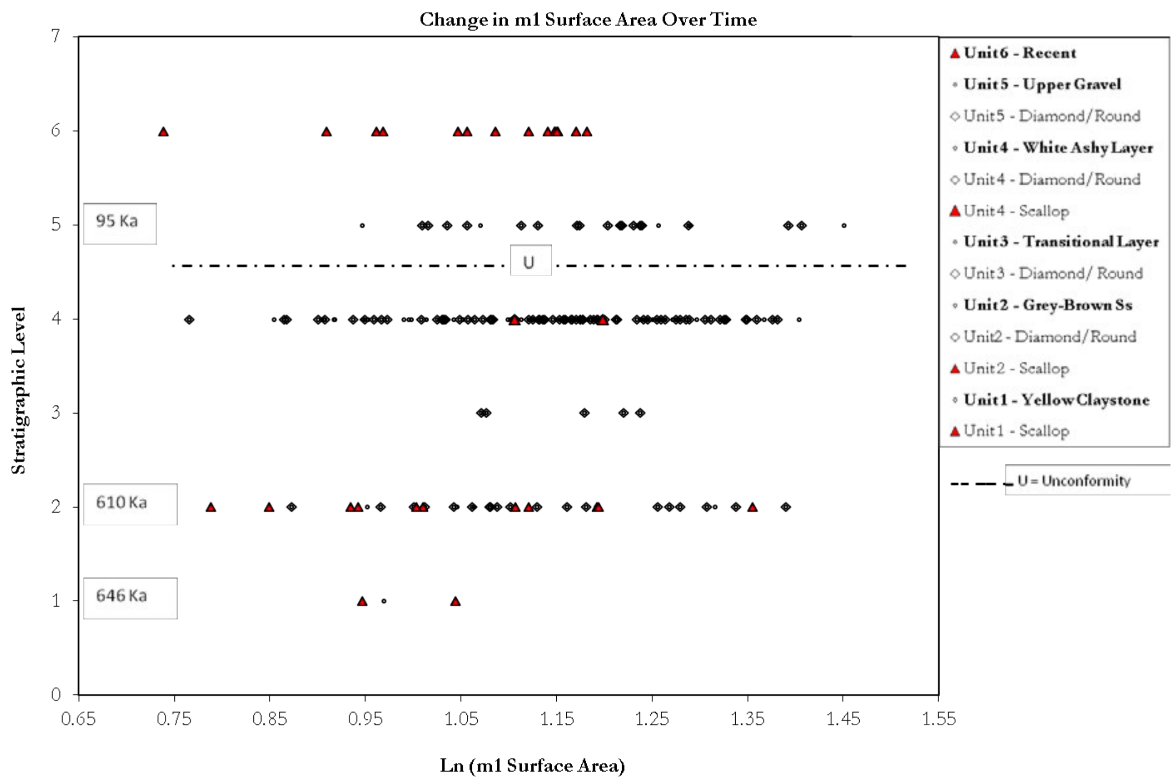


Figure 9. Natural log (ln) of the m1 surface area (length × width) for *Thomomys* specimens from each stratigraphic level of occurrence at Fossil Lake, Oregon. Geochronology from associated tephras is also shown (Martin and others, 2005).

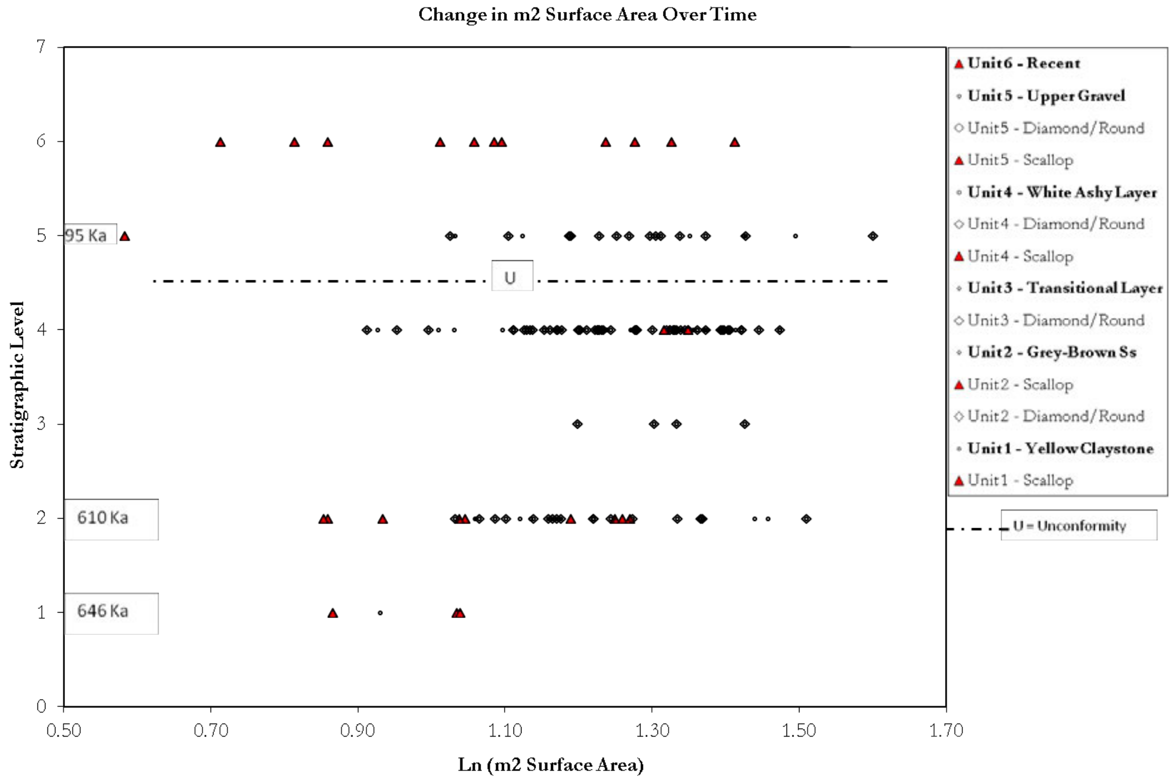


Figure 10. Natural log (ln) of the m2 surface area (length × width) for *Thomomys* specimens from each stratigraphic level of occurrence at Fossil Lake, Oregon. Geochronology from associated tephras is also shown (Martin and others, 2005).

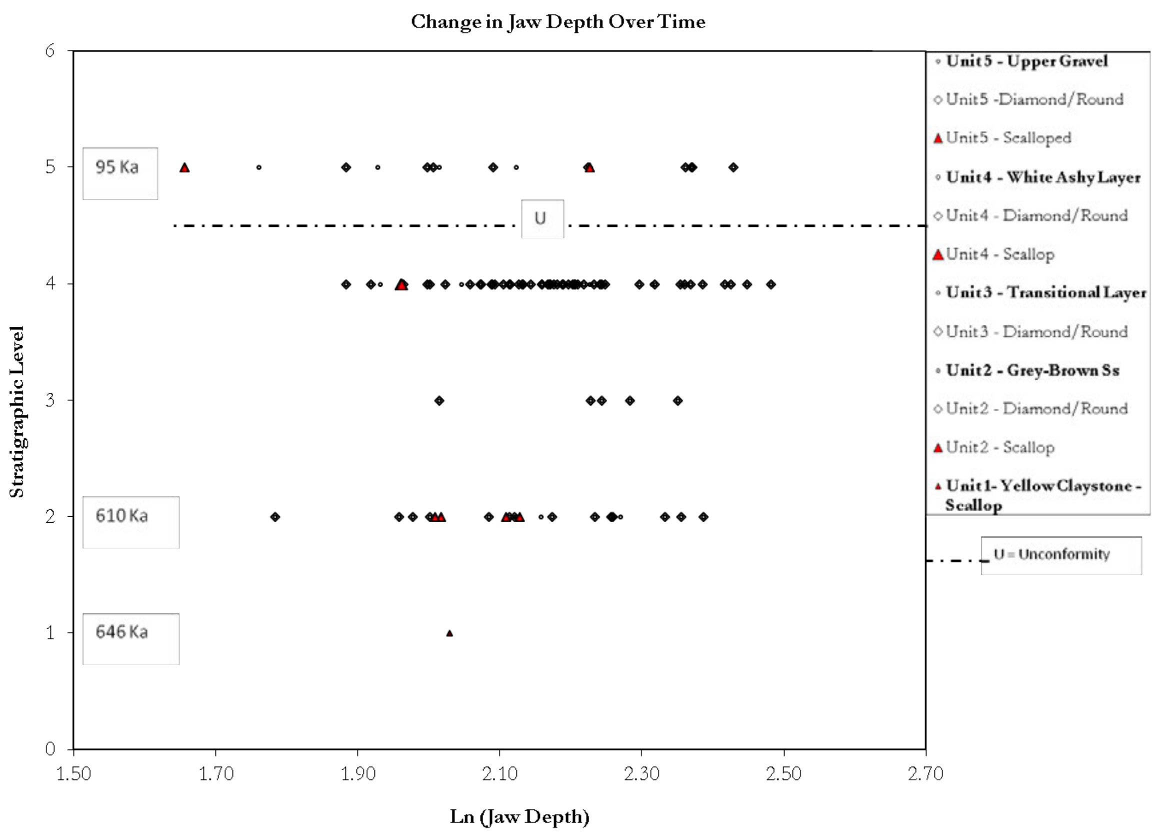


Figure 11. Natural log (ln) of the jaw depth for *Thomomys* specimens from each stratigraphic level of occurrence at Fossil Lake, Oregon. Geochronology from associated tephras is also shown (Martin and others, 2005).

Recent work by Martin and others (2005) that used rare earth elements (REE) as an indicator of paleoenvironmental conditions suggests that climatic conditions at Fossil Lake have been shifting through time toward more arid (hot/cold) or xeric conditions. Indeed, modern conditions at Fossil Lake are those of a temperate desert. Changes in the maximum body size of gophers is directly related to environmental conditions such as climate, in that a more arid climate produces less abundant and less nutritious food sources (Dalquest and Scheffer, 1944; Davis, 1939; Rogers, 1991; Smith and Patton, 1984; Verts and Carraway, 1999). Therefore, an overall trend toward smaller body size (as indicated by tooth size) should be observable in the gophers at Fossil Lake, if Martin and others (2005) are correct. Indeed, a trend toward smaller size is observed in Figure 7 and supports interpretations by Martin and others (2005).

DISCUSSION

Gingerich (1974) discussed size variability in the teeth of living mammals, indicating that teeth at the ends of the tooth rows are more variable than those in the middle. Teeth that form early in ontogeny before significant change takes place in the hormonal balance of males and females should be the least variable. The m1 is the first tooth to form in the permanent dentition and therefore should be the least affected by sexual dimorphism and the least variable tooth in the dentition (Gingerich, 1974). Additionally, teeth bounded by other teeth (m1 is bounded by p4 and m2) are restricted during growth by the bounding tooth row. As a result, bounded teeth cannot change without the entire tooth row changing, further contributing to the conservative nature of m1. With large sample sizes, analyses of variation of middle versus end teeth in the tooth row may determine the existence of bimodal populations and, ultimately, detect the presence of sympatric species. Bloch and Gingerich (1998) used this technique to differentiate a new species of carpolestid plesiadapiform from Eocene deposits. However, the lower dentition of *Thomomys* from Fossil Lake is highly variable in size and shape. Figures 7–9 clearly show that the highly variable m1 is at least as variable in size and shape as p4 (Table 2). A major source of variation in the occlusal shape and pattern is change that occurs through ontogeny and sexual dimorphism of rodents. Additionally, variants in the cusp patterns of one species may approach the patterns found in a different species (Chomko, 1990).

Davis (1938) found size in *Thomomys* to be directly correlated with soil conditions and inversely correlated with elevation. Body size and sexual dimorphism in pocket gophers are strongly influenced by the nutritional value of their food, whereas variation in shape is more likely to reflect genetic changes (Rogers, 1991). Therefore, size is affected by nutritional quality, soil depth and friability, elevation, and genetic variability (Hadly, 1997). If maximum body size in gophers is directly related to environmental conditions such as climate, substrate, elevation, and food source as Davis (1939) and Vaughan (1967) suggested, then trends in p4 size can be used to interpret past conditions. Size appears to increase from Unit 1 through Unit 5, then decrease dramatically in Recent specimens. Given that the substrate and elevation have changed very little over the duration of the Pleistocene, trends in p4 size can be attributed to climate changes in that a more arid recent climate produced less abundant and less nutritious food sources. This interpretation is further supported by climatic interpretations at Fossil Lake made by Martin and others (2005).

All Recent *T. talpoides* specimens from Fossil Lake, Oregon, possess a lingual scallop on the anterior loph of the p4 (Type 2 morphology); a feature not shared with the majority of fossil specimens. Type 2 morphology among *Thomomys* species is an exclusive *T. talpoides* trait (Chomko, 1990; Verts and Carraway, 1999). However, a small number of the fossil specimens do possess a lingual scallop on the anterior loph of p4 and are therefore attributed to *T. talpoides*. The appearance of *T. talpoides* occurs at the lowest stratigraphic level at Fossil Lake. However, the development of the lingual scallop is generally poor in specimens lowest in the section (1 and 2); becoming comparable to modern *T. talpoides* in the upper units (4 and 5). Therefore, the specimens of Fossil Lake show the evolutionary development of the lingual scallop on the anterior loph of p4 in *T. talpoides*.

Kurten and Anderson (1980) reported the oldest record for *T. talpoides* as Sangamonian (Rancholabrean, late Pleistocene; 125–75 ka [McKay and Berg, 2008]) from near Medicine Hat, Alberta. Unit 1 of Fossil Lake is Irvingtonian (early Pleistocene) based on faunal correlations and is approximately 646 ka based on correlation with a dated tephra layer (Rye Patch Dam tephra) at the top of Unit 1 (Martin and others, 2005). Therefore, the occurrence of *T. talpoides* in Unit 1 of the Fossil Lake sequence represents the first appearance of *T. talpoides* at Fossil Lake, Oregon, and the first unequivocally documented occurrence of *T. talpoides* in the Irvingtonian of Oregon.

The remaining fossil specimens of *Thomomys* sp. from Fossil Lake with Type 1 p4 morphology are attributed to *T. townsendii* based on additional cranial material associated with several specimens. The range of *T. townsendii* is restricted to deep, moist, alkaline, lacustrine sediments associated with Pleistocene lake bottoms throughout the region and does not extend into dry sagebrush country (Davis, 1937; Rogers, 1991; Verts and Carraway, 2003). Elftman (1931), Allison (1966), and Rogers (1991) all attributed fossil material collected from Fossil Lake to *T. townsendii*. The partial crania collected from Fossil Lake (units 2, 3, and 4), exhibit the following characteristics which align them with *T. townsendii* (Verts and Carraway, 2003):

- sphenoidal fissure open; narrow slit-like
- infraorbital foramen even with anterior portion of Incisive foramen
- m1 produces protuberance into orbit

CONCLUSIONS

- All Recent *Thomomys* specimens from Fossil Lake possess a lingual scallop on the anterior loph of the p4, a morphology consistent with *Thomomys talpoides*. Indeed, Verts and Carroway (1999, 2003) reviewed both *Thomomys talpoides* and *T. townsendii*, stating that *T. talpoides* currently occurs in the Fossil Lake area, and *T. townsendii* occurs just to the east in Malheur and Harney counties, Oregon.
- Most fossil gopher specimens at Fossil Lake possess Type 1 p4 morphology and are attributed to *T. townsendii* on the basis of additional cranial material (partial skulls) associated with several specimens. Elftman (1931), Allison (1966), and Rogers (1991) all attributed fossil material collected from Fossil Lake to *T. townsendii*.
- *Thomomys townsendii* is the predominant species of fossil gopher at Fossil Lake, Oregon.
- This study shows that a small number of fossil specimens possess the lingual scallop on the anterior loph of the p4. These specimens are assigned to *T. talpoides* on the basis of p4 morphology, which compares favorably with modern *T. talpoides*.
  - The first appearance of the lingual scallop in fossil specimens is low in the section (Unit 1).
  - Development of the lingual scallop is generally poor in specimens lowest in the section (1 and 2) becoming comparable to modern *T. talpoides* in the upper units (4 and 5).
- The occurrence of *T. talpoides* in Unit 1 of the Fossil Lake sequence represents the first appearance of *T. talpoides* at Fossil Lake, Oregon, and the first unequivocally documented occurrence of *T. talpoides* in the Irvingtonian (early Pleistocene) of Oregon. This occurrence is approximately 646 ka based on correlation with a dated tephra layer (Rye Patch Dam tephra).
- Finally, the appearance, disappearance, and reappearance of *T. talpoides* at Fossil Lake in various strata (over time) seem to follow climatic conditions over the duration of deposition of Fossil Lake sediments. During times of high aridity (xeric conditions), *T. talpoides* appears in the fossil populations. As the climate becomes wetter (more mesic), conditions apparently become unfavorable for *T. talpoides*, or *T. talpoides* is out-competed by *T. townsendii*, and *T. talpoides* disappears from the fossil populations. *T. talpoides* reappears higher in section (later) when climatic conditions in the Fossil Lake area again become more xeric and conditions become unfavorable for *T. townsendii*. Indeed, the modern population is composed of *T. talpoides* and conditions are quite xeric.

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DOGAMI NEWS HIGHLIGHTS

— contributed by Ali Ryan, DOGAMI Public Information Officer

DOGAMI adds lidar data

DOGAMI and the Oregon Lidar Consortium have since 2003 been working toward an ultimate goal of providing high-quality lidar high-quality lidar coverage for the entire state. The state's lidar collection expanded significantly in 2013, as data for Klamath County, the Rogue Basin area, and portions of Union, Umatilla, Baker, and Wallowa counties were added.

Current lidar coverage for the state of Oregon. The online DOGAMI Lidar Data Viewer provides a way to explore the data and print specific extents

Statewide landslide database expands

More than 46,000 known landslide locations are now included in the Statewide Landslide Database for Oregon (SLIDO). In June 2014, DOGAMI released SLIDO version 3.1, which compiles all landslides identified on published maps.

More landslides have been mapped in the past five years than in the previous 60, said Bill Burns, DOGAMI engineering geologist. Use of lidar has dramatically expanded landslide knowledge. Nearly 20,000 landslides mapped since 2009 have come from geologic and landslide mapping that used lidar. "When we've finished mapping with lidar for the whole state, we'll have a very different — and much better — understanding of landslides," Burns said.

Landslide maps help communities plan, prepare

Landslide maps and risk analyses can help communities plan and prepare for landslides, whether the slides triggered by heavy rain, development, or natural hazards like earthquakes. DOGAMI's landslide work in 2013 includes studies for Astoria, Clackamas County, Vernonia, and Harbor Hills in Curry County.

"With base maps derived from lidar technology and a landslide mapping protocol developed here at DOGAMI, we are able to quickly and precisely map landslides, even in heavily forested areas," says Bill Burns, DOGAMI engineering geologist.

Maps and assessments can be used by city planning and emergency management officials to develop and refine emergency response plans, public outreach activities, the selection of appropriate safe-haven sites, and mitigation of critical facilities and infrastructure. For example, by combining the hazard maps with transportation data, potential road blockages can be identified and alternative routes located.

Tsunami mapping completed for Oregon coast

With the completion of tsunami inundation maps and evacuation brochures for the entire Oregon coast, the state is now more tsunami-ready.

DOGAMI developed a total of 131 new maps, including 89 new tsunami inundation maps (TIMS) and 42 new evacuation maps. The work was completed under a federal grant to create a new generation of tsunami maps. Creation of the maps was accompanied by intensive outreach and education efforts to help vulnerable coastal communities prepare.

Inundation scenario data were released in October 2013, followed by release of model output files of maximum tsunami wave elevations, velocities, flow depths at specific locations over the course of the entire simulation, and other data in December 2014. Release of the data used in map creation supports the work of scientists, engineers, and emergency managers concerned with tsunami hazard mitigation.

Stunning poster reveals Willamette River

Lidar technology has dramatically improved geologic mapping — and it can also be used to create striking artistic images. The Willamette River historical channels poster by Daniel E. Coe was created using a lidar-derived digital elevation model, with the dynamic movements of the river beautifully detailed in shades of blue. The poster has sold 650 copies since its release in April 2013, and was featured in the North American Cartographic Information Society's first Atlas of Design.

Tsunami preparedness outreach events along the Oregon coast help residents understand the science behind tsunamis and introduce participants to new tsunami inundation maps for their communities.

Mapping Oregon's earthquake risks

Oregon continues to increase its knowledge of the threat posed by great earthquakes from the Cascadia Subduction Zone. In June 2013, DOGAMI released the earthquake impact data for the Oregon Resilience Plan, which estimates the state's vulnerabilities to earthquake-related hazards and recommends policies to increase resilience.

The foundation for the Oregon Resilience Plan was laid in 2011, when the Oregon Legislative Assembly House of Representatives passed House Resolution 3, acknowledging the threat posed to Oregon by great earthquakes from the Cascadia Subduction Zone. The Resolution also charged the Oregon State Seismic Safety Policy Advisory Commission (OSSPAC) to prepare a resilience plan for Oregon that would estimate current vulnerabilities to earthquake-related hazards. The plan was delivered to the Oregon Legislative Assembly on February 28, 2013.

The impact data include definitive digital versions of the data and maps used by the Oregon Resilience Plan workgroups and OSSPAC as well as a description of the data sources and methods used to prepare the scenario maps.

Explore geology with paper, mobile recreation maps

DOGAMI now offers its popular geologic guide and recreation map series two ways — with water-resistant paper maps or as mobile maps through the PDF Maps app for Apple and Android. The series puts the geology of Oregon's volcanic peaks into the hands of hikers, along with must-have trail details like distance, elevation, and amenities.

"Hiking is an amazing way to experience Oregon's geology," says Daniel E. Coe, the maps' cartographer. "With mobile maps, you can capture that experience, from exactly where you took that lava flow photo to marking the best viewpoints."

The map series features new-generation maps created with lidar technology for the ultimate in outdoor exploration. The Mount Hood and Three Sisters maps include distances and elevations for more than 70 trails, including the Pacific Crest National Scenic Trail. The Crater Lake map shows distances and elevations for all park trails, including the Pacific Crest National Scenic Trail. Maps also include features like highways, service roads, wilderness areas, and recreation spots.

The mobile maps get a boost with features like tracking location on the map, measuring distance, adding geotagged photos and dropping placemarks at points of interest. Maps are also downloaded to the mobile device, making multiple maps easy to access.

Unravelling the geology of Oregon's southern coast

New maps by DOGAMI reveal more than ever before about the complex and intriguing geology of the southern Oregon coast. Mapping includes the stretch of coast between Crook Point and Bandon in Curry County.

"We understand this area's complex geology much better now, thanks to lidar mapping technology," says Jason McClaughry, DOGAMI geologist. "The new map will allow us and partner agencies to focus on areas that need more study for hazards, mineral resources, and water issues."

The work increases understanding of geologic conditions that control the distribution, quantity, and quality of groundwater resources, the distribution of terrain susceptible to landslides and seismic hazards, and areas of potential aggregate and other mineral resources. Mapping also highlights potential areas for future study.

DOGAMI geologists mapped the complex geology in the Cape Blanco area as part of the 2013 STATEMAP project. To date, the coastal portions of seven quadrangles in Curry and Coos counties have been mapped in this multi-year project.

This geologic mapping is part of a multi-year project, begun in 2012, to map the Oregon coast from the California border north to Coos Bay. The effort is supported in part by the U.S. Geological Survey (USGS) STATEMAP component of the National Cooperative Geologic Mapping Program.

Adding to understanding of coastal erosion

Oregon's coast has undergone major coastal erosion over the past century — and DOGAMI geologists are continuing to advance understanding of how the coast has and will continue to change.

A new assessment of shoreline change along the Pacific Northwest coast from the late 1800s to present also found that while the majority of beaches are stable or slightly accreting (adding sand), many Oregon beaches have experienced an increase in erosion hazards in recent decades.

DOGAMI's Jonathan Allan, a co-author on the report, pointed to Oregon "hot spots" where erosion has been significant and bluffs have failed.

"The beaches at Gleneden Beach and Neskowin, for example, contain coarse sand, which contrasts with the finer-grained beaches along much of the Oregon coast," Allan says. "These beaches tend to be steeper and reflective of breaking wave energy, which makes them more dynamic. When coupled with the development of rip current embayments, it often results in hotspot erosion, which leads to the development of hazards when homes are placed too close to the beach."

Allan and his colleagues in DOGAMI's Newport Coastal Field Office contribute to the NANOOS Beach and Shoreline Changes System to document the spatial variability of beach change, including seasonal, multi-year and long-term changes. In 2013, the program was expanded to include new observation sites at Gold Beach, Rogue Shores, Nesika Beach, and Netarts.

DOGAMI in 2013 also took an in-depth look at erosion risks in Waldport, where local landowners have been concerned about ongoing erosion to beaches and dunes alongside Old Town Waldport during the past decade. The erosion has been caused by winter storms and possible changes in the locations of intertidal channels, which are especially abundant near the study area.

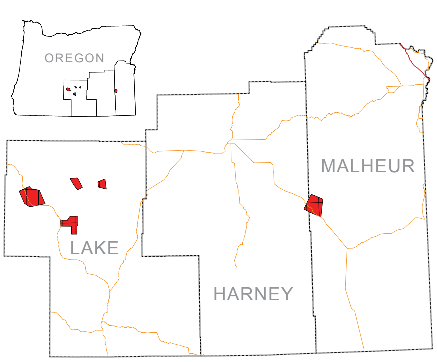
"We looked at historical shorelines and found that they're changing for several reasons," says report co-author Laura Stimely. "It's because of locally generated wind waves, changes in the amount of sand in the intertidal zone, variations in water levels, and more."

Oregon's geothermal hotspots

A new version of DOGAMI's geothermal information web map was released in February 2013. The Geothermal Information Layer for Oregon, release 2 (GTILO-2) web map displays wells that were drilled for geothermal exploration, water wells with elevated temperatures, and warm and hot springs.

"With the web map, both the public and industry users can get a good overview of what's out there," says Clark Niewendorp, DOGAMI geothermal resources evaluator. "Nine different base maps allow for different ways to see how our geothermal resources are distributed in the state."

DOGAMI also released Digital Data Series TIRILO-1, Thermal Infrared Information Layer for Oregon (preview). Remotely sensed thermal infrared (TIR) imagery has been used in geothermal exploration for decades both as airborne and satellite-based imagery to look for warm ground and thermal features. The goal with this project was to test whether TIR data with very high spatial resolution and accuracy could be used to identify warm springs or ground that was only slightly warmer than background levels.



Extents of newly acquired remotely sensed thermal infrared (TIR) data in Oregon.

"This experiment in the collection of high resolution, high accuracy TIR and lidar imagery for geothermal exploration has been generally successful," says Ian Madin, DOGAMI Chief Scientist. The combined imagery was able to locate several low-thermal-amplitude, long-spatial-wavelength anomalies, several of which were almost certainly associated with true ground temperature differences — though not necessarily geothermal.

DOGAMI excellence recognized

DOGAMI garnered several awards in recent years. The Western States Seismic Policy Council (WSSPC) selected the Oregon Seismic Rehabilitation Grant Program for a 2013 Overall Award in Excellence for Mitigation Efforts. The program, managed by the Oregon Military Department/Oregon Emergency Management, with the use of rapid visual screening (RVS) assessments conducted by DOGAMI, provides grant funds to eligible applicants. In addition, WSSPC selected DOGAMI *Special Paper 43, Simulating tsunami inundation at Bandon, Coos County, Oregon, using hypothetical Cascadia and Alaska earthquake scenarios* (preview) for 2013 Award in Excellence for Use of New Technology. The award recognizes the state-of-the-art method for modeling tsunami hazards and developing tsunami hazard maps described in the publication, and its positive impact in improving mapping for coastal communities in the Pacific Northwest.

The Association of Earth Science Editors selected Oregon: A Geologic History as the 2010 winner of the AESE Outstanding Publications Award in the maps category. The map is based on data found in the Oregon Geologic Data Compilation (OGDC) data set.

Kate Mickelson, dinosaur discoverer!

DOGAMI geologist Kate Mickelson was 12 years old when she came across bone fragments in the Kimmeridgian-age Tidwell Member of the Morrison Formation in Utah while out on a dig with her mom, paleontologist Debra Mickelson, and coworker Stephen Czerkas. Bones in the chalkstone included a cranium fragment, vertebrae, ribs, and limb sections. Czerkas and Mickelson named the holotype *Utahdactylus kateae* in honor of the state and Kate. The fossils are housed in the Dinosaur Museum, Blanding, Utah. While there is some debate about whether the fragments are those of a pterosaur, there is no doubt who first detected this enduring diapsid!

(photo credit: K. Mickelson)

IN MEMORIAM

Lenin "Len" Ramp, 2012 (retired from DOGAMI 1989 after 37 years of service)

Ronald P. Geitgey, DOGAMI Mineral Resources Geologist, 2012 (retired from DOGAMI in 2004 after 19 years of service)

George W. Walker, 2014 (USGS geologist, 1:500,000-scale geologic map of Oregon with N. S. MacLeod, 1991)

MINED LAND RECLAMATION AWARDS

Each year the Mineral Land Regulation and Reclamation Program (MLRR) of the Oregon Department of Geology and Mineral Industries (DOGAMI), with an independent panel of experts, selects specific mine sites and operators to receive industry and Department recognition for outstanding reclamation, mine operation and salmon protection (The Oregon Plan Award). Awards, based on an operator's performance during the previous calendar year, are presented at the Oregon Concrete and Aggregate Producers Association (OCAPA) annual conference.

"The companies and government organizations we recognize with these annual awards show an understanding of the issues involved in surface mining today and are committed to protecting the undisturbed environment around the site. They also are committed to the communities where they are based," notes Gary Lynch, Assistant Director of Regulation for DOGAMI's MLRR office. "The recognition is also an encouragement to others in the mining industry to follow suit."

The Mineral Lands Regulation and Reclamation program at DOGAMI serves as a steward of the state's mineral production, while encouraging best practices within the industry. MLRR's goals include environmental protection, conservation, effective site reclamation, and operational guidance regarding other engineering and technical issues. Contact Gary Lynch, Assistant Director of Regulation, MLRR, at (541) 967-2053 for more information.

For more information on the Mined Land Reclamation Awards program, contact Ben Mundie, telephone (541) 967-2149; email: ben.a.mundie@mlrr.oregongeology.com

AWARD CATEGORIES

Outstanding Operator recognizes operations that have done an excellent job of mine development and/or operations on a daily basis. Outstanding operations can lead to outstanding reclamation.

The outstanding operator is divided into two divisions to recognize that large corporations have a distinct advantage over small, family-owned operations in their ability to bring resources to a mine operation. The ***Outstanding Operator*** award (called "Outstanding Small Operator" prior to 2011) recognizes those operators who go beyond the regulations to protect surface and ground water, to protect adjacent natural resources, to protect adjacent properties, and utilizing innovative techniques to minimize adverse impacts. The ***Outstanding Operator, Division II*** award recognizes that "mom-and-pop" operations as well as large corporations do business in Oregon. The Outstanding Operator award recognizes those operators who go beyond the regulations to protect surface and ground water, to protect adjacent natural resources, to protect adjacent properties, and utilizing innovative techniques to minimize adverse impacts.

Outstanding Reclamation recognizes operations that go beyond the minimum requirements of the DOGAMI-approved reclamation plan or that use innovative techniques to achieve successful reclamation.

Outstanding Reclamation / Agency recognizes reclamation by a government agency, which is considered separately from private operations because of the resources available to agencies not available to private operators.

Reclamationist of the Year recognizes an individual from the mining industry who provides an enthusiasm and creativity in producing outstanding operation and reclamation.

Oregon Plan recognizes operations that voluntarily create or enhance salmonid habitat within a permitted area or that volunteer equipment for offsite use.

Special Recognition, a new award category for 2012, recognizes an individual from the mining industry who has shown outstanding commitment and dedication in promoting the aggregate industry on the ground, politically, or through public education.

Good Neighbor recognizes those operators who go the extra mile to insure adjacent landowners are not adversely impacted by the mine operation or who look for ways to benefit the community at large.

Voluntary Reclamation recognizes those operators who perform reclamation on lands that have been deemed exempt from the reclamation law.

Outstanding Planning recognizes operators who, prior to receiving a permit, submit detailed innovative or creative integrated reclamation plans.

(continued on page 41)

Latham Excavation of Bend won the 2013 Good Neighbor Award for efforts to reduce off-site impacts and complete interim and concurrent reclamation on previously disturbed areas at the Johnson Road Pit in Deschutes County.

(MLR Awards, continued)

MLR 2009-2013 AWARD WINNERS

2009 (GIVEN IN 2010)

- **Outstanding Reclamation**
  River Rock Properties - Jackson County
- **Outstanding Operator**
  Jim Turin & Sons, Inc. - Clackamas County
- **Outstanding Planning**
  Whetstone Engineering - Jackson County

2010 (GIVEN IN 2011)

- **Outstanding Operator**
  Wilsonville Concrete Products Commercial Redi-Mix, Brown's Island, Marion County
- **Outstanding Small Operator**
  Rock Solid Sand & Gravel, Aylett Pit, Morrow County
- **Outstanding Reclamation**
  Myron Corcoran, Defiance 1 & 2, Josephine County
- **Outstanding Voluntary Reclamation**
  Umpqua Sand & Gravel, Umpqua Pit, Douglas County
- **Oregon Plan**
  Carlon's Gravel Pit, Josephine County
- **Good Neighbor**
  JC Compton Company, Salem Industrial Park, Marion County

2011 (GIVEN IN 2012)

- **Outstanding Reclamation**
  Plum Creek Timberlands LP, Siletz George Quarry, Lincoln County
- **Good Neighbor**
  Da-Tone Rock Products, Joe Hall Pit, Curry County
- **Outstanding Operator**
  Cornerstone Industrial Minerals Corporation, Tucker Hill Operation, Lake County
- **Outstanding Operator Division II**
  Kauffman Crushing, Inc., Eckman Creek Quarries, Lincoln County

2012 (GIVEN IN 2013)

- **Outstanding Operator**
  River Bend Sand and Gravel / CPM Development Corporation, Dalton Quarry, Salem
- **Outstanding Reclamation**
  Knife River Materials–Roseburg Operations, Smith Bar, Roseburg
- **Outstanding Reclamation / Agency**
  BLM Roseburg District, Lee Creek, Roseburg
- **Reclamationist of the Year**
  Ed McGill / River Bend Sand and Gravel, Salem
- **Oregon Plan**
  Copeland Sand and Gravel, Inc., Hyde Bar, Grants Pass
- **Special Recognition**
  Robert Hogensen / Green and White Rock Products, Corvallis

2013 (GIVEN IN 2014)

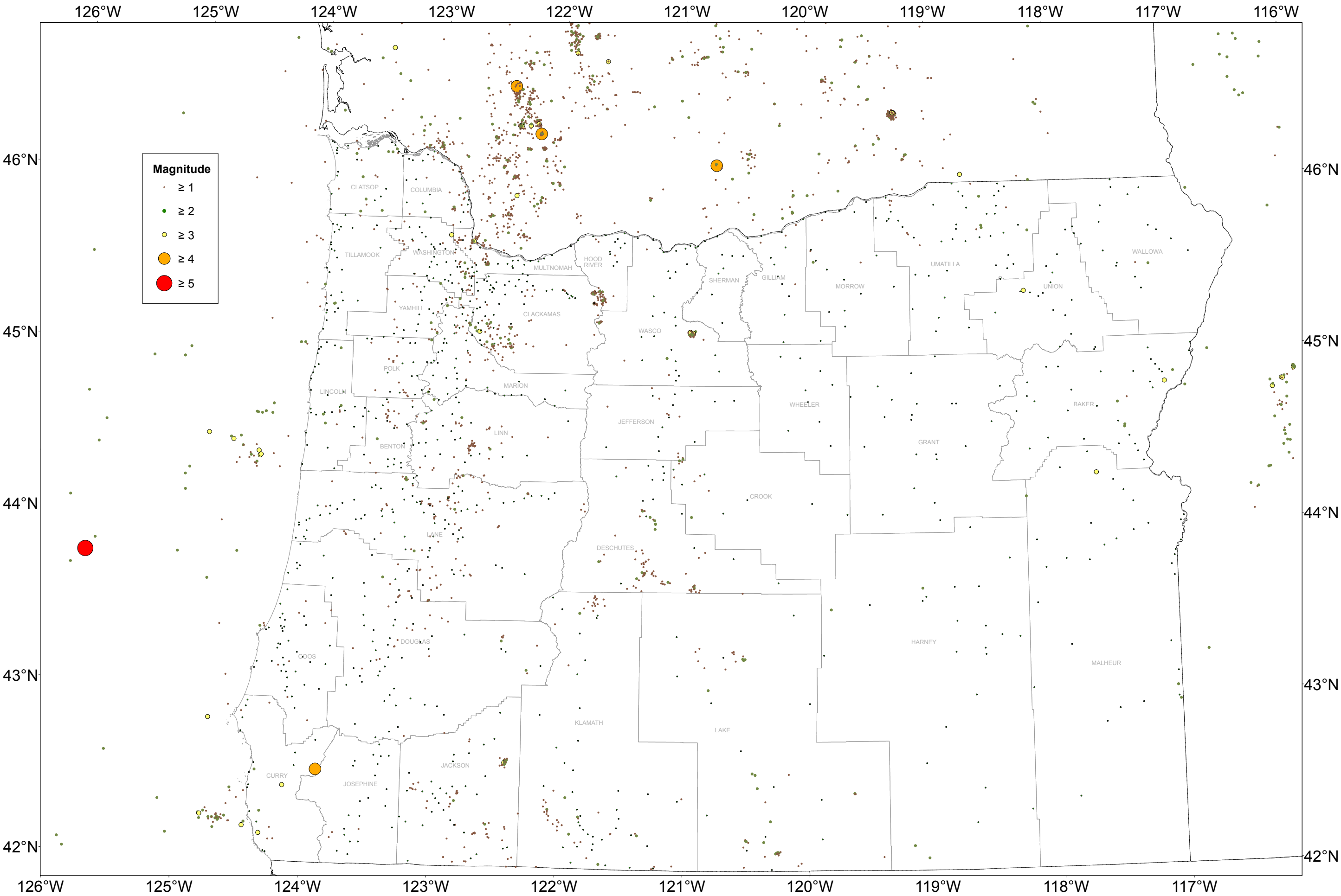
- **Outstanding Reclamation**
  Oregon Resources Corporation, Coos Bay
- **Voluntary Reclamation**
  Triple C Redi-Mix Inc., Baker City
- **Outstanding Operator**
  Southern Oregon Ready-Mix, Central Point
- **Outstanding Operator, Division II**
  Western Mine Development, Baker County
- **Good Neighbor**
  Latham Excavation, Bend
- **Oregon Plan Award**
  Weyerhaeuser Company
- **Special Recognition Award**
  Bob Short, consultant to CalPortland Company

To learn more about the MLR award winners, visit www.oregongeology.org/mlrr/awards.htm

Oregon Resources Corporation of Coos Bay won the 2013 Outstanding Reclamation Award for efforts to minimize the impacts to surrounding landowners and complete successful reclamation at their heavy minerals mining site in Coos County. Top photo: 2012, during operation; bottom photo: 2014, after reclamation.

OREGON SEISMICITY 2009-2013

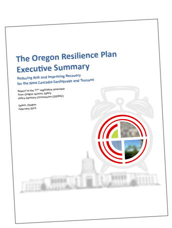
Map data were generated from the ANSS/CNSS Worldwide Earthquake Catalog (http://www.ncedc.org/anss/catalog-search.html).



Magnitude 3+ earthquakes in Oregon 2009–2013. M3 earthquakes are noticeably felt but generally do not cause any damage.

Date & Time	Latitude, °N	Longitude, °W	Depth	Magnitude
2009				
02/26/09 09:52 AM	42.5405	123.8962	38.95	4.1
03/20/09 10:44 PM	45.1352	120.959	14.96	3
04/20/09 09:41 PM	45.1335	120.955	16.33	3.6
07/25/09 08:57 AM	44.289	117.655	7.6	3.8
2010				
01/02/10 04:36 PM	45.137	120.9555	15.47	3.6
05/14/10 07:03 PM	45.3595	121.7522	5.31	3
07/03/10 10:25 PM	42.4402	124.1527	33.13	3.7
07/28/10 04:12 PM	43.756	125.815	10	5.2 (offshore)
07/30/10 01:51 PM	44.809	117.072	16.7	3.3
09/04/10 11:04 AM	42.1967	124.4567	23.64	3.01
12/30/10 09:17 AM	45.1315	120.932	16.69	3.6
2011				
No magnitude 3+ earthquakes in Oregon in 2011.				

Date & Time	Latitude, °N	Longitude, °W	Depth	Magnitude
2012				
02/26/12 10:15 AM	42.8158	124.7627	22.38	3.12
03/12/12 11:37 AM	44.3558	124.4455	26.12	3.12
03/20/12 08:43 AM	44.3613	124.4387	29.55	3.17
03/20/12 09:28 AM	44.3833	124.4563	33.29	3.7
06/05/12 08:35 PM	45.681	122.945	8.8	3
09/08/12 04:57 AM	45.123	122.6897	22.89	3.54
10/16/12 06:22 AM	42.252	124.793	24.6	3
11/19/12 02:15 PM	45.6473	122.7548	20.05	3.17
11/30/12 09:30 PM	42.1557	124.3232	11.8	3.21
2013				
01/25/13 12:41 AM	44.4432	124.6663	34.5	3.03
01/25/13 03:43 AM	44.476	124.867	6.2	3
03/24/13 11:39 AM	42.612	122.4102	15.7	3.1
12/23/13 02:55 AM	45.3602	118.206	8.7	3



How prepared is Oregon for a great subduction zone earthquake? Read the Oregon Resilience Plan (http://www.oregon.gov/OMD/OEM/osspac/docs/Oregon_Resilience_Plan_Final.pdf), which estimates current vulnerabilities and recommends policies to address those vulnerabilities.

DOGAMI PUBLICATIONS 2009–JUNE 2014

Publications are available from Nature of the Northwest, 800 NE Oregon Street, Suite 965, Portland, OR 97232, info@naturenw.org, (961) 673-2331; For online purchasing, go to http://www.naturenw.org, select "Store" and "Maps and Reports" and use the short identification of the publication (e.g., RMS-1) for a search.

Published in 2009

Oregon geologic data compilation, release 5 (statewide) [OGDC-5], compiled by Lina Ma and others, $30.

Fact sheet, FEMA flood map modernization, 2 p., online.

Geologic Map GMS-119, **Geologic map of the Oregon City 7.5' quadrangle, Clackamas County, Oregon**, by Ian P. Madin, 46 p. plus appendices, 1:24,000, 1 pl., $15.

Interpretive Map Series

IMS-26, **Landslide inventory map of the northwest quarter of the Oregon City quadrangle, Clackamas County**, Oregon, by William J. Burns and Ian P. Madin, 1:8,000, 1 pl., $15.

IMS-27, **Landslide inventory map of the southwest quarter of the Beaverton quadrangle, Washington County**, Oregon, by William J. Burns, 1:8,000, 1 pl., $15.

IMS-28, **Oregon: a geologic history**, by Ian P. Madin, 1 plate, 1:633,600, 1 pl., $15.

IMS-29, Landslide inventory maps for the Canby quadrangle, Clackamas, Marion, and Washington Counties, Oregon, William J. Burns, 1:8,000, 4 pl., $15.

Lidar Data Quadrangle (LDQ) project areas*, compiled by John English, single and bundled quadrangle data, $200 per DVD.*

- South Coast release
- Camp Creek release
- Ontario release
- Rogue Valley release

Lidar Imagery Series (LIS), 4 quarter-quadrangle PDFs per quadrangle on each CD, $30 per CD.

- **Forest Grove** 7.5' quadrangle, Washington County, Oregon
- **Laurelwood** 7.5' quadrangle, Washington and Yamhill Counties, Oregon
- **Dundee** 7.5' quadrangle, Washington and Yamhill Counties, Oregon
- **Scholls** 7.5' quadrangle, Washington and Yamhill Counties, Oregon
- **Damascus** 7.5' quadrangle, Clackamas and Multnomah Counties, Oregon
- **Sandy** 7.5' quadrangle, Clackamas and Multnomah Counties, Oregon
- **Newberg** 7.5' quadrangle, Yamhill, Washington, and Marion Counties, Oregon
- **Sherwood** 7.5' quadrangle, Clackamas, Washington, Marion, and Yamhill Counties, Oregon
- **Redland** 7.5' quadrangle, Clackamas County, Oregon
- **Estacada** 7.5' quadrangle, Clackamas County, Oregon

Open-File Reports

O-08-08, Preliminary geologic map of the Mule Hill 7.5' quadrangle, Klamath County, Oregon, and Siskiyou County, California, Stanley A. Mertzman and others, 37 p., 1:24,000, 1 pl., $15.

O-09-01, **Beach and shoreline response to an artificial landslide at Rocky Point, Port Orford, on the southern Oregon coast**, by Jonathan C. Allan and Roger Hart, 54 p., $15.

O-09-02, **Preliminary geologic map of the Robinson Butte 7.5' quadrangle, Jackson County**, Oregon, by Stanley A. Mertzman and others, 40 p., 1:24,000, 1 pl., $15.

O-09-03, **Preliminary digital geologic compilation map of part of northwestern Oregon**, by Lina Ma, Ray E. Wells, Alan R. Niem, Clark A. Niewendorp, and Ian P. Madin, 1:175,000, $15.

O-09-04, Preliminary geologic map of the Brownsville 7.5 quadrangle, Linn County, Oregon, Mark L. Ferns and Jason D. McClaughry, 1:24,000, 1 pl., $15.

O-09-05, Preliminary geologic map of the Lewisburg quadrangle, Benton, Linn, Polk, and Marion counties, Oregon, Thomas J. Wiley, 10 p., 1:24,000, 1 pl., $15.

O-09-06, Coastal erosion hazard zones in southern Clatsop County, Oregon: Seaside to Cape Falcon, Robert C. Witter, Thomas Horning, and Jonathan C. Allan, 39 p., 16 pl., $15.

O-09-07, Lidar mosaic imagery of Mount Hood and surrounding area, Oregon, Ian P. Madin, 1:15,000, 1 pl., $15.

O-08-08, **Preliminary geologic map of the Mule Hill 7.5' quadrangle, Klamath County, Oregon, and Siskiyou County, California**, by Stanley A. Mertzman and others, 37 p., 1:24,000, 1 pl., $15.

O-09-09, Lidar mosaic imagery of the Portland Basin, Oregon and Washington, Ian P. Madin, 1:20,000, 1 pl., $15.

O-09-10, Preliminary geologic map of the Waterloo 7.5' quadrangle, Linn County, Oregon, Mark L. Ferns and Jason D. McClaughry, 1:24,000, 1 pl., $15.

O-09-11, Preliminary geologic map of the Sweet Home 7.5' quadrangle, Linn County, Oregon, Jason D. McClaughry, 1:24,000, 1 pl., $15.

Special Papers

SP-41, **Tsunami hazard assessment of the northern Oregon coast: A multi-deterministic approach tested at Cannon Beach, Clatsop County, Oregon**, by George R. Priest, Chris Goldfinger, Kelin Wang, Robert C. Witter, Yinglong Zhang, and António M. Baptista , 87 p. plus appendix, $15.

SP-42, **Protocol for inventory mapping of landslide deposits from light detection and ranging (Lidar) imagery**, by William J. Burns and Ian P. Madin, 30 p., $15.

Web map, DOGAMI Lidar Viewer, online.

Published in 2010

Bulletin B-107, Geology of the upper Grande Ronde River basin, Union County, Oregon, Mark L. Ferns, Vicki S. McConnell, Ian P. Madin, and Jenda A. Johnson, 65 p., 1:100,000, 1 pl., $30.

Cascadia, Winter 2010, Oregon's earthquake risk and resiliency, 12 p., online.

Digital Data Series

MILO-2, Mineral information layer for Oregon, Release 2 (MILO-2), Clark A. Niewendorp and Ronald P. Geitgey, compilers, $30.

Fact Sheets

TsunamiReady, TsunamiPrepared: Oregon Coast-Wide National Tsunami Hazard Mitigation Program, 2 p., online.

Understanding landslide deposit maps, 2 p., online.

Interpretive Map Series

IMS-30, Landslide inventory maps for the Oregon City quadrangle, Clackamas County, Oregon, William J. Burns and Katherine A. Mickelson, 1:8,000, 4 pl., $15.

IMS-31, Landslide inventory maps for the Astoria quadrangle, Clatsop County, Oregon, William J. Burns and Katherine A. Mickelson, 1:8,000, 4 pl., $15.

IMS-32, Landslide inventory maps for the Lake Oswego quadrangle, Clackamas, Multnomah, and Washington Counties, Oregon, William J. Burns and Serin Duplantis, 1:8,000, 5 pl., $15.

IMS-33, Landslide inventory maps for the Portland quadrangle, Multnomah and Washington Counties, Oregon, William J. Burns and Serin Duplantis, 1:8,000, 5 pl., $15.

(DOGAMI Publications, continued from page 43)

Lidar Data Quadrangle (LDQ) project areas*, compiled by John English, single and bundled quadrangle data, $200 per DVD.*

- Mt. Hood release
- Calapooia release
- Central Willamette release
- McKenzie River release
- North Santiam release
- South Willamette release

Lidar Landscapes Series

Posters, by Daniel E. Coe, 1 p., $10:

- Umpqua Lighthouse State Park
- Big Obsidian Flow and other major flows, Newberry Crater
- Netarts Bay
- Honeyman State Park
- Willamette River Historic Channels
- Mount Hood and the Parkdale Lava Flow

Postcard set (same as poster images), Daniel E. Coe, 16 p., $4. Also available individually.

Open-File Reports

O-10-01, Map of Oregon coast showing topography and bathymetry, Rudie J. Watzig, 1:500,000, 1 pl., $15.

O-10-02, Tsunami evacuation building workshop, September 28-29, 2009, Cannon Beach, Seaside, and Portland, Oregon, Yumei Wang, complier, 35 p. text, plus 200 p. PowerPoint slides, $15.

O-10-03, Digital geologic map of the southern Willamette Valley, Benton, Lane, Linn, Marion, and Polk Counties, Oregon, Jason D. McClaughry, Thomas J. Wiley, Mark L. Ferns, and Ian P. Madin, 116 p., 1:63,360, 1 pl., $30.

O-10-03, Digital geologic map of the southern Willamette Valley, Benton, Lane, Linn, Marion, and Polk Counties, Oregon, Jason D. McClaughry, Thomas J. Wiley, Mark L. Ferns, and Ian P. Madin, 116 p., 1:63,360, 1 pl., $50.

O-10-04, Lidar-based map of Coos Bay and North Bend, Coos County, Oregon, Jed T. Roberts, Rudie J. Watzig, and Sarah A. Robinson, 1 p., 1:8,000, 1 pl., $15.

O-10-04, Lidar-based map of Coos Bay and North Bend, Coos County, Oregon, Jed T. Roberts, Rudie J. Watzig, and Sarah A. Robinson, 1 p., 1:8,000, 1 pl., $50.

One-percent annual flood hazard and exposure risk maps for Coos County, by Mathew A. Tilman; each publication contains 1 pl., $15:

- O-10-05, City of Bandon
- O-10-06, City of Coos Bay
- O-10-07, City of Coquille
- O-10-08, City of Lakeside
- O-10-09, City of Myrtle Point
- O-10-10, City of North Bend
- O-10-11, City of Powers

FEMA flood zone change maps for Coos County, by Mathew A. Tilman; each publication contains 1 pl., $15:

- O-10-12, City of Bandon
- O-10-13, City of Coos Bay
- O-10-14, City of Coquille
- O-10-15, City of Lakeside
- O-10-16, City of Myrtle Point
- O-10-17, City of North Bend
- O-10-18, City of Powers

Published in 2011

Digital Data Series

- OHMI, Oregon Historical Mining Information archive (OHMI), online.
- SLIDO-2.0, Statewide Landslide Information Database for Oregon, release 2.0.

Fact Sheets

- Oregon Lidar Consortium (OLC), 2 p., online.
- New FEMA flood maps for Coos County, Oregon, 4 p., online.

Interpretive Map Series

IMS-34, Landslide inventory maps of the Beaverton quadrangle, Washington County, Oregon, William J. Burns, Ian P. Madin, and Katherine A. Mickelson, 1:8,000, 5 pl., $15.

IMS-35, Landslide inventory maps of the Linnton quadrangle, Multnomah and Washington Counties, Oregon, William J. Burns, Ian P. Madin, Katherine A. Mickelson, and Marina C. Drazba, 1:8,000, 5 pl., $15.

Lidar Data Quadrangle (LDQ) project areas*, compiled by John English, single and bundled quadrangle data, $200 per DVD.*

- North Coast release
- Northern Coast Range release
- Malheur Basin release

Lidar Landscapes Series

Mount Hood geologic guide and recreation map, Tracy Pollock, 2 p., $6.

Open-File Reports

O-11-01, Partial landslide inventory of the western portion of Coos County, Oregon, William J. Burns, Ian P. Madin, Katherine A. Mickelson, and Kendra J. Williams, 1:100,000, 1 pl., $15.

O-11-02, Salem City Center, Marion County, Oregon, Tracy Pollock, 1:5,900, 1 pl., $15.

O-11-03, Preliminary geologic map of the Lake of the Woods North 7.5' quadrangle, Klamath County, Oregon, Stanley A. Mertzman and others, 49 p., 1:24,000, 1:52,000, 1:75,000, 1 pl., $15.

O-11-04, Physiographic map of Lava Butte, Deschutes County, Oregon, Rachel Lyles, 1 pl., $15.

O-11-05, Stream channels of the northern Willamette Valley, Clackamas, Marion, Polk, Washington, and Yamhill counties, Oregon, Daniel E. Coe, 1:36,000, 1 pl., $15.

O-11-06, Stream channels of the Tualatin Valley and Lower Willamette River, Clackamas, Multnomah, Washington, and Yamhill counties, Oregon, Daniel E. Coe, 1:36,000, 1 pl., $15.

O-11-07, Corvallis City Center/Oregon State University, Benton County, Oregon, Tracy Pollock, 1:5,900, 1 pl., $15.

O-11-08, Eugene City Center/University of Oregon, Lane County, Oregon, Tracy Pollock, 1:5,900, 1 pl., $15.

O-11-09, Channel migration hazard maps, Coos County, Oregon, John T. English and Daniel E. Coe, 18 p., 1:6,000; 1:12,000, 27 pl., $25.

O-11-10, Lidar-based map of downtown Portland, Multnomah County, Oregon, Tracy Pollock, 1 pl., $15.

O-11-11, Geologic database and generalized geologic map of Bear Creek Valley, Jackson County, Oregon, Thomas J. Wiley, Jason D. McClaughry, and Jad A. D'Allura, 75 p., 1:63,360, 1 pl., $30.

O-11-12, Geologic map of the Hawks Valley-Lone Mountain Region, Harney County, Oregon, Alicja Wypych, William K. Hart, Kaleb C. Scarberry, Kelly C. McHugh, Stephen A. Pasquale, and Paul W. Legge, 28 p., 1:24,000, 1 pl., $15.

O-11-13, Channel migration hazard maps for the Sandy River, Multnomah and Clackamas counties, Oregon, John T. English, Daniel E. Coe, and Robert D. Chappell, 1:6,000; 1:12,000, 12 pl., $25.

O-11-14, Stream channels of the central Willamette Valley, Benton, Linn, Marion, and Polk counties, Oregon, Daniel E. Coe, 1:36,000, 1 pl., $15.

O-11-15, Channel migration hazard maps for the Hood River, Hood River County, Oregon, John T. English, Daniel E. Coe, and Robert D. Chappell, 1:6,000, 9 pl., $25.

O-11-16, Multi-hazard and risk study for the Mount Hood region, Multnomah, Clackamas, and Hood River Counties, Oregon, William J. Burns and others, 179 p., 1:72,000, 7 pl., $30.

O-11-17, Baseline observations and modeling for the Reedsport wave energy site, Douglas County, Oregon: Monitoring beach and shoreline morphodynamics, Jonathan C. Allan, Roger Hart, and Laura L. Stimely, 28 p., $15.

Special Paper

SP-43, Simulating tsunami inundation at Bandon, Coos County, Oregon, using hypothetical Cascadia and Alaska earthquake scenarios, Robert C. Witter, Yinglong Zhang, Kelin Wang, George R. Priest, Chris Goldfinger, Laura L. Stimely, John T. English, and Paul A. Ferro, 57 p., various, 3 pl., $30.

Tsunami evacuation brochure/map (based on TIM series data), *free online: www.oregontsunami.org:*

Web Map

Web map, Hazards and Assets Viewer for Mount Hood, online.

(DOGAMI Publications, continued from page 44)

Published in 2012

Cascadia, Winter 2012, The 2011 Japan earthquake and tsunami: Lessons for the Oregon Coast, 16 p., online.

Digital Data Series

GTILO-2, Geothermal Information Layer for Oregon, release 2 (GTILO-2), Clark A. Niewendorp, Tracy R. Ricker, Kelley W. Rabjohns, and Shane H. Brodie, $30. GTILO web map: http://www.oregongeology.org/sub/gtilo/

Fact Sheets

Mount Hood multi-hazards risk study, 4 p., online.

Geothermal exploration and development in Oregon, 4 p., online.

Interpretive Map Series

IMS-36, Missoula floods - inundation extent and primary flood features in the Portland metropolitan area, Clark, Cowlitz, and Skamania Counties, Washington, and Clackamas, Columbia, Marion, Multnomah, Washington, and Yamhill Counties, Oregon, William J. Burns and Daniel E. Coe, 1 pl., $15.

IMS-37, Landslide inventory maps of the Scholls quadrangle, Washington County, Oregon, William J. Burns, Katherine A. Mickelson, Serin Duplantis, and Kendra J. Williams, 1:8,000, 4 pl., $15.

IMS-38, Landslide inventory maps of the Sandy quadrangle, Clackamas and Multnomah Counties, Oregon, William J. Burns, Katherine A. Mickelson, and Serin Duplantis, 1:8,000, 4 pl., $15.

IMS-39, Landslide inventory maps of the Forest Grove quadrangle, Washington County, Oregon, William J. Burns, Katherine A. Mickelson, Serin Duplantis, and Kendra J. Williams, 1:8,000, 4 pl., $15.

IMS-40, Landslide inventory maps of the Sauvie Island quadrangle, Columbia and Multnomah Counties, Oregon, and Clark County, Washington, William J. Burns, Serin Duplantis, and Katherine A. Mickelson, 1:8,000, 4 pl., $15.

IMS-41, Landslide inventory maps of the Mount Tabor quadrangle, Multnomah County, Oregon, and Clark County, Washington, William J. Burns, Katherine A. Mickelson, and Serin Duplantis, 1:8,000, 4 pl., $15.

IMS-42, Landslide inventory maps of the Washougal quadrangle, Multnomah County, Oregon, and Clark County, Washington, William J. Burns, Katherine A. Mickelson, and Serin Duplantis, 1:8,000, 4 pl., $15.

IMS-43, Landslide inventory maps of the Camas quadrangle, Multnomah County, Oregon, and Clark County, Washington, William J. Burns, Katherine A. Mickelson, and Serin Duplantis, 1:8,000, 4 pl., $15.

IMS-44, Landslide inventory maps of the Dixie Mountain quadrangle, Washington, Multnomah, and Columbia Counties, Oregon, William J. Burns, Katherine A. Mickelson, Serin Duplantis, and Ian P. Madin, 1:8,000, 4 pl., $15.

IMS-45, Landslide inventory maps of the Vancouver quadrangle, Multnomah County, Oregon, and Clark County, Washington, William J. Burns, Katherine A. Mickelson, and Serin Duplantis, 1:8,000, 4 pl., $15.

IMS-46, Landslide inventory maps of the Gales Creek quadrangle, Washington County, Oregon, William J. Burns, Serin Duplantis, and Katherine A. Mickelson, John M. Spritzer, and Ray E. Wells, 1:8,000, 4 pl., $15.

IMS-47, Landslide inventory maps of the Hillsboro quadrangle, Washington and Multnomah Counties, Oregon, William J. Burns, Katherine A. Mickelson, Serin Duplantis, and Kendra J. Williams, 1:8,000, 4 pl., $15.

IMS-48, Landslide inventory maps of the Gladstone quadrangle, Clackamas and Multnomah Counties, Oregon, William J. Burns, Katherine A. Mickelson, Serin Duplantis, and Ian P. Madin, 1:8,000, 4 pl., $15.

IMS-49, Landslide inventory maps of the Damascus quadrangle, Clackamas and Multnomah Counties, Oregon, William J. Burns, Ian P. Madin, Serin Duplantis, Katherine A. Mickelson, and Cullen B. Jones, 1:8,000, 4 pl., $15.

IMS-50, Landslide inventory maps of the Sherwood quadrangle, Clackamas, Washington, Marion, and Yamhill Counties, Oregon, William J. Burns, Katherine A. Mickelson, and Serin Duplantis, 1:8,000, 4 pl., $15.

IMS-51, Landslide inventory maps of the Redland quadrangle, Clackamas County, Oregon, William J. Burns, Serin Duplantis, Katherine A. Mickelson, and Ian P. Madin, 1:8,000, 4 pl., $15.

IMS-52, Landslide inventory maps of the Estacada quadrangle, Clackamas County, Oregon, William J. Burns, Serin Duplantis, Katherine A. Mickelson, and Ian P. Madin, 1:8,000, 4 pl., $15.

IMS-53, Inventory of landslide deposits from light detection and ranging (lidar) imagery of the Portland metropolitan region, Oregon and Washington, William J. Burns, Ian P. Madin, Katherine A Mickelson, and Serin Duplantis, 1:63,360, 1 pl., $15.

***Lidar Data Quadrangle (LDQ) project areas**, compiled by John English, single and bundled quadrangle data, $200 per DVD.*

- Klamath release
- Deschutes release
- Ochoco release
- Pine Creek release

Lidar Landscapes Series

Three Sisters geologic guide and recreation map, Daniel E. Coe, 2 p., $6.

Open-File Reports

O-12-01, Preliminary geologic map of the Mount McLoughlin 7.5-minute quadrangle, Jackson and Klamath Counties, Oregon, S. A. Mertzman and others, 16 p., 1:24,000, 1 pl., $15.

O-12-02, Lidar-based surficial geologic map and database of the greater Portland, Oregon, area, Clackamas, Columbia, Marion, Multnomah, Washington, and Yamhill Counties, Oregon, and Clark County, Washington, Lina Ma, Ian P. Madin, Serin Duplantis, and Kendra J. Williams, 30 p., 1:63,360, 1 pl., $25.

O-12-03, Digital geologic map of the Hood River Valley, Hood River and Wasco Counties, Oregon, Jason D. McClaughry, Thomas J. Wiley, Richard M. Conrey, Cullen B. Jones, and Kenneth E. Lite, Jr., 142 p., 1:36,000, 1 pl., $30.

O-12-04, Western Oregon seismic reflection data imagery, 22 pl., $25.

O-12-05, Regional hazard maps of the City of Silverton, Marion County, Oregon, William J. Burns and Katherine A. Mickelson, 21 p., 1:8,000, 2 pl., $15.

O-12-06, Landslide hazard and risk study of the U.S. Highway 30 (Oregon State Highway 92) corridor, Clatsop and Columbia Counties, Oregon, Katherine A. Mickelson and William J. Burns, 105 p., 1:24,000, 4 pl., $15.

O-12-07, Lidar data and landslide inventory maps of the North Fork Siuslaw River and Big Elk Creek watersheds, Lane, Lincoln, and Benton Counties, Oregon, William J. Burns, Serin Duplantis, Cullen B. Jones, and John T. English, 15 p., 1:24,000, 2 pl., $15.

O-12-08, An "expanded" geospatial database of beach and bluff morphology determined from lidar data collected on the northern Oregon coast: Tillamook and Clatsop Counties, Jonathan C. Allan and Erica L. Harris, 27 p., $15.

Special Papers

SP-44, Coastal flood insurance study, Coos County, Oregon, Jonathan C. Allan, Peter Ruggiero, and Jed T. Roberts, 127 p., $15.

SP-45, Protocol for shallow-landslide susceptibility mapping, William J. Burns, Ian P. Madin, and Katherine A. Mickelson, 32 p., 1:8,000, 1 pl., $15.

(DOGAMI Publications, continued from page 45)

Tsunami evacuation brochure/map (based on TIM series data), *free online: www.oregontsunami.org:*

- Brookings and Harbor
- Coos Bay
- Gold Beach
- Port Orford
- Nesika Beach and Ophir
- Garibaldi/Barview
- Bay City
- Cape Meares
- Netarts
- Oceanside
- Tillamook
- Rockaway Beach
- Nehalem River Valley (Manzanita, Nehalem, Wheeler)
- Newport North
- Newport South
- Pacific City
- Neskowin
- Sand Lake and Tierra Del Mar

Tsunami inundation maps (TIM series) for Oregon coastal communities, 2 pl. (local [Cascadia] and distant [Alaska]), $10 per publication:

Coos County

- TIM-Coos-01, Lakeside West, 1:10,000
- TIM-Coos-02, Lakeside East, 1:10,000
- TIM-Coos-03, Saunders Lake, 1:10,000
- TIM-Coos-04, Haynes Inlet, 1:12,000
- TIM-Coos-05, Coos Bay - North Bend, 1:12,000
- TIM-Coos-06, Coos River North, 1:12,000
- TIM-Coos-07, Coos River South, 1:12,000
- TIM-Coos-08, Charleston - Cape Arago, 1:12,000
- TIM-Coos-09, Barview - South Slough, 1:12,000
- TIM-Coos-10, Isthmus Slough, 1:10,000
- TIM-Coos-11, Catching Slough, 1:10,000
- TIM-Coos-12, Bullards Beach, 1:12,000
- TIM-Coos-13, Leneve, 1:12,000
- TIM-Coos-14, Coquille, 1:12,000
- TIM-Coos-15, Coquille River, 1:12,000
- TIM-Coos-16, Bandon, 1:12,000
- TIM-Coos-17, New River, 1:12,000

Curry County:

- TIM-Curr-01, Langlois, 1:10,000
- TIM-Curr-02, Cape Blanco, 1:10,000
- TIM-Curr-03, Denmark, 1:10,000
- TIM-Curr-04, Port Orford, 1:10,000
- TIM-Curr-05, Humbug Mountain, 1:10,000
- TIM-Curr-06, Sister Rock, 1:10,000
- TIM-Curr-07, Nesika Beach, 1:10,000
- TIM-Curr-08, North Rogue River, 1:10,000
- TIM-Curr-09, Gold Beach, 1:12,000
- TIM-Curr-10, Cape Sebastian, 1:8,000
- TIM-Curr-11, Pistol River, 1:10,000
- TIM-Curr-12, Carpenterville, 1:10,000
- TIM-Curr-13, Harris Beach, 1:10,000
- TIM-Curr-14, Chetco River, 1:10,000
- TIM-Curr-15, Winchuck River, 1:10,000
- TIM-Curr-16, Brookings, 1:12,000.

Tillamook County

- TIM-Till-01, Arch Cape - Falcon Cove, 1:10,000 [re-released 2013]
- TIM-Till-02, Manzanita - Nehalem, 1:10,000
- TIM-Till-03, Nehalem East, 1:10,000
- TIM-Till-04, Rockaway Beach, 1:10,000
- TIM-Till-05, Garibaldi - Bay City, 1:10,000
- TIM-Till-06, Tillamook North, 1:12,000
- TIM-Till-07, Tillamook South, 1:12,000
- TIM-Till-08, Cape Meares, 1:10,000
- TIM-Till-09, Netarts - Oceanside, 1:10,000
- TIM-Till-10, Cape Lookout, 1:10,000
- TIM-Till-11, Sand Lake, 1:10,000
- TIM-Till-12, Pacific City, 1:10,000
- TIM-Till-13, Nestucca Bay, 1:10,000
- TIM-Till-14, Neskowin, 1:10,000

Web Maps

Oregon HazVu: Statewide Geohazards Viewer, online.

Statewide Landslide Information Database for Oregon, release 2 (SLIDO-2), online.

Published in 2013

Digital Data Series

AQILO-1, Aqueous Chemistry Information Layer for Oregon, Release 1 (AQILO-1), Tracy R. Ricker and Clark A. Niewendorp, 1:500,000, 1 pl., $30.

OGDU-1, Oregon Geothermal Direct-Use Sites, Release 1 (OGDU-1), Cullen B. Jones and Clark A. Niewendorp, 1:500,001, 1 pl., $30.

ORGPP-1, Oregon Geothermal Power Plant Sites, Release 1 (ORGPP-1), Clark A. Niewendorp, 1:500,002, 1 pl., $30.

RAILO-1, Radiometric Age Information Layer for Oregon, release 1 (RAILO-1), Tracy R. Ricker and Clark A. Niewendorp, 1:1,000,000, 1 pl., $30.

TIRILO-1, Thermal Infrared Information Layer for Oregon, release 1 (TIRILO-1), Clark A. Niewendorp,compiler, $150.

VVO-1, Volcanic Vents of Oregon, Release 1 (VVO-1), Sarah R. Doliber and Clark A. Niewendorp, 1:500,003, 1 pl., $30.

Fact Sheets

Tsunami inundation and evacuation maps for Oregon, 2 p., online.

Oregon Department of Geology and Mineral Industries (DOGAMI), 2 p., online. [updated]

Interpretive Map Series

IMS-54, Landslide inventory maps of the northern half of the Vernonia quadrangle, Columbia County, Oregon, William J. Burns, Katherine A. Mickelson, and Evan C. Saint-Pierre, 1:8,000, 2 pl., $15.

IMS-55, Landslide inventory maps of the southern half of the Pittsburg quadrangle, Columbia County, Oregon, William J. Burns, Katherine A. Mickelson, and Evan C. Saint-Pierre, 1:8,000, 2 pl., $15.

Lidar Data Quadrangle (LDQ) project areas*, compiled by John English, single and bundled quadrangle data, $200 per DVD.*

- Northeast Oregon release,
- Klamath release
- Rogue Basin release

Lidar Landscapes Series

Lidar Intensified 2014 calendar, Daniel E. Coe, 28 p., $12.

Crater Lake geologic guide and recreation map, Daniel E. Coe, 2 p., $6.

Willamette River historical stream channels, Oregon, Daniel E. Coe, 1 p., 1 pl., $15.

Open-File Reports

O-13-01, Change detection analysis using serial lidar data along a portion of the Upper Sandy River, Multnomah and Clackamas Counties, Oregon, John T. English, 1 inch = 1,000 feet, 1 pl., $15.

O-13-02, Landslide inventory map of the Harbor Hills area, Curry County, Oregon, William J. Burns, Serin Duplantis, and Cullen B. Jones, 1:14,000, 1 pl., $15.

O-13-03, Lidar-based maps for the City of Vernonia, Columbia County, Oregon, pursuant to Oregon Executive Order No. 10-07, DOGAMI, 1:5,000, 5 pl., $15.

O-13-04, Scoping of mineral potential: proposed Rogue Wilderness Area Additions, Josephine, Curry, Douglas, and Coos Counties, Oregon, Clark A. Niewendorp, 16 p., $15.

O-13-05, Landslide inventory, susceptibility maps, and risk analysis for the City of Astoria, Clatsop County, Oregon, William J. Burns and Katherine A. Mickelson, 33 p., plus appendices., 1:8,000, 9 pl., $15.

O-13-06, Ground motion, ground deformation, tsunami inundation, coseismic subsidence, and damage potential maps for the 2012 Oregon Resilience Plan for Cascadia Subduction Zone Earthquakes, Ian P. Madin and William J. Burns, 36 p., 38 pl., $30.

O-13-07, Oregon Beach Shoreline Mapping and Analysis Program: Quantifying short- to long-term beach and shoreline changes in the Gold Beach, Nesika Beach, and Netarts littoral cells, Curry and Tillamook Counties, Oregon, Jonathan C. Allan, Laura L. Stimely, 47 p., $15.

O-13-08, Landslide hazard and risk study of northwestern Clackamas County, Oregon, William J. Burns, Katherine A. Mickelson, Cullen B. Jones, Sean G. Pickner, Kaleena L. B. Hughes, and Rachel Sleeter, 38 p., 1:50,000; 1:8,000, 74 pl., $30.

O-13-09, Earthquake risk study for Oregon's critical energy infrastructure hub, Yumei Wang, Steven F. Bartlett, and Scott B. Miles, 159 p., $15.

O-13-10, Channel migration hazard data and maps for the Sandy River, Multnomah and Clackamas counties, Oregon, John T. English, Daniel E. Coe, and Robert D. Chappell, 1:6,000; 1:12,000, $25.

O-13-11, Channel migration hazard data and maps for the Hood River, Hood River County, Oregon, John T. English, Daniel E. Coe, and Robert D. Chappell, 1:6,000, $25.

(DOGAMI Publications, continued from page 46)

O-13-12, 3D geology and shear-wave velocity models of the Portland, Oregon, metropolitan area, Warren P. Roe and Ian P. Madin, 48 p., $30.

Tsunami animations, time histories, and digital point data for flow depth, elevation, and velocity, George R. Priest, Robert C. Witter, Y. Joseph Zhang, Kelin Wang, Chris Goldfinger, Laura L. Stimely, John T. English, Sean G. Pickner, Kaleena L.B. Hughes, Taylore E. Wille, and Rachel L. Smith, $30. per publication:

- O-13-13, South Coast project area, Curry County, Oregon
- O-13-14, Bandon project area, Coos and Curry Counties, Oregon
- O-13-15, Coos Bay project area, Coos County, Oregon
- O-13-16, Central Coast project area, Coos, Douglas, Lane, and Lincoln Counties, Oregon
- O-13-17, Tillamook project area, Tillamook County, Oregon
- O-13-18, Clatsop project area, Clatsop County, Oregon

O-13-19, Tsunami inundation scenarios for Oregon, George R. Priest, Robert C. Witter, Y. Joseph Zhang, Kelin Wang, Chris Goldfinger, Laura L. Stimely, John T. English, Sean G. Pickner, Kaleena L.B. Hughes, Taylore E. Wille, and Rachel L. Smith, 18 p., $30.

O-13-20, Evaluation of erosion hazard zones along the Alsea Bay shoreline between the Alsea Bay Bridge and the Port of Alsea, Lincoln County, Oregon, Laura L. Stimely and Jonathan C. Allan, 41 p., $30.

O-13-21, Geologic map of the southwestern Oregon coast between Crook Point and Port Orford, Curry County, Oregon, Jason D. McClaughry, Lina Ma, Cullen B. Jones, Katherine A. Mickelson, and Thomas J. Wiley, 55 p., 1:24,000, 4 pl., $30.

O-13-22, Cascadia Subduction Zone earthquakes: A magnitude 9.0 earthquake scenario, Cascadia Region Earthquake Workgroup, 28 p., $15. [revised 2013]

O-13-23, Silicic volcanism in the Menagerie Wilderness and adjacent regions of the Western Cascades in Oregon, Geoffrey W. Cook, Craig M. White, and James L. Crowley, 15 p., 1:12,000, 1 pl., $15.

Tsunami inundation maps (TIM series) for Oregon coastal communities, 2 pl. (local [Cascadia] and distant [Alaska]), $10 per publication:

Clatsop County:

- TIM-Clat-01, Clatsop Spit, 1:10,000
- TIM-Clat-02, Warrenton North, 1:10,000
- TIM-Clat-03, Warrenton South - Rilea, 1:10,000
- TIM-Clat-04, Astoria, 1:10,000.TIM-Clat-05, oungs River North, 1:10,000
- TIM-Clat-06, Youngs River South, 1:10,000
- TIM-Clat-07, Del Rey Beach, 1:10,000
- TIM-Clat-08, Gearhart - Seaside, 1:12,000
- TIM-Clat-09, Cannon Beach, 1:12,000
- TIM-Clat-10, Arch Cape - Falcon Cove, 1:10,000

Douglas County:

- TIM-Doug-01, Siltcoos Lake, 1:10,000
- TIM-Doug-02, Tahkenitch Lake, 1:10,000
- TIM-Doug-03, Gardiner, 1:10,000
- TIM-Doug-04, Reedsport, 1:10,000
- TIM-Doug-05, East Gardiner, 1:10,000
- TIM-Doug-06, Umpqua River West, 1:10,000
- TIM-Doug-07, Sulphur Springs, 1:10,000
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- TIM-Doug-09, Clear Lake, 1:10,000

Lane County:

- TIM-Lane-01, Neptune, 1:10,000
- TIM-Lane-02, Heceta Head, 1:10,000
- TIM-Lane-03, Mercer Lake, 1:10,000
- TIM-Lane-04, Florence, 1:12,000
- TIM-Lane-05, Cushman - Wendson, 1:12,000
- TIM-Lane-06, Tiernan - Mapleton, 1:10,000
- TIM-Lane-07, Dunes City, 1:10,000
- TIM-Lane-08, Siltcoos Lake, 1:10,000

Lincoln County:

- TIM-Linc-01, Lincoln City North, 1:10,000
- TIM-Linc-02, Lincoln City South, 1:10,000
- TIM-Linc-03, Gleneden Beach - Siletz River, 1:12,000
- TIM-Linc-04, Depoe Bay, 1:10,000
- TIM-Linc-05, Otter Rock - Beverly Beach, 1:10,000
- TIM-Linc-06, Newport North, 1:10,000
- TIM-Linc-07, Newport South, 1:10,000
- TIM-Linc-08, Toledo, 1:10,000
- TIM-Linc-09, Yaquina River, 1:10,000
- TIM-Linc-10, Seal Rock, 1:10,000
- TIM-Linc-11, Driftwood Beach, 1:10,000
- TIM-Linc-12, Waldport, 1:10,000
- TIM-Linc-13, Tidewater, 1:10,000
- TIM-Linc-14, Ocean Shores, 1:10,000
- IM-Linc-15, Yachats, 1:10,000

TIM-Till-01, Arch Cape - Falcon Cove, Tillamook County, Oregon, 1:10,000. [re-release]

Tsunami evacuation brochure/map (based on TIM series data), *free online:* *www.oregontsunami.org*:

- Reedsport/Gardiner/Winchester Bay
- Lakeside
- Depoe Bay
- Gleneden Beach
- Lincoln Beach
- Lincoln City-North
- Lincoln City-South
- Seal Rock
- Toledo
- Waldport
- Yachats
- Yachats North (San Marine)
- Florence
- Dunes City
- Arch Cape
- Astoria
- Cannon Beach
- Seaside and Gearhart
- Sunset Beach and Del Rey Beach (Clatsop Plains)
- Youngs River Valley
- Warrenton and Clatsop Spit

Web Map

GTILO-2, Geothermal Information Layer for Oregon, release 2 (GTILO-2), online.

Released in 2014 (through June)

SLIDO-3.0 web map, data, and web services: *http://www.oregongeology.org/sub/slido/*

and SLIDO-3.1: data release on web only

O-14-01, Geologic map of the southern Oregon coast between Port Orford and Bandon, Curry and Coos Counties, Oregon, Thomas J. Wiley, Jason D. McClaughry, Lina Ma, Katherine A. Mickelson, Clark A. Niewendorp, Laura L. Stimely, Heather H. Herinckx, and Jonathan Rivas, 66 p., 3 pl., scale 1:24,000, geodatabase.

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Geologic guide and recreation maps:

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Other popular online picks:

- Statewide Seismic Needs Assessment Using Rapid Visual Screening (RVS): *http://www.oregongeology.org/sub/projects/rvs/*
- Individual seismic needs assessment site reports: *http://www.oregongeology.org/sub/projects/rvs/county/county-sites.htm*

All *Ore Bin* and *Oregon Geology* past issues–

- *http://www.oregongeology.org/sub/quarpub/OrGeo.htm*

All Geologic Map Series (GMS) maps–

- *http://www.oregongeology.org/sub/publications/GMS/gms.htm*

All Oregon coast tsunami evacuation maps/brochures–

- *http://www.oregongeology.org/sub/publications/GMS/gms.htm*

Interactive maps–

- Oregon HazVu: Statewide Geohazards Viewer
- SLIDO: Statewide Landslide Information Database for Oregon
- DOGAMI Lidar Data Viewer
- MILO: Mineral Information Layer for Oregon
- Oil and Gas Log Data Viewer
- Pacific Northwest Tsunami Evacuation Zones (via NANOOS NVS)

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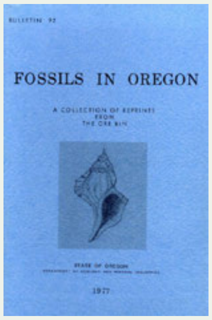
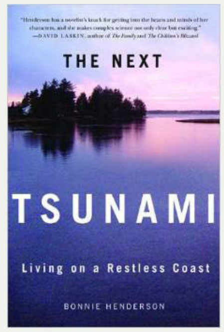
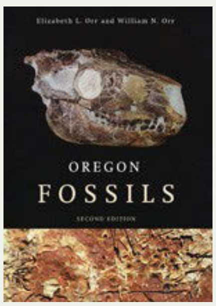


DOGAMI Bulletin 92, Fossils in Oregon: A collection of reprints from the *Ore Bin*, by Margaret L. Steere, ed., 1977, 227 p. $5. Also available as part of compilation CD-ROM Bulletin 106.



The Next Tsunami: Living on a Restless Coast, by Bonnie Henderson. Oregon State University Press, Corvallis. Paperback, 320 p., 2014. $19.95.



Oregon Fossils, 2nd ed., by Elizabeth L. Orr and William N. Orr, Oregon State University Press, Corvallis. Paperback, 390 p., 2009. $24.95.

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