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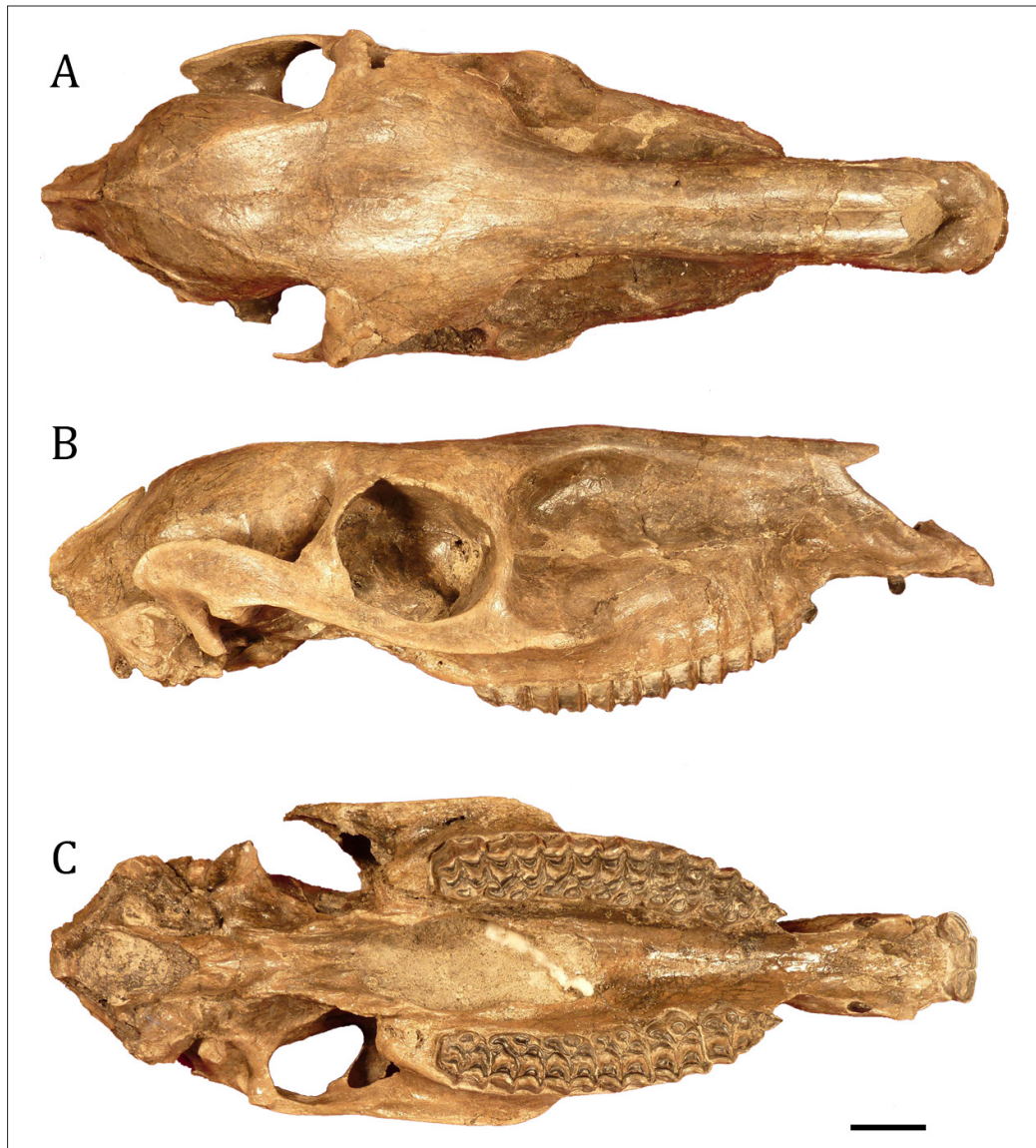
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Cover photo: Skull of *Acritohippus isonesus* in dorsal (A), lateral (B) and ventral (C) views from the mid-Miocene Mascall Formation type locality in central Oregon (specimen JODA 1316). Scale bar=3 cm.

The fauna and chronostratigraphy of the middle Miocene Mascall type area, John Day Basin, Oregon, USA

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The Mascall fauna is a well-known middle Miocene (Barstovian) mammalian assemblage in the Pacific Northwest. It has been collected for over 100 years and collecting intensity has increased since the establishment in 1975 of a national monument enclosing the type area of the formation. Despite its importance to biostratigraphy, biogeography of Barstovian taxa, and paleoecological studies, the fauna at the type locality has not been taxonomically examined in more than 50 years. Evaluation and classification of the stratigraphy of the Mascall Formation (Bestland et al. 2008) has prompted a faunal revision in order to place taxa within the new stratigraphic framework. Here we report on the fauna from the type area of the Mascall Formation in central Oregon, and conclude that 20 taxa are new to the fauna, and several taxa previously assigned to distinct species are synonymized. We also place specimens and taxa within a robust stratigraphic framework, calibrated with new U-Pb radioisotopic ages for the Mascall Tuff (15.122±0.017 Ma), the most fossiliferous layer in the formation, and the Kangaroo Tuff (13.564±0.018 Ma), the upper most tuff in the formation.

Keywords: Barstovian, mammals, LA-ICPMS, ID-TIMS, Oregon

INTRODUCTION

The Mascall Formation, located in central Oregon amongst the well-known John Day Basin deposits (Fig. 1), contains a diverse Barstovian (North American Land Mammal Age; NALMA) fauna. Collection of the fauna dates back to the 1870s when field crews were sent by E.D. Cope and O.C. Marsh (Merriam 1901, Prothero et al. 2006). John C. Merriam of the University of California, Berkeley (UCB) was the first to both describe the Mascall Formation and make significant collections (Merriam 1901, Merriam and Sinclair 1907). Theodore Downs, also of UCB, continued focused fieldwork and analysis of the fauna during the 1940s and 1950s (Downs 1956). By the time the Wood Committee (Wood et al. 1941) published their treatise on the NALMAs, the Mascall fauna was considered to be an assemblage indicative of the

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Barstovian and used as one of the principal correlative faunas for that land mammal age (Tedford et al. 2004). Later, with the establishment of John Day Fossil Beds National Monument (JDNM), park employees began to systematically collect the deposits, adding to and refining the faunal list, an activity that is still underway.
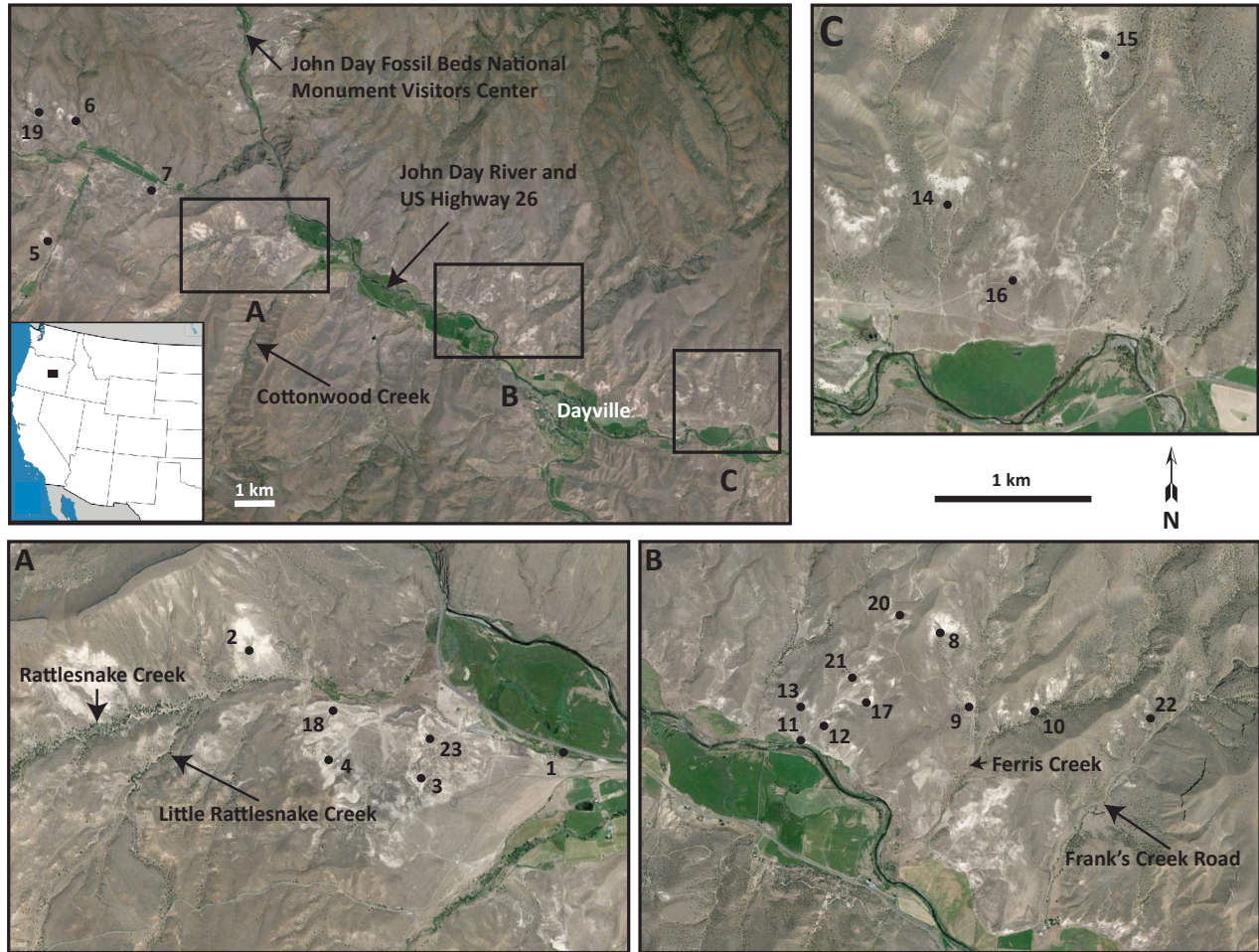
While the composition of the Mascall fauna shares similarities with other early Barstovian North American faunas, it exhibits some important differences that suggest the Pacific Northwest faunas are different from other middle Miocene faunas (Pagnac 2005, Tedford et al. 2004). In general, comparing Barstovian faunas across North America suggests provincialism during this time (Barnosky and Carrasco 2002, Tedford et al. 2004). However, a recent study by Pagnac (2005) found that no solid conclusions could be made because the Mascall fauna has not been thoroughly studied since Downs (1956). Complicating comparison of the Mascall fauna to other Barstovian faunas is the fact that many published specimens have not been reported with adequate stratigraphic data,

Figure 1. Map of the Mascall Formation type area in east-central Oregon (upper left, inset). Maps **A–C** show the fossil localities within the bounded areas marked **A–C**. Numbers correspond to localities in Table 1.

nor have their published identifications been updated with current taxonomy. Therefore, a key goal of this work is to provide the stratigraphic and taxonomic refinement needed to adequately compare the Mascall fauna with other Barstovian faunas, a prerequisite to gaining insight into biogeographic patterns, paleoecological patterns, and evolutionary relationships. In addition, the Mascall fauna was one of the key faunas used in characterizing the Barstovian (Wood et al. 1941), making it all the more important to have an accurate stratigraphic and taxonomic framework. We focus on describing the fauna at the Mascall Formation type locality in the John Day Basin of eastern Oregon and discuss other deposits in Oregon that are attributed to (e.g., Crooked River, Hawk Rim) or are contemporaneous with the Mascall Formation.

Since the last comprehensive review of the Mascall fauna was compiled by Downs (1956), systematic collecting by the staff at JDNM has resulted in the addition of over 1200 new specimens, which are included in this analysis. To build a more robust stratigraphic framework, tuff layers throughout the section were dated; here we report radioisotopic ages for the Mascall Tuff (=Downs (1956) unit 5), a partially reworked tuff deposit from which most of the fossils in the Mascall Formation have been recovered, and the Kangaroo Tuff, the uppermost tuff in the type section (Bestland et al. 2008).

GEOLOGICAL CONTEXT

The approximately 610-meter-thick Mascall Formation deposits at its type location contain a series of siltstone and claystone paleosols with sporadic tuffs and diatomite. The formation and its stratigraphy was reviewed in Bestland et al. (2008); with the formation subdivided into three units (lower, middle and upper), based on stratigraphic marker beds (Fig. 2). The boundary between the lower and middle units is the base of the Mascall Tuff layer. The middle and upper units are separated by a prominent conglomerate interval. The majority of fossils are found in the lower and middle units, with only fragmentary heavily-weathered specimens coming from the upper units. The Mascall Tuff is a reworked massive tuffaceous siltstone that varies
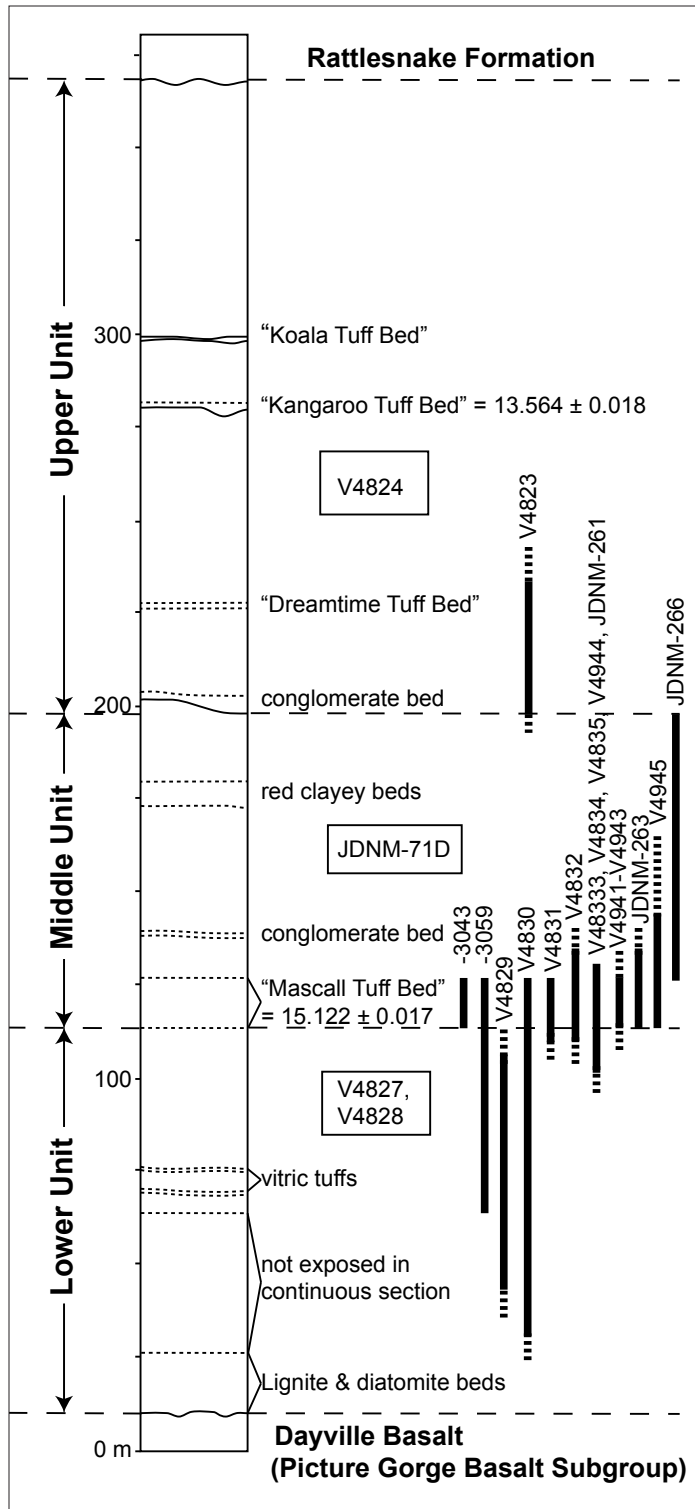
Figure 2. Stratigraphy of the Mascall Formation in the type area (modified from Bestland et al. 2008). Stratigraphic ranges of localities are indicated by vertical lines. Dashed lines indicate uncertainty. Localities in boxes have unknown stratigraphic coverage, but are known from the unit they are within. New radiometric dates are given for the Mascall and Kangaroo Tuff Beds.

widely in thickness (over 10 m in places). It preserves the majority of fossils known from the entire Mascall Formation (Bestland et al. 2008) and corresponds to Downs' (1956) unit 5, from which he recovered most of his fossil material. The Mascall Tuff itself can be divided into two lithostratigraphically distinct beds, with only the lower one being fossiliferous. The upper, nonfossiliferous bed is highly bioturbated and indurated, with sections of it containing loosely horizonated inceptisols. Above the Mascall Formation in its type section is the late Miocene (early Hemphillian) Rattlesnake Formation (Merriam et al. 1916, 1925). In the type area there is a large angular unconformity between the two, varying from 6° to 15° (Merriam et al. 1925).

CHRONOSTRATIGRAPHIC CONTEXT

In its type area, the Mascall Formation sits on top of the Dayville Basalt of the Picture Gorge Basalt Subgroup. The Dayville Basalt has been paleomagnetically and radiometrically studied, and dated between 16.5 and 16.3 Ma (Long and Duncan 1982, Hooper and Swanson 1990). These basalts are part of the larger Columbia River Basalt regime (Bailey 1989). A tuff in the lower part of the Mascall Formation at the type section was dated by Fiebelkorn et al. (1983) at 16.2±1.4 Ma. Swisher (1992) dated a tuff (unit 2 of Downs (1956)) low in the Mascall Formation in the type area at 15.77±0.07 Ma. McLaughlin et al. (2016) dated two volcanic ash beds within alluvial floodplain deposits at Hawk Rim, a site near the Crooked River southwest of the type locality of the Mascall Formation. The litho- and biostratigraphy of these deposits suggest correlation to the Mascall Formation, and a $^{40}Ar/^{39}Ar$ plagioclase date of 16.44±0.05 Ma for the "Double Tuff" and U-Pb zircon date of 16.26±0.02 Ma for the "Hawk Rim Tuff" provide the best constraints on the age of the lowermost Mascall Formation deposition, though at a site peripheral to the type area discussed here. Prothero et al. (2006) analyzed the magnetostratigraphy of the lower and middle Mascall in the type area and determined its correlation with Chrons C5Bn1n-C5Br giving the fauna an age of 14.8–16 Ma. The unconformably overlying Rattlesnake Formation has a prominent tuff bed, the Rattlesnake Ash Flow Tuff, dated at 7.14±0.03 Ma (Jordan et al. 2004). Prothero et al. (2006) also did a paleomagnetic stratigraphy study of the type Rattlesnake section (directly adjacent and above the type Mascall section), correlating it with magnetic Chrons C3Bn to C3Br2n (6.9–7.3 Ma). These dates indicate a substantial hiatus between the deposition of the Upper Member of the Mascall Formation and the lower fanglomerate member of the Rattlesnake Formation.

ENVIRONMENTAL AND REGIONAL CONTEXT

The Mascall Formation begins at the height of the

mid-Miocene Climatic Optimum (MMCO) (Zachos et al. 2001, 2008), a period of globally warmer temperatures and wetter conditions (e.g., Wolfe 1981). Bestland et al. (2008) hypothesized the paleosols spanning all units of the Mascall Formation represent climatic optimum conditions. The MMCO was followed by global cooling, beginning at 15 Ma, which appears to have been stepwise and regionally variable (Vincent and Berger 1985, Flower and Kennett 1993, Retallack 2007). This cooling led to more open and presumably arid habitats, which in turn supported grazing mammals in heightened abundance (Wolfe 1981, Wing 1998, Janis et al. 2002). However, the paleosols of the Mascall Formation during this global cooling phase indicate wetter conditions than in other parts of the continent, such as the Great Plains. This may suggest that the Pacific Northwest received more rainfall during the post MMCO interval (Bestland et al. 2008).

There is a rich paleobotanical record in the lower horizons of the Mascall Formation. Chaney (1925) originally described the flora as an oak-madrone forest similar to those in Northern California today. He later revised this interpretation (Chaney 1956, 1959, Chaney and Axelrod 1959), comparing the Mascall paleoflora to the deciduous forests of the Ohio River Basin and Szechuan China, as well as elements related to the Mississippi Valley cypress swamps (Dilhoff et al. 2009). Krull (1998) comprehensively studied all the stratigraphic layers with paleobotanical material, and concluded that the Mascall "paleoflora" is not a single, contemporaneous assemblage, but rather many stratigraphically and temporally separated assemblages of plants growing in the area. In conjunction with the paleosol record, which contains sequences of maturing and fining upward soils, the superposed plant horizons reveal shifts between a Mediterranean-like climate and a more humid subtropical climate with leaf size and diversity increasing upsection as paleosol units become more developed (Krull 1998). Combining the paleobotanical record and the paleosol record, Bestland et al. (2008) concluded the Mascall Formation shifted between "a humid, temperate climate with both Mediterranean climatic aspects (dry, warm summer) and continental climate aspects (cool to cold winter)" through section.

There are several deposits in the Pacific Northwest that may be similar in age (Bailey 1989, Nash and Perkins 2012) and depositional environment to the Mascall Formation, and in some cases these strata may represent lateral equivalents. The Simtustus Formation in the Deschutes Basin of central Oregon, approximately 100 km due west of the John Day Basin, overlays and interstratifies the Columbia River Basalt Group like the Mascall Formation and contains a similar fauna. Downs (1956), in fact, included the Gateway Locality (CIT 368 and V-3427) of the Simtustus Formation in his description of the Mascall fauna. The base of the Simtustus Formation is dated at 15.5 Ma and the overlying Pelton Basalt is dated at 7.6 Ma, with an unconformity between the two (Smith 1986). The Simtustus Formation is dominantly fluvial and mixed pyroclastic and epiclastic sediments, in contrast to the Mascall Formation that is dominantly lacustrine and pycroclastic sediments (Smith 1986). Besides the Gateway Locality, Barstovian mammal fossils have also been recovered from the Coburn Wells sites near Madras (JDNM loc. 248 and 249). Satellite imagery has revealed additional outcrop areas with potential for more fossil material. For the purposes of this faunal review, specimens from the Simtustus Formation (Coburn Wells and Gateway Localities) are not included; however, see the discussion below on regional faunal differences between all Mascall-equivalent deposits.

Mascall-equivalent deposits located near the Crooked River, approximately 50 km southwest of the John Day Basin, also contain a Barstovian fauna. Downs (1956) considered these deposits as part of the Mascall fauna, but he listed the Mascall type locality and Crooked River faunal lists separately. We do not include specimens from the Crooked River area in the type Mascall faunal list reported here, because of the uncertainty of their geologic context due to the complex tectonic setting. Localities that Downs (1956) considered as yielding components of the type Mascall fauna, but which we exclude here, are: Beaver Creek localities: V4949 (old -895), V4950 (old -897 and Osmont 7), Osmont 6(-896); Camp Creek locality V4951 (possibly old -900 and Paulina); Grindstone Creek (-901); Crooked River locality V4948. In addition, there are more recently discovered localities in the Crooked River area, Cave Basin and Hawk Rim (McLaughlin et al. 2016). The fauna recovered from these localities so far demonstrate similarities to the Mascall fauna *sensu stricto* (see below) and McLaughlin et al. (2016) places the Hawk Rim fauna within the Mascall Formation.

Farther away, in southern Oregon, the Butte Creek Volcanic Sandstone (in which the Beatty Buttes, Corral Butte and Fish Fin Rim localities are found) contains an early Barstovian fauna (Wallace 1946, Janis et al. 1998). The Butte Creek Volcanic Sandstone also includes an early Barstovian fauna at the Red Basin localities in southeastern Oregon (Shotwell 1968). Shotwell (1968) also collected late Barstovian fossils from the Quartz Basin localities in the Deer Butte Formation near Owhyee Reservoir, and from nearby localities that yielded the Skull Springs fauna from the Battle Creek Formation. To the east, across the Owhyee Reservoir, close to the Idaho border, is the Sucker Creek Formation, which contains an early and late Barstovian fauna (Scharf 1935). Numerous other Barstovian deposits are found throughout the western United States, as described in Tedford et al. (2004), and include the faunas of the Virgin Valley Formation,

Barstow Formation, Pawnee Creek Formation, Valentine Formation, and Olcott Formation.

MATERIALS AND METHODS

Specimen Collection

Over the 100+ years of collecting in the Mascall Formation the majority of specimens have been found as float material; however, some specimens are found in situ, particularly those from the Mascall Tuff (Unit 5 of Downs 1956). Screen wash testing was performed on paleosol, channel, and anthill deposits to recover microvertebrate fossils. The paleosol deposits do not contain abundant enough material to make this approach practical and known channel deposits, which are in the upper member of the formation, and anthills do not contain identifiable fossil material.

Collection in the Mascall Formation in its type area has occurred more or less continuously from the 1870s to the present. With the establishment of John Day Fossil Beds National Monument, field crews have collected in the type area every year; however, not all sites in the type area are visited annually, as rates of erosion are generally low. In 1988, the monument acquired an extensive collection of Mascall and Rattlesnake Formation specimens from the Grant County Chamber of Commerce. These specimens were originally collected by the Weatherfords, a local ranching family. Their property was on and surrounded by Mascall and Rattlesnake deposits. The two sons, Frank and Walter, collected fossils from these deposits, sometimes selling them to interested paleontologists such as E.L. Furlong and C. Stock of UC Berkeley. Their collection contains some of the best representations of certain taxa in both the Mascall and Rattlesnake faunas. However, there is no locality information for any of the specimens and though Walt Weatherford took some people to areas where specimens had been collected, both brothers passed away before any specific locality data was relayed to JDNM. In 1999, Elise Schloeder collected in the type area of the Mascall Formation, collecting valuable specimens that confirm species on the faunal list. During the summers of 2010 and 2011, we collected extensively in the Mascall Formation, adding new localities and placing specimens within the stratigraphic framework.

Localities and Biostratigraphy

Over many decades of collecting in the type Mascall area, several localities from multiple stratigraphic levels have been identified (Fig. 2). Early collections from the American Museum of Natural History (AMNH) and the Yale Peabody Museum (YPM) have only descriptive names for specimen locations. Starting with collections made by J.C. Merriam of the Univesity of California Museum of Paleontology (UCMP), localities were numbered; however, exact location and stratigraphic level was not recorded. Theodore Downs (1956) established well georeferenced localities and tried to match old UCMP localities to his when possible. For example, UCMP -903 (Old Sneider Ranch) encompasses UCMP V4831 through V4835 from Downs (1956). In addition, because local ranch ownership has changed, locality names have also changed. For example, Old Sneider Ranch is now referred to as the Clausen Ranch or Ferris Creek. And lastly, several institutions have collected in the type Mascall area. Each institution has used a different locality number or name for Mascall deposits. This is especially true when considering locality numbers given to general collections that are recorded from the Mascall type area (see Table 1). We have attempted to clarify and synonymize locality data in Table 1.

Localities were relocated using published records and field notes, and were assigned to one of the three Mascall Formation units (Fig. 1, Bestland et al. 2008). Extensive field surveys during the summers of 2010 and 2011 yielded additional localities that were also placed into the stratigraphic framework. The stratigraphic range of each locality is presented in Figure 2. Because the Hemphillian age Rattlesnake Formation deposits are in close proximity and directly overlay parts of the Mascall Formation in the type area, there has been confusion regarding the provenance of some specimens. This is particularly true with earlier collections and those made by local ranchers. In addition, one locality (UCMP V4825) contains outcrop of both formations and it is unclear which specimens originate from each deposit. Specimens from this locality can only be placed in a formation through taxonomic identification or sometimes by examination of preservation and adhered matrix. Specimens from the Rattlesnake Formation often have reddish-brown silt matrix and are commonly etched by plant roots, while specimens from the Mascall Formation usually have a lighter white or yellow tuffaceous matrix, and no etching by plant roots. However, in some instances, specimens that represent species that range through the Barstovian (Mascall Formation) to Hemphillian (Rattlesnake Formation) may have unknown formation origin. For the purposes of this study, specimens that fall into this situation are not included, unless they are the only occurrence of the taxon in the Mascall Formation, in which case it is noted and only tentatively assigned to the fauna. The same problem of provenance is true for specimens collected by the Weatherfords. Therefore, any taxon only collected by the Weatherfords or has unknown stratigraphic provenance is noted with an asterisk in the faunal list (Table 2) and reference specimens in the systematic paleontology descriptions that fall into this category have their locality

Table 1. Recorded localities in the Type Mascall Formation area.

UCMP loc. no.	Loc. synonym	Name(s)	Notes	Map No.
-816		Cottonwood Creek 1	Possibly YPM "Cottonwood Creek"	
-882		Mascall Misc. 1		
-884		Mascall Misc. 2	See V4825	
-885		Mascall Misc. 3		
-886		Mascall Misc. 4		
-903		Old Sneider Ranch	See V4830-4835	
-3043	JDNM-262 UO 2993	Mascall Roadcoat		1
-3047		Mascall		
-3048		Mascall		
-3049		Mascall	See V4827	
-3059	JDNM-179	Mascall Bowl		2
-3063		Mascall	See V4823	
-3064		Mascall		
-3066		Mascall		
V4823		Mascall	Possibly UCMP -3063, possibly YPM "Mascall Ranch", possibly YPM "1 mile west of Cottonwood Creek"	3
V4824		Mascall 10	Possibly YPM "Mascall Ranch", possibly YPM "1 mile west of Cottonwood Creek"	4
V4825	JDNM-30	Mitchell Road, Confusion	Possibly UCMP -815, -817, -884, -887, -3042	
V4826		Mascall 12	No specimens	
V4827	JDNM-70	Mascall 13, Birch Creek	Possibly UCMP -3049	5
V4848		Mascall 14		6
V4829	JDNM-71A	Rock Creek		7
	JDNM-71B	Rock Creek Southwest		7
	JDNM-71C	Rock Creek South		7
	JDNM-71D	Rock Creek Southeast		7
V4830	JDNM-201	Mascall 16, Ferris Creek Bowl, Old Sneider Ranch, North of Dayville	Part of UCMP -903 (Old Sneider Ranch), part of LACM 1869 (North of Dayville)	8
V4831 (=V4913)	JDNM-264	Mascall 17, Old Sneider Ranch, North of Dayville	Part of UCMP -903 (Old Sneider Ranch), part of LACM 1869 (North of Dayville)	9
V4832 (=V4914)	JDNM-202	Mascall 18, Ferris Creek North, Old Sneider Ranch, North of Dayville	Part of UCMP -903 (Old Sneider Ranch), part of LACM 1869 (North of Dayville)	10
V4833 (=V4915)		Mascall 19, Old Sneider Ranch, North of Dayville	Part of UCMP -903 (Old Sneider Ranch), part of LACM 1869 (North of Dayville)	11
V4834	JDNM-260	Mascall 20, Old Sneider Ranch, North of Dayville	Part of UCMP -903 (Old Sneider Ranch), part of LACM 1869 (North of Dayville)	12
V4835		Mascall 21, Old Sneider Ranch, North of Dayville	Part of UCMP -903 (Old Sneider Ranch), part of LACM 1869 (North of Dayville)	13
V4941 (=V4912)		Mascall 22, Van Horn Ranch, Mackay Ranch		14
V4942		Mascall 23, Van Horn Ranch, Mackay Ranch		15

Table 1. Recorded localities in the Type Mascall Formation area (continued).

UCMP loc. no.	Loc. synonym	Name(s)	Notes	Map No.
V4943		Mascall 24, Van Horn Ranch, Mackay Ranch		16
V4944		Mascall 25, Old Sneider Ranch, North of Dayville	Part of UCMP -903 (Old Sneider Ranch), part of LACM 1869 (North of Dayville)	17
V4945		Mascall 26		18
V4946		Mascall 27, McDonald Ranch		19
V6440			"Dayville 9.8 miles east", no specimens.	
V65400		Cottonwood Creek 5, YPM "*Ticholeptus* beds of Cottonwood Creek"		
V65405		Rattlesnake Creek Mascall		
V67153 (=V6403)	JDNM-4	Mascall General, YPM John Day River/Valley	Includes -3506 (Rattlesnake Misc.) in part	
	JDNM-261	Ferris Creek Below BLM Road		20
	JDNM-263	West Mascall 20		21
	JDNM-265	Frank's Creek Road		22
	JDNM-266	Mascall Red Hills		23
	CIT 113	Dayville	Unclear what area this encompasses	
	CIT 183	Mascall Type Area, Near Rattlesnake Creek, West of Weatherford Ranch	Possibly -3059	
	CIT 184	Mascall	Unclear what area this encompasses	
	LACM 1869	North of Dayville and West of John Day Highway	Some of this locality overlaps with V4830-V4831, some of this locality overlaps with localities near Cottonwood and Rattlesnake Creeks. Specimens purchased from the Weatherfords were also assigned this locality number.	
	LACM 5535	Mascall Area General	Unclear what area this encompasses	
	LACM 3178	Rattlesnake Creek, Wheeler County	Unclear what area this encompasses	

noted with an asterisk.

Radioisotopic Age Determinations

Samples of the four prominent tuffaceous layers (Mascall, Dreamtime, Kangaroo, and Koala) (Bestland et al. 2008) in the middle and upper units of the Mascall Formation, as well as two minor tuffaceous layers ("gray vitric tuff" at 2 m and "gray vitric tuff with black glass" at 26 m in the Rock Creek Section of Bestland (1998)) in the lower unit of the Mascall Formation were collected for radioisotopic age determination. Of the six, the Mascall and Kangaroo contained homogeneous populations of zircons for analysis. Initial U-Pb dates and geochemical compositions were obtained by laser ablation inductively coupled plasma-source mass spectrometry (LA-ICPMS) from spots placed on zircon crystals sectioned and imaged via cathodoluminescence. Following this screening, selected zircon crystals were analyzed by chemical abrasion isotope dilution thermal ionization mass spectrometry (CA-IDTIMS; Mattinson 2005) for high-precision age analysis. Details of the analytical methods can be found in Davydov et al. (2010), Schmitz and Davydov (2012), and Rivera et al. (2013). The reported CA-IDTIMS U-Pb age uncertainties are based upon non-systematic analytical errors, including counting statistics, instrumental fractionation, tracer subtraction, and blank subtraction (Schmitz and Schoene 2007). Weighted mean age errors on groups of crystals are reported at the 95% confidence interval, which is the internal analytical error multiplied by the square root of the mean squared weighted deviation (MSWD) and the Student's t multiplier for n-1 degrees of freedom. These

Table 2. Vertebrate taxa from the type Mascall Formation and their stratigraphic ranges. Asterisks signify either collected by Weatherfords and/or unknown stratigraphic provenance resulting in tentative placement on the faunal list. Question marks indicate uncertainty in specimen identification for the horizon.

Taxon	Stratigraphic Unit		
	Lower	Middle	Upper
Lipotyphla			
Soricidae			
Pseudotrimylus mawbyi	X	-	-
Talpidae			
Mioscalops cf. *ripafodiator*	-	X	-
Carnivora			
Canidae			
Tephrocyon rurestris	X	X	-
Leptocyon cf. leidyi	X*	X*	-
Canidae indet.	X*	X	-
Amphicyonidae			
Cynelos sinapius	X*	X	-
Felidae			
Pseudaelurus sp.	X*	X*	-
Mustelidae			
Leptarctus oregonensis	X	X	-
Mustelidae indet.*	n/a	n/a	n/a
Procyonidae			
*Bassariscus lycopotamicus**	n/a	n/a	n/a
Lagamorpha			
Leporidae			
Hypolagus fontinalus	-	X	-
Hypolagus parviplicatus	X*	X*	-
Archaeolagus sp.	X	-	-
Leporidae indet.	X	X	X
Rodentia			
Castoridae			
Euroxenomys sp.	-	X	-
Heteromyidae			
Balantiomys oregonensis	X*	X	-
Prodipodomys mascallensis	-	X	-
Geomyidae	-	X	-
Mylagaulidae			
Hesperogaulus gazini	X	X*	-

Table 2. Continued.

Taxon	Stratigraphic Unit		
	Lower	**Middle**	**Upper**
Mylagaulidae indet.	X*	X*	-
Sciuridae			
Protospermophilus malheurensis	-	X	-
Protospermophilus oregonensis	X	-	-
Sciurini indet.	-	X	-
Sciuridae indet.	X	X	X
Cricitidae	-	X	-
Perissodactyla			
Equidae			
cf. *Kalobatippus**	n/a	n/a	n/a
Desmatippus avus	X*	X	-
Parahippus sp.	X*	X	-
Archaeohippus ultimus	X	X	-
Acritohippus isonesus	X	X	X
Merychippine species A	X	X	-
Rhinocerotidae	X	X	X
Artiodactyla			
Tyassuidae			
"*Cynorca*" *hesperia*	X*	X	-
"*Cynorca*" sp.	X*	X	-
Tayassuidae indet.	X	X	-
Palaeomerycidae			
Dromomeryx borealis	X	X	-
Rakomeryx sinclairi	X*	X	-
Merycoidodontidae			
Ticholeptus zygomaticus	X	X	-
Merycoidodontidae indet.	X*	X	-
Camelidae			
Miolabis transmontanus	-	X	-
cf. *Procamelus*	-	X	-
Camelidae	X	X	-
Moschidae			
Blastomeryx gemmifer	X(?)	X	X(?)
Parablastomeryx sp.	X	X*	-
Proboscidea			
Proboscidea indet.	X	X	X(?)

error estimates should be considered when comparing our ^{206}Pb/^{238}U dates with those from other laboratories that used tracer solutions calibrated against EARTHTIME gravimetric standards. When comparing our dates with those derived from other decay schemes (e.g., ^{40}Ar/^{39}Ar, 187Re–187Os), the uncertainties in tracer calibration (0.03%; Condon et al. 2015, McLean et al. 2015) and U-decay constants (0.108%; Jaffey et al. 1971) should be added to the internal error in quadrature. Quoted errors for calculated weighted means are thus of the form ±X(Y)[Z], where X is solely analytical uncertainty, Y is the combined analytical and tracer uncertainty, and Z is the combined analytical, tracer, and ^{238}U decay constant uncertainty.

Taxonomic Identification

Specimens collected from the Mascall Formation and curated at the UCMP, JDNM, and LACM were identified by direct examination of comparable museum material and published descriptions. Taxonomy follows chapters of the recent Evolution of Tertiary Mammals of North America volumes (Janis et al. 1998, 2008) unless otherwise noted. Measurements were taken to the nearest 0.01 mm with Folwer Sylvac digital calipers.

Institutional Abbreviations—AMNH, American Museum of Natural History; **AMNH FM**, American Museum of Natural History Frick Collection; **CIT**, California Institute of Technology; **JDNM**, John Day Fossil Beds National Monument Locality; **JODA**, John Day Fossil Beds National Monument Specimen; **LACM**, Los Angeles County Museum; **RV**, University of California at Riverside Locality; **UCMP**, University of California Museum of Paleontology specimen; **UOMNCH**, University of Oregon Museum of Natural and Cultural History; **USNM**, United States National Museum; **YPM**, Yale Peabody Museum.

Measurement Abbreviations—ap, anteroposterior length; **t**, transverse width.

RESULTS

Faunal List and Biostratigraphy

A revised faunal list for the type area of the Mascall Formation is presented in Table 2 along with biostratigraphic assignments to the lower, middle, and upper sections of the formation. The majority of fossil specimens originated from the Mascall Tuff (Unit 5 of Downs (1956)) and in paleosols just below and above the tuff. Specimens in the upper member of the formation are rare and well-worn, indicating a high degree of transport. The scarcity of material in the upper member is peculiar given the similarity of the deposits to the lower and middle members of the formation (Bestland et al. 2008).

Taphonomy has some definite influence on the taxonomic representation within the Mascall fauna; fossil material from the Mascall Formation is typically from large-bodied taxa, likely a reflection of some preservational biases against smaller specimens.

The fossiliferous horizons of the Mascall Formation (the lower unit and lower sections of the middle unit) are assigned to the early Barstovian (Ba1) NALMA based on: 1) the presence of *Hesperogaulus* Korth, 1999, which has a first occurrence during the early Barstovian; 2) the presence of *Euroxenomys* Samson and Radulesco, 1973, *Desmatippus* Scott, 1893, *Parahippus* Leidy, 1858, "*Cynorca*" Cope, 1867, and *Rakomeryx* Frick, 1937, which have their last occurrence during the early Barstovian; and 3) the presence of *Tephrocyon* Merriam, 1906, which had a limited temporal occurrence during this time period (Tedford et al. 2004). Although the Mascall Formation deposits extend into the late Barstovian (upper deposits of the middle unit and the upper unit) as inferred by U-Pb dates reported here, there are no defining taxa found in these horizons. Without diagnostic stratigraphically-constrained taxa or a better independent chronology, i.e., more dated tuffs or magnetostratigraphy in the middle and upper units, it is difficult to precisely place a boundary between the early and late Barstovian ages in the type Mascall area.

Radioisotopic Age Determinations

Zircon crystals from the Kangaroo Tuff are prismatic grains with consistent patterns of internal oscillatory zoning in cathodoluminescence. Coupled with LA-ICPMS U-Pb data, this suggests a single population of primary volcanic crystals. CA-IDTIMS analyses on eight crystals selected on the basis of zoning pattern, geochemical and age screening via LA-ICPMS yielded concordant and equivalent U-Pb dates with a weighted mean ^{206}Pb/^{238}U age of 13.564±0.018 (0.022) [0.027] Ma (n=8; MSWD=2.78; probability of fit=0.0068) (Fig. 3, Appendix 1, 2). This date is interpreted to estimate the eruption and depositional age of the volcanic deposit.

The Mascall Tuff sample contained a more diverse assemblage of rounded as well as equant to elongate prismatic grains consistent with derivation from a more heterogeneous population of magmatic and detrital grains from intraformational volcanics in the John Day Formation. Only relatively elongate, sharply facetted grains, many with adhering volcanic glass, were selected for subsequent analysis. Of the selected zircons analysed via LA-ICPMS, three were Paleogene and 38 were Miocene. Eight of the Miocene zircons were targeted for CA-TIMS. Of these, one produced an older age of 15.26 Ma.

The remaining seven grains produced a weighted mean ^{206}Pb/^{238}U date of 15.122±0.017 (0.019)[0.025] Ma (n=7; MSWD=1.65; probability of fit=0.13) (Fig. 3; Appendix 1, 2). We interpret this population as representing the pyroclastic component of the tuff sample, and thus an estimate of the eruption event and depositional age of the volcanic deposit.

The Koala Tuff sample contained few (<20) zircon crystals from a heterogenous population. LA-ICPMS spot ages of 15 crystals range from 211 to 13 Ma, with only three crystals producing Miocene ages. Results indicate the detrital nature of the Koala Tuff and demonstrate that it is a reworked deposit. A larger sample, however, may yield more Miocene crystals to allow further investigation

of the age of this tuff. The Dreamtime Tuff sample did not contain zircons and therefore was not analyzed further. Likewise, the two tuffaceous layers in the lower unit ("gray vitric tuff" at 2 m and "gray vitric tuff with black glass" at 26 m in the Rock Creek Section of Bestland (1998)), contained very few zircons and therefore further analyses were not pursued.

These new dates, combined with earlier ones (Long and Duncan 1982, Fiebelkorn et al. 1983, Hooper and Swanson 1990, Swisher 1992) place the lower boundary of Mascall Formation within the reversed polarity Chron C5Br (~16 Ma) and the Mascall Tuff within normal polarity Chron C5Bn2n (15.034–15.155 Ma), in agreement with Prothero et al. (2006). The formation has sediments
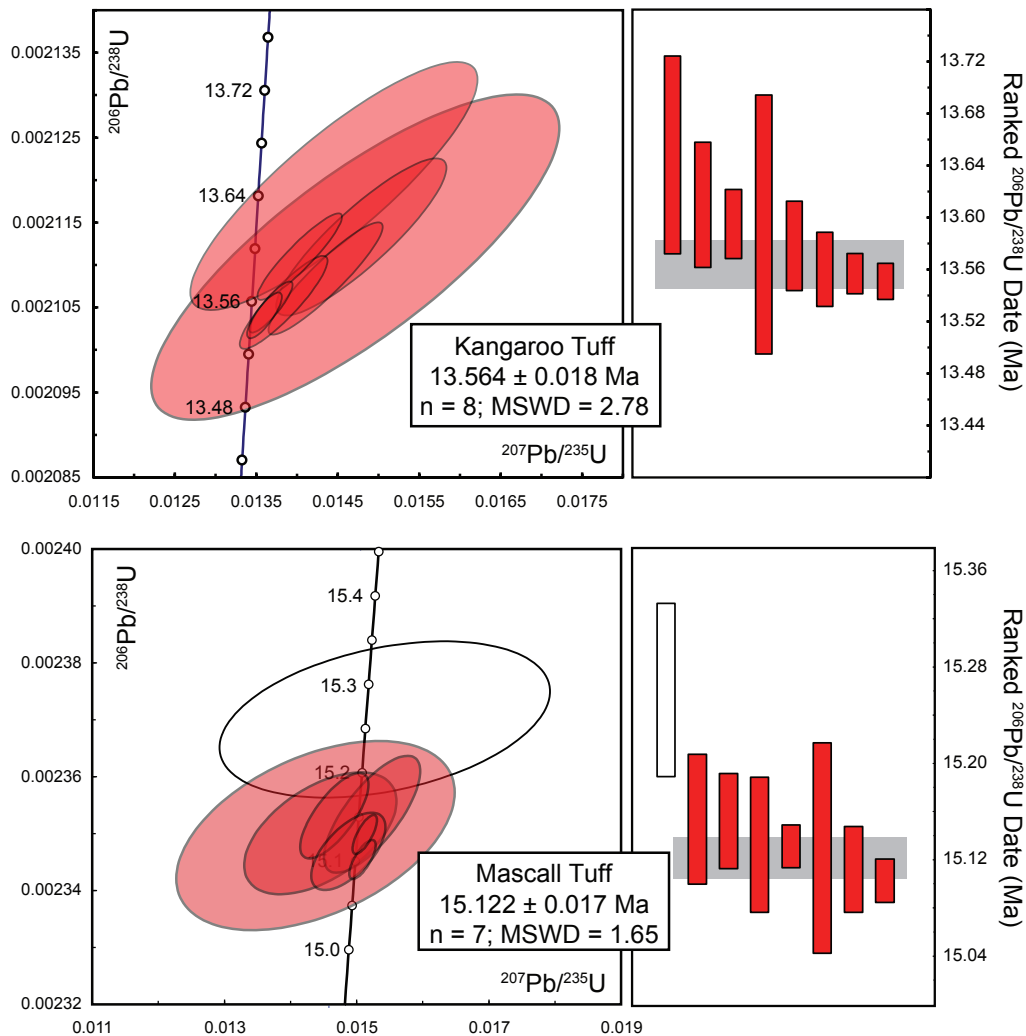
Figure 3. Chemical abrasion isotope dilution thermal ionization mass spectrometry (CA-TIMS) zircon age results as U-Pb concordia (left) and ranked ^{206}Pb/^{238}U date (right) plots for the Kangaroo Tuff (above) and Mascall Tuff (below). All error bars are plotted as 2 standard deviations. Horizontal gray bar in the ranked date plot indicates calculated age.

at least up through Chron 5ABr (13.5 Ma).

SYSTEMATIC PALEONTOLOGY

All taxa within the type Mascall area are reported. Specimens that record a new occurrence are described and some taxa previously thought to be taxonomically distinct are synonymized. Localities with an asterisk indicate the specimen was collected by the Weatherfords.

MAMMALIA Linnaeus, 1758
SORICOMORPHA Gregory, 1910
SORICIDAE Fischer von Waldheim, 1817
HETEROSORICINAE Viret and Zapfe, 1951
PSEUDOTRIMYLUS Gureev, 1971
Pseudotrimylus mawbyi Repenning, 1967
Fig. 4

Referred specimen—Left dentary fragment with m1 through m3, JODA 13865.
Occurrence—JDNM-71.
Description—Referral to this taxon was based on the following diagnostic characters: m1 is low-crowned and all cingulum are inflated; entoconid is a blunt cuspid detached from metaconid and thoroughly merged with the hypolophid; metalophid joins protolophid labially; talonid of the m3 has cresentic loph, is not distinctly bicuspid and is very small compared to the m1; the stout molars are far to the rear relative to the anterior edge of the ascending ramus; mental foramen is below the talonid of the m1 and placed in a depression on the labial side of the dentary that leads to the premolar region anterodorsally (Repenning 1967).
Remarks—Repenning (1967) described the new species *Trimylus mawbyi* from UOMNCH 19486, found five miles southwest of the south end of Guano Lake in Lake County, Oregon. He placed it within the Barstovian and noted that the associated fauna is "virtually identical to that from the Mascall Formation". UOMNCH 19486 was originally described and assigned to *Heterosorex* Gaillard, 1915 by Mawby (1960), who also noted the specimen was from a Mascall Formation equivalent. Additional referred specimens for the species are from the Beatty Buttes fauna, age equivalent to the Mascall Formation (Repenning 1967, Gunnell et al. 2008). The species was reassigned to *Pseudotrimylus* by Gunnell et al. (2008).

TALPIDAE Fischer von Waldheim, 1817
TALPINAE Fischer von Waldheim, 1817
SCALOPINI Trouessart, 1879
MIOSCALOPS Wilson, 1960
Mioscalops cf. *ripafodiator* Hutchinson, 1968
Fig. 5a, b

Figure 4. *Pseudotrimylus mawbyi* left dentary with m1–m3 in occlusal view, JODA 13865. Scale bar=1mm.

Referred specimens—From JDNM-4: right dentary fragment with partial m2 and m3, JODA 6414. From JDNM-226: left radius, JODA 15537.
Occurrence—JDNM-4, JDNM-226.
Description—The right dentary (JODA 6414, Fig. 5A) includes the posterior portion of the ramus and the masseteric fossa, but lacks the ascending ramus and associated processes. The preserved portion of the dentary is relatively robust, with a depth of 2.43 mm at the anterior margin of the m3. The molars are well-worn, but clearly low-crowned. A distinct cingulum is present on the buccal surface of both molars, and the anterior margin of the m3. The m2 is missing most of the trigonid, with only the protolophid and posterior portions of the protoconid and metaconid remaining. In both the m2 and m3 the cristid obliqua joins the metalophid lingually, and the buccal reentrant valley is deep. Low, but distinct metastylids are present in both the m2 and m3, with a small notch separating them from the entoconid crest. The m2 talonid is worn flat, but the m3 talonid is basined and shows a well-developed hypolophid and entoconid crest. The m2 has a distinct entostylid (posterior accessory cuspid of Hutchinson 1968).
The radius (JODA 15537, Fig. 5B) is incomplete, missing the capitular process and glenoid cavity from the proximal end. The approximate functional length of the radius is 6.88 mm. The distal end of the radius is 'scalloped' in medial view (Fig. 5B), as is typical of *Scalopina* (Hutchinson 1968).
Remarks—These are the only known specimens of

Talpidae from the Mascall type deposits. Both the dentary and radius were collected in situ from the Mascall Tuff. While not reported previously from the Mascall Formation, talpids are common from other mid Miocene sites in Oregon (Hutchison 1968). Hutchinson (1968) described five mole taxa from Barstovian sites in Oregon: *Mystipterus pacificus*, *Mioscalops ripafodiator*, *Domninoides* sp., *Scapanoscapter simplicidens*, and *Achlyoscapter longirostris.* All of these taxa, with the exception of *S. simplicidens*, were found at Quartz Basin, while *M.* cf. *ripafodiator*, *Domninoides* sp. and *S. simplicidens* were found at the geographically and chronologically close Red Basin (Hutchinson 1968).

Though the Mascall material is insufficient for species identification, both the morphology and size of the dentary and radius are similar to described specimens of *Mioscalops* (Ostrander 1986, *Scalopoides* of Wilson 1960, Hutchinson 1968, Gunnell et al. 2008). The teeth of JODA 6414 are relatively low-crowned, as in both *Mystipterus* Hall, 1930 and *Mioscalops*. As in *Mioscalops*, the protoconid and hypoconid of JODA 6414 are angular, there are distinct metastylids on the m2 and m3, and the cristid obliqua joins the metaconid relatively lingually (Wilson 1960, Hutchinson 1968). The metastylid and entoconid crest are present, and close the talonid lingually, as in both *Mystipterus* and *Mioscalops*, but the metastylid of JODA 6414 is relatively prominent as in *Mioscalops*. The preserved portion of the dentary is relatively robust, like that of the Barstovian *Mioscalops ripafodiator* (Hutchinson 1968).

Figure 5. *Mioscalops cf. ripafodiator.* **A.** Right dentary fragment with partial m2 and m3, JODA 6414. **B.** Radius, JODA 15537. Scale bar=1 mm.

Features of the dentition also rule out the other taxa previously described from the Barstovian of Oregon (Hutchinson 1968). In *Domninoides* Green, 1956, the cristid obliqua joins the metastylid rather than the metaconid, and the talonid is open lingually (Hutchinson 1968), unlike JODA 6414. The trigonid of JODA 6414 is not anteroposteriorly compressed, as it is in *Scapanoscapter* (Hutchinson 1968, Gunnell et al. 2008). Unlike JODA 6414, in *Achyloscapter* there is no metastylid and the cristid obliqua joins the protolophid buccal to the metaconid (Hutchinson 1968, Gunnell et al. 2008).

The radius (JODA 15537) is relatively robust compared to that of shrew-moles (Urotrichini), but relatively elongate and gracile compared to those of *Domninoides* and living Scalopini (Hutchison 1968, Freeman 1979). The radius is overall quite similar to described specimens of *Mioscalops*, suggesting a mole that was less specialization for burrowing than *Domninoides* and *Scapanoscapter*, as well as more recent Scalopini (Hutchison 1968).

CARNIVORA Bowdich, 1821
CANIDAE Fischer von Waldheim, 1817
CANINAE Gill, 1872
LEPTOCYON Matthew, 1918
Leptocyon sp.
Fig. 6a, b

Referred specimens—Right dentary fragment with p3 and p4, JODA 2312; right dentary fragment with p4, JODA 2313.

Occurrence—JDNM-4*.

Description—Referral to *Leptocyon* is based on both specimens displaying diastemata separating the premolars (characteristic of L*eptocyon* and *Vulpes* Frisch, 1775) and the presence of weak premolar cusplets (Tedford et al. 2009). As described by Tedford et al. (2009), the lower premolars are lower-crowned (note the p3 of JODA 2312) than the late Barstovian and Clarendonian *L. vafer* Leidy, 1858. Dimensions of the premolars fall within the range of *L. leidyi*; however, definitive diagnostic elements are not preserved. Measurements for each are JODA 2312: p3 ap=5.38 mm, p4 ap=6.82 mm, t=3.03 mm; JODA 2313: p4 ap=7.48 mm, t=3.01mm.

Remarks—These specimens were collected by the Weatherfords without records of provenance, making it difficult to place them into a stratigraphic framework. Occurrence of *Leptocyon* in the Mascall Formation is not surprising given its wide distribution in the early Barstovian, including records from California, Colorado, Montana, Nebraska, and New Mexico, as well as its presence at several Arikareean sites from the John Day Formation of Oregon (Tedford et al. 2009).

TEPHROCYON Merriam, 1906
Tephrocyon rurestris Condon, 1896

Holotype—From Cottonwood Creek: skull with right C1 (broken), P1 alveoli, left and right P2 through M2 (left P3 broken) and mandible with canine, p1 alveoli and left and right p2 through m3, UOMNCH 23077 (Wang et al., 1999: fig. 68).

Referred specimens—From Cottonwood Creek: partial dentary with p4 and m1, UOMNCH 24191; maxillary fragment with P4, UOMNCH 24192; left P4, M1 and M2, right P4, and left m2 and m3, YPM 12713 (Downs 1956; fig. 12a). From V4824: left M1, JODA 17392. From V4834: partial left m1, UCMP 39297 (Downs, 1956: fig. 12c). From JDNM-4*: left p4 through m2, JODA 1336; partial m1, JODA 2318; right dentary with p4-m1, JODA 2396. From JDNM-71: right M1, JODA 6644.

Occurrence—Cottonwood Creek, UCMP V4834, JDNM-4*, JDNM-71.

Remarks—These specimens were originally identified as *Tomarctus rurestris* Condon, 1896 and then recombined to *Tephrocyon rurestris* according to Wang et al. (1999). The complete description of the holotype and species description are presented in Wang et al. (1999)

CANIDAE INDET.

Referred specimens—From JDNM-4: left calcaneum, JODA 4282; P2, JODA 6413. From JDNM-4*: left calcaneum, JODA 15283; lower premolar, JODA 2393.

Occurrence—JDNM-4, JDNM-4*.

Description—The two calcanea, JODA 4282 (ap=33.91 mm, t=14.18 mm) and JODA 15283 (ap=36.8 mm, t=17.55 mm), are similar in size especially when you take into account that JODA 4282 is significantly worn, which accounts for its smaller size. JODA 6413 is a large P2 with an anteroposterior length of 8.13 mm and a transverse width of 3.95 mm. It may represent a larger canid or belong to *Tephrocyon*. JODA 2393 has an anteroposterior length of 9.27 mm and a transverse width of 5.82 mm.
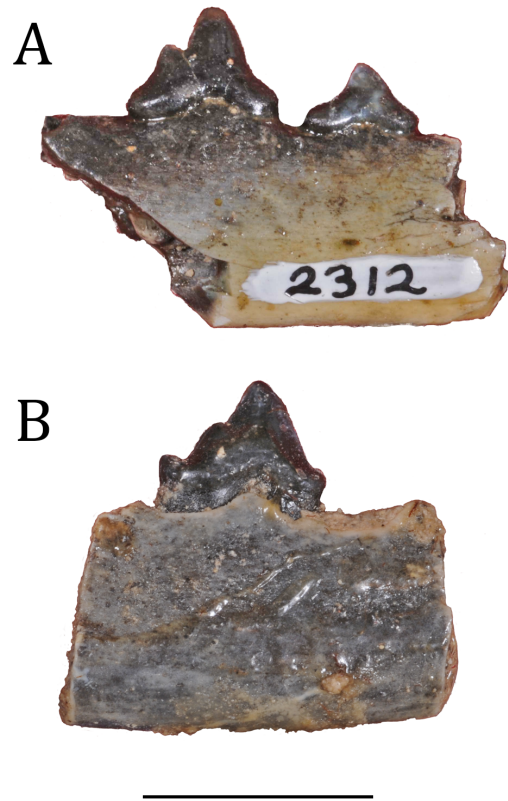
AMPHICYONIDAE Haeckel, 1886
CYNELOS Jourdan, 1862
Cynelos sinapius (Matthew, 1902) Hunt, 1998

Referred specimens—From CIT 113: right dentary with i3 through m2, CIT 207. From UCMP V4835: left calcaneum, UCMP 39304. From JDNM-4*: right M3, JODA 2315.

Occurrence—CIT 113, UCMP V4835, JDNM-4*.

Description and Remarks—The fourth premolar

Figure 6. *Leptocyon* sp. **A.** Right dentary fragment with p3-p4 in lateral view, JODA 2312. **B.** Dentary fragment with p4 in lateral view, JODA 2313. Scale bar=1cm

through second molar of CIT 207 have broken crowns; p1-p3 are worn and the canine is heavily worn on the medial side. Stock (1930) assigned CIT 207 to *Amphicyon sinapius* Matthew, 1902 based on comparisons with specimens from the lower Snake Creek and Pawnee Creek beds. *Amphicyon sinapius* was recombined as *Cynelos sinapius* by Hunt (1998). Confirmation of identification is based on the size of m1 (ap=38 mm), which falls within the range reported in Hunt (1998). In addition, the lower third premolar is the same size as p2 and neither have accessory cusps. p1 is lost and p4 does not have posterior accessory cusps. Overall the premolars are slender and laterally compressed and m2 is rectangular. The locality description is listed as Dayville, Oregon so exact location in unknown; however, Stock (1930) mentions that the specimen was found in Mascall deposits and he was aware of issues associated with Rattlesnake and Mascall faunas mixing in the area. UCMP 39304 has a maximum anteroposterior length of 85.07 mm and transverse width at the sustentaculum of 42.6 mm. It is assigned to *C. sinapius* based on size, however, this is a tentative identification. JODA 2315 is also tentatively assigned to

C. sinapius. It has an anteroposterior length of 10.23 mm and a transverse width of 15.48 which is small for the species. This specimen was collected by the Weatherfords; however, if it came from the Rattlesnake it would mean either that *C. sinapius* ranges higher than the Mascall, or that there is a Hemphillian amphicyonid with very similar morphology. Given that there are no known Hemphillian records of amphicyonids in North America (Hunt 1998) we place this specimen in the Mascall Formation.

FELIDAE GRAY, 1821
PSEUDAELURUS GERVAIS, 1850
Pseudaelurus sp.
FIG. 7

Referred specimen—Right complete astragalus, JODA 15306.

Occurrence—JDNM-4*.

Description and Remarks—The size of this astragalus (length=35.88 mm, width at trochlea facet=20.08 mm, width at head=19.46 mm) is the same as examined specimens of *Puma concolor* Linnaeus, 1771 (length=36.60 mm, width at trochlea facet=20.86 mm, width at head=20.28 mm), but the neck is longer and the head is oriented more perpendicular to the trochlea facet. Shotwell (1968) found an upper canine, lower m1, and a fragment of a P4 (UOMNCH 23469) of a similarly large felid from Red Basin locality 2495. The m1 measures 16.1 mm, close in size to a specimen of *Puma concolor*, which measured 15.6 mm (Rothwell 2003). Three species of *Pseudaelurus* exhibit similar m1 lengths, and their ranges overlap the aforementioned specimens (*P. validus* Rothwell, 2001, *P. intrepidus* Leidy, 1858, *P. marshi* Thorpe, 1922) (Rothwell 2003); therefore, we cannot identify this specimen to species. JODA 15306 was collected by the Weatherfords and has preservation typical of Mascall Formation specimens, but the exact provenance is unknown and it is impossible to say whether or not the specimen was actually recovered from the Mascall or Rattlesnake. McLaughlin et al. (2016) identified a right mandibular ramus with broken c, p3, p4 and m1 (JODA 14977) as the late Hemingfordian *P. skinneri* Rothwell, 2003 from Hawk Rim. The last occurrence of *Pseudaelurus* in North America is during the late Barstovian (Rothwell 2003), which would be consistent with the occurrence in the Mascall.

MUSTELIDAE FISCHER VON WALDHEIM, 1817
LEPTARCTUS LEIDY, 1857
Leptarctus oregonensis STOCK, 1930

Holotype—From CIT 113: Left partial maxilla with P4 and M1, right partial maxilla with P4, right M1, incisor, nasals, zygomatic arches, occipital crest, CIT 206.

Referred specimens—From JDNM-262: partial skull including the cranial cavity, zygomatic arches, and complete palate with left and right M1, UOMNCH 10869. From V4824: right P4, UCMP 39102. From V4825: dentary fragment with right m1 and the two roots of p4, JODA 3335. From JDNM-71: left second phalanx, JODA 7500.

Occurrence—CIT 113, JDNM-262, UCMP V4824, UCMP V4825, JDNM-71.

Remarks—This species is well documented from the Mascall in Stock (1930) and Downs (1956). UOMNCH 10869, recovered from the Mascall Tuff during road excavation, has recently been described by Calede et al. (2012). JODA 7500 extends the known range of the species to the lower Mascall unit. CIT 206 dimensions of the individual teeth are P4: ap=6.03 mm, t=4.81 mm; ap=6.3 mm, t=5.18 mm; M1: ap=7.12 mm, t=6.2 mm; ap=6.9 mm, t=6.51 mm; I: ap=2.38 mm, t=1.8 mm. The locality for the type specimen (CIT 113) is described by Stock (1930) as "Mascall deposits north of the east fork of the John Day River, approximately, 1.5 miles northwest of Dayville, Oregon.

MUSTELIDAE INDET.

Referred specimens—Left dentary fragment with p4, m1, and alveoli for m2, UCMP 39958.

Occurrence—UCMP V67153.

Description and Remarks—UCMP 39958 is described in Downs (1951). The talonid and trigonid are about equal in length. The talonid is slightly basined with an internal cingulum that merges with the metaconid. The hypoconid is separated from the protoconid by a deep, worn groove. The trigonid is open with a medium-sized metaconid, posterior to the protoconid. The p4 has a posterior notch. It is unlike the Barstovian mustelid *Plionictis* Matthew, 1924 in that the trigonid of m1 is not much longer than the talonid and the talonid

Figure 7. *Pseudaelurus* sp. Right astragalus in dorsal view, JODA 15306. Scale bar=1cm.

is not narrow. It is too small to be *Sthenictis* Peterson, 1910, another Barstovian mustelid. UCMP 39958 is unlike *Watay tabutsigwii* McLaughlin, Hopkins and Schmitz, 2016 from Hawk Rim, as that taxon has a trenchant talonid like hypercarnivorous ischyrictines. The talonid of UCMP 39958 is basined as in *Martes* Frisch, 1775. It was originally identified as *Martes* (Downs 1951); however, Anderson (1994) and Hughes (2012) have questioned whether many "*Martes*" taxa prior to the late Miocene were related to the extant genus. Sato et al. (2003) suggested the oldest true *Martes* is *M. wenzensis* Frisch, 1775 from the Pliocene of Poland (Wolsan 1989). Anderson (1994) suggested the extant *Martes americana* Turton, 1806 is a late Pleistocene immigrant to North America. The locality for UCMP 39958 is unknown (V67153 is assigned to specimens with no locality information for the Mascall Formation). The specimen tag in the UCMP says Mascall or Rattlesnake Formation. Downs (1951) mentions UCMP 39958 and states "it cannot be considered a valid Mascall allocation" (pg. 102). Given the material, more precise taxonomic identification is not possible and it remains unknown if this specimen belongs to the Mascall or Rattlesnake Formation. The oldest known and well-dated member of the subfamily including *Martes*, the Guloninae, is *Pekania occulta* Samuels and Cavin, 2013 from the Rattlesnake Formation.

PROCYONIDAE Gray, 1825
PROCYONINI Gray, 1825
BASSARISCUS Coues, 1887
?Bassariscus lycopotamicus Cope, 1879

Referred specimen—No specimen number available.
Occurrence—"Loup Fork of Cottonwood Creek" (Cope 1879, p.67).
Description—The type specimen, a lower jaw described by Cope (1879), has been lost but is figured in Cope and Matthew (1915). Gregory and Downs (1951) provide the taxonomic history of this specimen. They also provide a thorough description of the specimen and assign it to *?B. lycopotamicus*.
Remarks—Cope (1879) only mentions "Loup Fork of Cottonwood Creek" for locality information, therefore making it impossible to assign this specimen to either the Mascall or the Rattlesnake Formation. Gregory and Downs (1951) mention a second specimen attributable to this species from Paulina Creek (YPM 14313), but state their uncertainty of whether it came from Miocene or Pliocene deposits.

CARNIVORA INDET.

Referred specimens—From UCMP V4830: lower

canine, UCMP 39107. From V4834: axis, JODA 15606. From -903: distal section of a metatarsal or metacarpal, UCMP 2076. From JDNM-262: vertebra, JODA 15340.
Occurrence—UCMP V4830, V4834, UCMP -903, JDNM-262.
Description and Remarks—UCMP 39107 and UCMP 2076 are described in Downs (1956). The length of JODA 15340 is 27.36 mm. This specimen was recovered from the Mascall Tuff, in situ.

LAGOMORPHA Brandt, 1885
LEPORIDAE Fischer von Waldheim, 1817
HYPOLAGUS Dice, 1917
Hypolagus fontinalis Dawson, 1958
Fig. 8a, b

Referred specimens—From UCMP V4833: left p3, UCMP 41205; left p3, JODA 4283.
Occurrence—UCMP V4833.
Description—UCMP 41205 has a posteriorly inflected posteroexternal reentrant (PER) and a well-incised anteroexternal reentrant (AER). PER is uncrenulated and larger than in *H. parviplicatus* Dawson 1958. The third premolar has an anteroposterior length of 3.04 mm and transverse width of 2.42 mm. Based on the posteriorly inflected PER and smaller size than *H. parviplicatus* this specimen is assigned to *H. fontinalis*. The PER on JODA 4283 is not inflected posteriorly and there are no crenulations on the thin enamel of the PER (TN). The anteroposterior length is 2.86 mm and the transverse width is 2.1 mm falling within the size range for *H. fontinalus* (Voorhies and Timperley 1997). This specimen is placed in this taxon based on the uncrenulated TN and size.
**Remarks**—This is the first record of this species in the Barstovian of Oregon. The sizes of the Mascall *H. fontinalis* specimens fall between the average measurements for *H. fontinalis* and *H. parviplicatus* in Voorhies and Timperley (1997), but within the range of variation of the former. *Hypolagus fontinalis* differs from the other Barstovian species *H. tedfordi* White, 1988, *H. parviplicatus*, and *H.* cf. *voorhiesi* White, 1988 in the following ways: it differs from *H. tedfordi* in the posterior deflection of the PER and its larger ap length; it differs from *H. parviplicatus* in its smaller size, more well-incised AER, and an uncrenulated TN on the PER; and from all other species of *Hypolagus* in having a shallower incision of the PER (White 1988).

Hypolagus parviplicatus Dawson, 1958
Fig. 8c, d

Referred Specimens—From JDNM-4*: left p3, JODA 2326; left dentary with p3 through m2, JODA 2328. FROM CIT 183: right p3, CIT 4002.
Occurrence—JDNM-4*, CIT 183*.
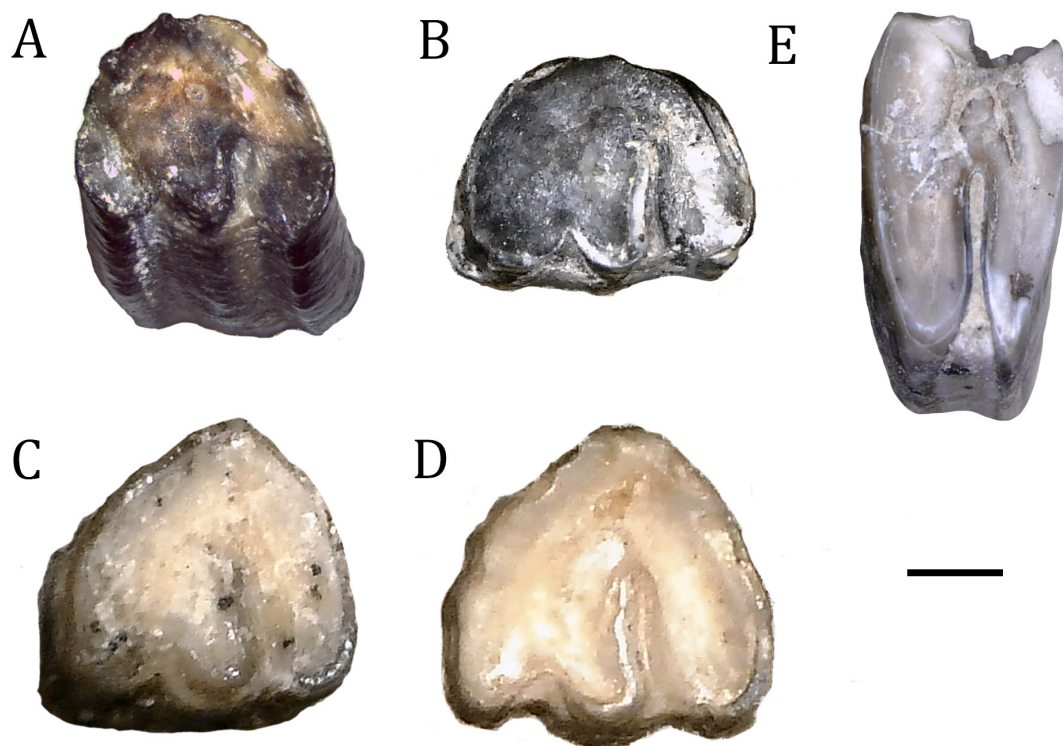
Figure 8. Leporidae. **A, B.** *Hypolagus fontinalis* left p3, UCMP 41205 (**A**),JODA 4283 (**B**). **C, D.** *Hypolagus parviplicatus* left p3, JODA 2328 (**C**); JODA 2326 (**D**). **E.** *Archaeolagus* sp. left M1 or M2, JODA 17386. All in occlusal view. Scale bar=1mm

Description—JODA 2326 does not have an inflected PER, AER is very shallow, thick enamel in PER (TH) is crenulated, ap=3.07 mm and t=3.15. The transverse width places this specimen within the size range of *H. parviplicatus* (Voorhies and Timperley 1997). The p3 of JODA 2328 has a shallow AER, the PER is straight with no crenulations on the TN, ap=3.04 mm and t=3.26 mm also consistent with placing the specimen in *H. parviplicatus*. CIT 4002 has a shallow AER and the PER does not inflect posteriorly. Unfortunately, the PER is not preserved well enough to make out whether the TN is crenulated, as is characteristic of *H. parviplicatus*. The specimen has an anteroposterior length of 2.96 mm and a transverse width of 3.01 mm, which is on the smaller end of the size range of the species, closer to *H. fontinalus*.

Remarks—CIT 4002 also contains three lower molars and one upper molar. All of these specimens were found in isolation by Weatherfords; therefore, we are hesitant to attribute them to the same species as CIT 4002, given that they cannot be distinguished morphologically and such assignment would be based on presumed age, thus introducing circularity. Instead, the Weatherford specimens are referred to Leporidae indet. and discussed below. This is the first record of this species in Oregon. The specimens differ from other Barstovian species of *Hypolagus* in the following ways: it is larger and has a less well incised AER than *H. fontinalis* and *H. tedfordi*, and from all other species in its less incised PER.

ARCHAEOLAGINAE Dice, 1929
ARCHAEOLAGUS Dice, 1917
Archaeolagus sp.
Fig. 8e

Referred specimens—left M1 or M2, JODA 17386.
Occurrence—JDNM-71A.
Description—The tooth has a strong, straight-walled cement-filled hypostria (lingual reentrant) crossing about halfway across the occusal surface of the tooth. Though the posterolabial corner of the tooth is missing, enamel is clearly absent from labial margin of tooth. There is an isolated chevron just labial to the hypostria. Anteriorposterior length is 2.08 mm and transverse width is 3.63 mm.

Remarks—This tooth is very similar to *Archaeolagus* specimens from the John Day Formation, which range from base of the Turtle Cove Member (Whitneyan) through the Johnson Canyon Member (late Arikareean) and are particularly abundant in upper John Day strata (Samuels and Kraatz 2015). There are

at least two species of *Archaeolagus* known from the John Day Formation, *A. ennisianus* Cope, 1881 and *A. primigenius* Matthew, 1907, both of which are similar in morphology to the Mascall specimen. JODA 17386 falls within the range of size variation for M1 samples of those two species in Oregon: *A. ennisianus* (n=16) M1ap mean=2.01 mm (range=1.89–2.19 mm), M1t mean=3.58 mm (range=2.95–3.89 mm); *A. primigenius* (n=6) M1ap mean= 2.06 mm (range=1.95–2.17 mm), M1t mean=3.46 mm (range=3.29–3.71 mm). This record is much younger than others in Oregon and may be the latest known occurrence of the genus, later than all records listed in Dawson (2008).

LEPORIDAE INDET.

Referred specimens—From UCMP V4830: ilium and ischium, UCMP 41204; proximal left third metatarsal, JODA 15318. From UCMP V4832: proximal end of tibia, UCMP 41211; left upper and lower molars, UCMP 39299; left dentary with m1 and incisor, UCMP 39294. From UCMP V4834: upper molars, JODA 4253 and JODA 4256; two lower molars, one upper molar, and 1 incisor, JODA 15294; proximal second metatarsal, JODA 15291; right partial calcaneum, JODA 15742. From JDNM-4*: upper molars, JODA 2325 and JODA 2327. From CIT 183*: 3 lower molars and 1 upper molar, CIT 4002; 5 premolars, CIT 4002A. From JDNM-266: 3 podial phalanges and terminal phalanx, JODA 15517. From JDNM-71: upper molar, JODA 3330. From JDNM-270: left calcaneum, JODA 15633.

Occurrence—UCMP V4830, UCMP V4832, UCMP V4834, JDNM-4*, CIT 183*, JDNM-266 JDNM-71, JDNM-270.

Description—UCMP 41211, a proximal tibia measuring 13.75 mm anteroposteriorly and 13.75 mm transversly. Crenulate hypostria in the upper molars indicate that these specimens are not *Archaeolagus*, but could be

Figure 9. *Balantiomys oregonensis* right dp4 in occlusal view, JODA 3767. Scale bar=1mm.

Hypolagus. Some of the molars listed above are within the size range of and could be attributed to *H. fontinalus*, while others are larger and could represent *H. parviplicatus*, but because they are not diagnostic they are not assigned to either species. Measurements for each tooth are included in Table 3. JODA 15633, a complete left calcaneum, has a length of 25.37 mm and width at the proximal end of 6 mm. JODA 15742, an incomplete right calcaneum, has a width of 4.52 mm at the proximal end.

Remarks—Downs (1956) identified CIT 4002, which includes a right p3, 4 right lower molars and one upper molar, as cf. *H. vetus* Kellogg, 1910. The p3 is reidentified above as *H. parviplicatus*, but the remaining specimens are not identified further than Leporidae because they do not show diagnostic features. JODA 15633 confirms the presence of leporids in the upper member of the Mascall Formation, making this group one of only four that spans the entire formation. JODA 15742, also a calcaneum, is smaller than 15633, again indicating more than one species of leporids was present in the Mascall fauna.

RODENTIA Bowditch, 1821
HETEROMYIDAE Gray, 1868
MIOHETEROMYINAE Korth, 1997
BALANTIOMYS Korth, 1997
Balantiomys oregonensis Gazin, 1932
Fig. 9

Referred specimens—From CIT 1869: left dentary with p4 through m3, CIT 4001; isolated P4, M1, M2 and M3, CIT 3999. From UCMP -3043: left dentary with dp4 and partial m1, JODA 3767. From UCMP V4823: upper right M3, JODA 15648.

Occurrence—CIT 1869*, UCMP -3043, UCMP V4823.

Description—CIT 4001 is tentatively placed in this genus on the following characteristics of the p4: metalophid cusps large and subequal in size, no anterioposterior valley between the metaconid and protostylid, anterostylid on anterior slope of protostylid. CIT 3999 is also tentatively placed in this genus, following Downs (1956). JODA 3767 is the first occurrence of a dp4 for the species (Fig. 9). The posterior cingulum is broad anteroposteriorly, connecting centrally to the hypoconid and entoconid. The hypoconid and entoconid are equal in size. The central enamel ridge connects to the protosylid. The protoconid/metaconid complex is crescent shaped.

Remarks—Korth (1997) has *B. oregonensis* as the only species belonging to the genus outside of the Great Plains. Full descriptions and a thorough discussion of CIT 3999 and 4001 are in Downs (1956). Overall, the specimens are fragmentary and well-worn, therefore, making identification difficult. Both specimens are from the Bode collection of 1929 and assigned to CIT location 1869. CIT 4001 is labeled from "West of Dayville

Highway" and was purchased by the Weatherfords. CIT 3999 is labeled from "North of Dayville". Downs (1956) identified UCMP 442, a partial skull with P4 through M3, as *Peridiomys* cf. *oregonensis* Gazin, 1932 and claims it is from the Mascall based on this identification even though it was originally assigned to the Hemingfordian of the John Day Formation. It is not an entoptychine based on the protoloph shape of the P4, however, the amount of wear makes it impossible to assign this specimen to *B. oregonensis* rather than to another primitive heteromyid. An additional specimen from CIT 1869, CIT 4000, is a dentary with heavily-worn p4–m2 making identification beyond Heteromyidae difficult; however, it does fall within the size range of *B. oregonensis*.

PRODIPODOMYS Hibbard, 1939
Prodipodomys mascallensis Downs, 1956

Holotype—From V4830: left dentary with i1, p4 through m3, UCMP 39094.

Referred specimens—From V4833: partial maxilla with partial palate, left P4 and M1, UCMP 39895. From CIT 1869: p4 and m1, CIT 4002B.

Occurrence—V4830, V4833, CIT 1869.

Description—All material is described in Downs (1956). For UCMP 39094 and CIT 4002B the p4 has an X-pattern and 2 roots, the m1 and m2 are subequal with an H-pattern, and the m3 is small. UCMP 39895 is assigned here to this taxon, but may belong to *Cupidinimus halli* Wood, 1936 based on the following: the protocone on P4 is distinct and does not attach to the hypostyle lingually; however, it connects to the metacone-hypocone complex more lingually than other species in the genus.

Table 3. Specimen measurements of Leporidae indet. **ap**=anteroposterior length; **t**=transverse width.

Specimen		ap (mm)	t (mm)
JODA 4253	MX	2.21	4.06
JODA 4256	MX	2.37	3.61
JODA 2325	MX	2.69	4.76
JODA 2327	MX	2.11	3.68
JODA 15294	mX	2.80	3.33
	mX	2.38	2.50
	MX	1.91	2.95
	I	--	2.35
UCMP 39299	mX	2.67	2.51
	MX	2.13	3.68
UCMP 39294	m1	2.56	2.94

There is no accessory cusp on the P4. The P4 is slightly wider than the M1.

Remarks—Downs (1956) originally assigned the type specimen to *P.? mascallensis*. It was reassigned to *Mojavemys mascallensis* Downs, 1956 by Lindsay (1972) and Barnosky (1986). Korth (1979) and Whistler (1984) suggested it should be assigned to *Cupidinimus* Wood, 1935, but did not provide evidence for doing so. Wahlert (1991) used *P. mascallensis* for comparison with *Harrymys* Munthe, 1988 and suggested that it was a candidate to include in *Harrymys* based on the R-shaped lower molars. It is assigned to *P. mascallensis* by Flynn et al. (2008). Downs (1956) assigned UCMP 39895 tentatively to *Peridiomys* cf. *oregonensis* Gazin, 1932 but was unsure if it belonged to Heteromyinae or Perognathinae. The hypsodonty of the premolar and first molar place it within Dipodomyinae (Flynn et al. 2008). Korth (1997) discusses the taxonomic confusion surrounding *P. mascallensis* because its cheek teeth are smaller and higher crowned than *Peridiomys* Matthew, 1924, it is stratigraphically much older than the otherwise first occurrence of *Prodipodomys* in the Hemphillian, and it is much smaller with lophate, lower-crowned molars than any species of *Mojavemys* Lindsay, 1972, suggesting it may represent an as yet unnamed genus of heteromyid.

GEOMYIDAE Bonaparte, 1845
GEOMYIDAE INDET.

Referred specimen—Dentary fragment with p4 through m2, JODA 3770.

Occurrence—UCMP -3043.

Description—The m1 and m2 of this specimen are broken down the middle but remain largely intact. All three teeth are heavily worn. The metalophid on the p4 is wide, flattened anteriorly and has broad connection with the hypolophid. The hypolophid has three cusps. This specimen is placed in Geomyidae based on the premolar's larger size than the molars.

Remarks—This specimen is similar to the entoptychine, *Gregorymys* Wood, 1936, by having p4 longer than the m1 and a hypolophid with three cusps (Flynn et al. 2008). It is unlike the geomyine, *Parapliosaccomys* Shotwell, 1967, because the metalophid is wide, and it is too small to be *Geomys* Rafinesque, 1817. JODA 3770 could be *Gregorymys*, but there is no anterior cingulum on the p4; however, that character is known to be variable in the genus (Flynn et al. 2008).

MYLAGAULIDAE Cope, 1881
HESPEROGAULUS Korth, 1999
Hesperogaulus gazini Korth, 1999

Referred specimens—From UCMP V4827: Nearly complete skull with partial P4 and complete M3, JODA 3308; From JDNM-4*: M2, JODA 2330.

Occurrence—UCMP V4827, JDNM-4*.

Description—Specimens are described in Calede and Hopkins (2012).

Remarks—A third specimen of this species (JODA 8678) is known from Coburn Wells in the Simtustus Formation, a Mascall equivalent ~113 km (70 miles) west of the type locality for the formation.

MYLAGAULIDAE INDET.

Referred specimens—From JDNM-4*: Partial left dentary with dp4 through m2 and erupting p4, JODA 2329. From UCMP -3059: right partial dentary with m1, m2, and erupting m3, UCMP 39292.

Occurrence—JDNM-4*, UCMP -3059*.

Description—JODA 2329 is described in Calede and Hopkins (2012). UCMP 39292 has quadrate m1 with 5 fossettes and two roots, more ovoid m2 with 5 fossettes and an unworn m3 with pronounced metaconid.

Remarks—Because JODA 2329 is a juvenile specimen, Calede and Hopkins (2012) did not assign it to a species but suggested it is either *Alphalaugus vetus* Matthew, 1924 or *Hesperogaulus gazini*. *Alphalaugus vetus* has been recovered from Mascall age-equivalent deposits in the Crooked River region to the south, but has not been identified from the type Mascall area to date. It was found by the Weatherfords and therefore the exact locality is unknown. UCMP 39292 may also belong to *A. vetus* or *H. gazini* based on size, but without the p4 it is impossible to identify further.

SCIURIDAE Gray, 1821
XERINAE Osborn, 1910
MARMOTINI Pocock, 1923
MARMOTINA Moore, 1959
PROTOSPERMOPHILUS Gazin, 1930
Protospermophilus oregonensis Downs, 1956

Holotype—Left dentary with i1, p4 through m3 and without coronoid and condylar processes, UCMP 39093.

Paratype—Left p4, UCMP 40241.

Occurrence—UCMP V4828.

Description—The type and paratype are described in Downs (1956) and Black (1963).

Remarks—Downs (1956) assigned the species to *Arctomyoides* Bryant, 1945 and Black (1963) reassigned it to *Protospermophilus*. The locality, UCMP V4828, is in deposits typical of a marginal lacustrine environment and possibly from the earliest sections of the formation (Downs 1956). We did not visit this site because it is on inaccessible private land; however, the other Mascall sites in the area (which were visited) are in the Lower Mascall, consistent with the interpretation in Downs (1956).

Protospermophilus malheurensis Gazin, 1932
Fig. 10

Referred specimen—Left M1, JODA 6416.

Occurrence—JDNM-4.

Description—The M1 is quadrate with four transverse lophs. It is assigned to this taxon based on the following: all of the lophs unite at the protocone; the anteroloph is convex anteriorly and attaches to the protocone lingually; the protoloph is straight and has a small protoconule; the metaloph is convex posteriorly, has a distinct metaconule and unites with the protocone, but narrows dramatically lingually; the posteroloph is expanded lingually to form an incipient hypocone (Goodwin 2008), is convex posteriorly and outward from the protocone, and unites with the metacone labially. There is a small mesostyle between the paracone and metacone.

Remarks—This is the first occurrence of this species in the Mascall Formation. It was recovered as float 2 m below the Mascall Tuff in the type area. The species was originally described as *Sciurus tephrus* by Gazin (1932) from the contemporaneous Skull Springs locality (Butte Creek Volcanis Sandstone Formation) in southeastern Oregon.

SCIURINAE Baird, 1857
SCIURINI Burmeister, 1854
SCIURINI INDET.
Fig. 11

Referred specimens—From JDNM-4: unprepared cranial and postcranial skeleton, JODA 6725; right, astragalus, JODA 15793.

Occurrence—JDNM-4

Description—JODA 6725 represents a potentially complete cranial and partial postcranial skeleton, presently embedded in a block of the Mascall Tuff. A few isolated fragments are currently free from the matrix, including the proximal end of the right humerus. The humerus of JODA 6725 is slightly smaller than that of extant *Sciurus*, and generally similar in morphology. The infraspinatus muscle insertion on the greater tuberosity is within a shallow depression, with the posterior margin flush with the articular surface of the head of the humerus. The deltoid ridge is narrow, but with distinct margins.

In JODA 15793 the lateral ridge of the trochlea is much larger than the medial ridge, the neck of the astragalus is

long and medially directed, the head of the astragalus is somewhat saddle-shaped, the astragalo-navicular facet and sustentacular facets are joined, the sustentacular facet is well-separated from the ectal facet, and there is a well-developed medial plantar tuberosity.

Remarks—There is a substantial gap between the latest confirmed records of *Protosciurus* in the Hemingfordian and the appearance of *Sciurus* in the Clarendonian (Emry et al. 2005, Goodwin 2008). Besides the specimens noted here, the only other early Barstovian records of tree squirrels in North America are specimens questionably assigned to *Protosciurus* from the Hidalgo Bluff and Trinity River local faunas on the Gulf Coast of Texas (Lezak 1979, Albright 1996). These specimens confirm the presence of tree squirrels in the Mascall fauna and their persistence in the region from the Oligocene through the mid Miocene. There is a definite similarity of the Mascall Formation specimens to both recent *Sciurus* and to Oligocene and early Miocene *Protosciurus*.

JODA 6725 and 15793 have a number of features that are characteristic of tree squirrels. In the proximal humerus of JODA 6725 the infraspinatus insertion and narrow deltoid ridge are characteristic of tree squirrels (Sciurini) (Emry and Thorington 1982, Emry et al. 2005). In contrast, ground squirrels (Marmotini) have a broad deltoid ridge and insertion of the infraspinatus into a pit on the greater tuberosity (Emry and Thorington 1982). As in extant Sciurinae (both tree squirrels—Sciurini, and flying squirrels—Pteromyini), the neck of the astragalus (JODA 15793) is long and medially directed, while the head of the astragalus is somewhat saddle-shaped (Emry and Thorington 1982, Ginot et al. 2016). As in extinct and extant Sciurini, the lateral ridge of the trochlea in JODA 15793 is much larger than the medial ridge, the astragalo-navicular facet and sustentacular facets are joined, while the ectal facet is well-separated, and there is a well-developed medial plantar tuberosity that forms a characteristic "hook" (Emry and Thorington 1982, Ginot et al. 2016). The two trochlear ridges are more similar in size and the astragalo-navicular facet and sustentacular facets are separated in ground squirrels (Marmotini) (Ginot et al. 2016). The sustentacular facet is not well-separated from the ectal facet in Pteromyini (Ginot et al. 2016). Overall, the morphology of the astragalus, JODA 15793, is most similar to *Protosciurus*, which is well-known from the John Day Formation (Korth and Samuels 2015). This is particularly true of the head of the astragalus, which is somewhat saddle-shaped in JODA 15793 and *Protosciurus*, but not to the extent observed in *Sciurus* (Emry and Thorington 1982, Ginot et al. 2016).

JODA 6725 is embedded in a soft tuffaceous matrix and particularly fragile, as a result it has not been prepared. Once extracted from the surrounding matrix, this specimen has the potential to fill an important gap in the record of tree squirrel evolution in North America.

SCIURIDAE INDET.

Referred specimens—From UCMP V4823: right calcaneus, JODA 15794. From JDNM-4: distal humerus, JODA 15750. From JDNM-70: right distal tibia, JODA 4278. From JDNM-71: incisor fragment, JODA 15769.
Occurrence—UCMP V4823, JDNM-4, JDNM-70,

Figure 10. *Protospermophilus malheurensis* left M1 in occlusal view, JODA 6416. Scale bar=1mm.
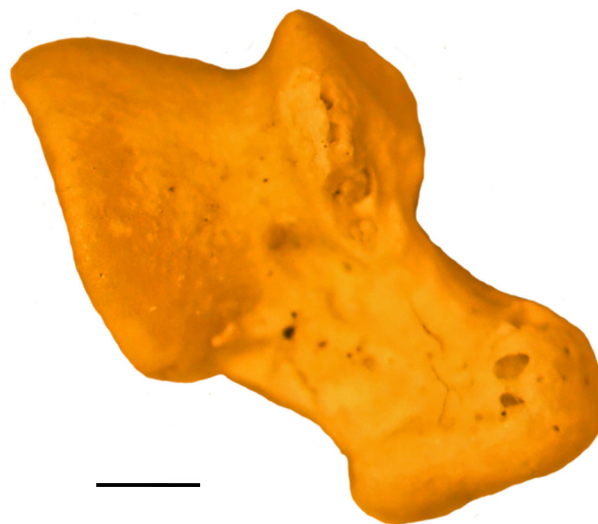
Figure 11. Sciurini right astragalus, JODA 15793. Scale bar =1mm.

JDNM-71.

Description—Length of JODA 15794, right calcaneus, is 7.7 mm. In JODA 15794 the tuber calcaneus is short and mediolaterally broad, the sustentacular facet is round and separated from the ectal facet by a broad groove, the peroneal process lies opposite the sustentacular facet, and the peroneal groove is weak and indistinct. The right distal tibia, JODA 4278, is similar in shape and size to *Sciurus niger* Linnaeus, 1758. The incisor, JODA 15769, is oval in cross section with a larger anteroposterior length than transverse width and a subtle rugosity of the enamel surface, as is characteristic of Sciuridae.

Remarks—This fragmentary postcranial material and incisor demonstrate the persistence of squirrels through the lower, middle and upper units of the Mascall Formation. JODA 15750 was collected from the Mascall Tuff in the type area. JODA 15794 was most likely collected from the upper unit deposits close to V4823. The morphology of JODA 15794 suggests that it comes from a ground squirrel (Marmotini). As is characteristic of marmotines, in JODA 15794 the tuber calcaneus is short and mediolaterally broad, the sustentacular facet is round and separated from the ectal facet by a broad groove, the peroneal process lies opposite the sustentacular facet, and the peroneal groove is weak and indistinct (Emry and Thorington 1982, Ginot et al. 2016). Unlike JODA 15794, in sciurines (Sciurini) the tuber calcaneus is elongate and laterally compressed, the sustentacular facet is triangular and very close to the ectal facet, the peroneal process is distally located, and the peroneal groove is distinct (Emry and Thorington 1982, Korth and Samuels 2015, Ginot et al. 2016).

CRICETIDAE Fischer von Waldheim, 1817

Referred specimen—Incisor, JODA 4957.
Occurrence—UCMP V4834.
Description—The incisor is a long oval shape (deeper than wide) in cross section with a curved face, bearing no ornamentation. The incisor has a length of 11.92 mm.
Remarks—*Copemys* Wood, 1936 (known from the Barstovian Sucker Creek, Quartz Basin and Skull Springs localities) has an incisor size and shape consistent with this specimen and similarly lacks ornamentation (Lindsay 2008). The eomyids *Pseudadjidaumo* Shotwell, 1956 (known from the Barstovian Quartz Basin locality) and *Leptodontomys* Shotwell, 1956 (known from Arikareean, Clarendonian, and Hemphillian localities in Oregon) are far smaller than *Copemys* and JODA 4957 (Shotwell 1956, Korth and Samuels 2015). In addition, *Pseudadjidaumo* has rounded enamel and smooth incisors (Flynn 2008). The eomyid *Pseudotheridomys* Schlosser, 1926 (known from the Barstovian Skull Springs and Quartz Basin localities) is similar in size to *Copemys*, but it bears a transversely compressed incisor (Shotwell 1967). This
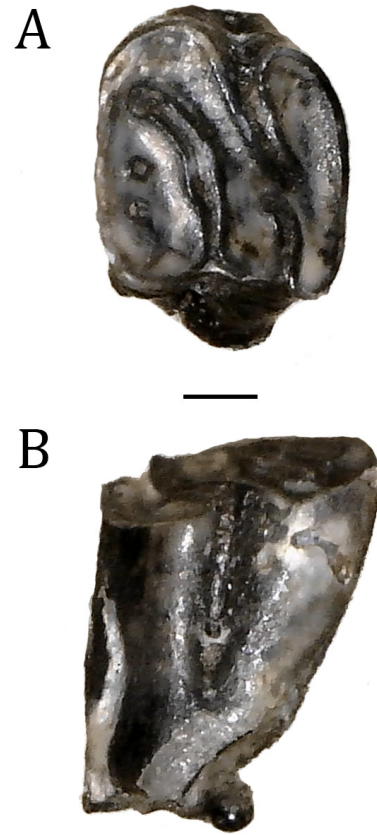
Figure 12. *Euroxenomys* sp. left P4, JODA 4682. **A.** Occlusal view. **B.** Medial view. Scale bar=1mm.

specimen marks the only identifiable occurrence of cricetids in the Mascall Formation, collected from the Mascall Tuff. The lack of cricetid material, however, is most likely due to preservational issues.

CASTORIDAE Gray, 1821
CASTOROIDINAE Allen, 1877
EUROXENOMYS Samson and Radulesco, 1973
Euroxenomys sp.
Fig.12A, B

Referred specimen—Left P4, JODA 4682.
Occurrence—JDNM-4.
Description—The P4 is rooted and mesodont, and measures ap=3.6 mm and t=3.7 mm. The tooth is dominated by a deep hypoflexus and mesoflexus, though a paraflexus and two metafossettes are present. The hypoflexus is long, extending anteriorly and buccally beyond the paraflexus. The paraflexus extends about 1/3 across the occlusal surface of the tooth and due to wear it is almost closed to create a parafossette. The mesoflexus is long and the lingual portion curves posteriorly. Posterior

to the mesoflexus there are two small fossettes comprising the metafossette. The tooth is well worn, but the hypostria is long, extending to the base of the enamel, and the parastria is persistent.

Remarks—Both *Euroxenomys* and *Monosaulax* Stirton, 1935 are fairly similar in dental morphology, and are known from early and middle Miocene sites in North America (Sutton and Korth 1995, Flynn et al. 2008). JODA 4682 belongs to *Euroxenomys* based on the rooted, mesodont P4 with a long hypostria and persistent parastria. While *Monosauualax* also displays rooted, mesodont premolars with a generally similar loph pattern, the stria of that taxon are distinctly shorter (Sutton and Korth 1995, Flynn et al. 2008).

Euroxenomys is well known from Europe and is considered to be closely related to the giant beaver *Trogontherium* Fischer von Waldheim, 1809 (Hugueney 1999). *Euroxenomys* has not previously been described from the Pacific Northwest, but it is known from several Hemingfordian and Barstovian sites in North America (Sutton and Korth 1995, Korth 2001, Flynn et al. 2008). *Euroxenomys wilsoni* Korth, 2001 is known from the Hemingfordian Martin Canyon Quarry A fauna of Colorado and Runningwater fauna of Nebraska (Wilson 1960, Korth 2001), while *E. inconnexus* Sutton and Korth, 2005 is known from the early Barstovian Anceney Local fauna of Montana (Sutton and Korth 1995). JODA 4682 is larger than described specimens of the similar age *E. inconnexus* (Sutton and Korth 1995), and more comparable in size to specimens of *E. wilsoni* from the Hemingfordian Martin Canyon Quarry A fauna of Colorado (Wilson 1960, Korth 2001).

This is not the only beaver known from the Mascall Formation or other middle Miocene sites in Oregon. McLaughlin et al. (2016) recently described the late Hemingfordian Hawk Rim fauna, which is also a part of the Mascall Formation, and among the taxa described was an incisor fragment from the large beaver *Anchitheriomys* sp. Roger, 1885. Shotwell (1968) described two species of *Monosaulax* from early Barstovian Quartz Basin localities (*M. typicus* and *M. progressus*) of southeast Oregon. While *Anchitheriomys* is interpreted as terrestrial, both *Euroxenomys* and *Monosaulax* are reconstructed as having had semi-aquatic habits based upon phylogenetic inferences and postcranial morphology (Rybczynski 2007, Samuels and Van Valkenburgh 2008). The presence of multiple semi-aquatic beavers in the Pacific Northwest in the middle Miocene likely reflects changes in climate at the time and resulting resurgence of woodlands in the region (Retallack 2007, Samuels and Hopkins 2017).

Figure 13. cf. *Kalobatippus* sp. left dp2 in occlusal view, UCR 312849. Scale bar=3mm.

PERISSODACTYLA Owen, 1848
EQUIDAE Gray, 1821
ANCHITHERIINAE Leidy, 1869
cf. *KALOBATIPPUS* Osborn, 1915
Fig.13

Referred specimen—Left dp2, UCMP 312849.
Occurrence—RV6855.
Description—UCMP 312849 is a well-worn, low-crowned, lower deciduous second premolar in the size range of *Kalobatippus* (ap=19.8, t=14 mm). The metaconid and protoconid are joined by a protolophid, the entoconid and hypoconid are joined by a hypolophid, and the cristid obliqua joins with the protolophid between the protoconid and metaconid.

Remarks—There is no locality data for RV6855; only that it is an old CIT location, labeled from the Mascall Formation, Oregon. Therefore, this specimen is tentatively placed on the faunal list. Another specimen of *Kalobatippus* (UCMP 1702) was collected from the Crooked River locality UCMP V4949. UCMP 1702 is a partial molar or premolar with a part of the base of the protocone, one half of the metaloph, a small internal section of the metacone and all of the hypostyle is present. It is too small to be *Hypohippus* Leidy, 1858 (approximate molar length: M1/M2=27.5 mm; m1/m2=26.0 mm) and is closer in size to *Kalobatippus* (approximate molar length: M1/M2=17.0 mm; m1/m2=19.0 mm) (MacFadden 1998). Downs (1956) assigned this specimen to cf. *Hypohippus* based on size; however, he could not rule out *Kalobatippus*. Comparison of these specimens to *Hypohippus* specimens from the Virgin Valley fauna indicate that it is too small to be attributed to that genus and most likely belongs to *Kalobatippus*. Hunt and Stepleton (2004) also reported cf.

Kalobatippus from the Upper John Day Formation, from the late Arikareean age Johnson Canyon Member and the Hemingfordian age Rose Creek Member strata south of Kimberly, OR; and also from Upper John Day Formation strata at Sutton Mountain, near Mitchell, OR.

ARCHAEOHIPPUS Gidley, 1906
Archaeohippus ultimus Cope, 1886

Holotype—From Cottonwood Creek: "nearly complete superior dentition with palate and sides of skull to the middle of the orbits and top of skull to above the infraorbital foramen" Cope (1886), AMNH FM 8174.

Referred specimens—From Cottonwood Creek: "part of ramus with roots of one premolar and part of another" Downs (1956), USNM 18746; single lower premolar, USNM 3909. From CIT 113: lower premolar, CIT 424. From unknown locality from the "Condon Collection": lower premolars, YPM 14258, 14259. From -3059: lower right molar, UCMP 31987; lower left molar, UCMP 26643; left dp4, UCMP 41195. From -903: right M3 and left P3, UCMP 1689; partial dentary with p3 through p4, UCMP 1700. From JDNM-4: right dentary fragment with m2 and m3, JODA 7010; right dentary fragment with p4 through m2, JODA 7368; right lower molar, JODA 14141; right lower molar, JODA 14620; left M2, JODA 16555.

Occurrence—CIT 113, Cottonwood Creek, UCMP -3059, UCMP -903, JDNM-4.

Remarks—All specimens are described in Downs (1956) except UCMP 41195 and JODA specimens. Measurements for JODA material are included in Table 4. The lower molars have the metaconid and metastylid separate and a well-developed hypoconulid. YPM 14258 and 14259 are listed from Mascall Ranch in the YPM database and Downs (1956) states they are most likely from the Mascall Formation. Hunt and Stepleton (2004) note the occurrence of *Archaeohippus* sp. from the Upper John Day Formation, in the late Arikareean age Johnson Canyon Member and the Hemingfordian age Rose Creek Member strata south of Kimberly, OR. Combined these records indicate the presence of the genus in Oregon from the earliest Miocene through the middle Miocene.

DESMATIPPUS Scott, 1893
Desmatippus avus Marsh, 1874

Holotype—From UCMP V65400: right p3 through m2, left p2, p3, p4 and m1, left P2 through M1, M3, and right P2, M2, a canine and fragments, YPM 11281.

Referred specimens—From JDNM-4: three upper molars (former type of *Parahippus brevidens* Marsh, 1874), YPM 11274. From JDNM-4*: right upper molar or premolar, JODA 1983; right M3, JODA 1992; right upper molar, JODA 2050; right and left P1 through M3, JODA 2435; upper molar, JODA 2428. From UCMP V4830-4835: left upper molar, UCMP 1701. From UCMP V4834: upper partial left premolar or molar, UCMP 40240. From CIT 113: upper molars or premolars, CIT 406 and CIT 407.

Occurrence—UCMP V65400, JDNM-4, JDNM-4*, UCMP V4830-4835, UCMP V4834, CIT 113, JDNM-4.

Description—All YPM and CIT material are described in Downs (1956). JODA specimens are new occurrences. JODA 1983 is a well-worn, low-crowned cheek tooth. It does not contain a crochet; however, there is cement present. It measures ap=17.42 mm and t=19.72 mm. JODA 1992 is also a well-worn, low-crowned specimen with no crochet (ap=16.87, t=18.65 mm). JODA 2050 has the following measurements: ap=17.25, t=15.29 mm. None of the molars nor premolars of JODA 2435 contain a crochet, and all are low-crowned and have minimal cement. They are similar in size and wear stage as YPM 11281. JODA 2428 also lacks a crochet, is low-crowned and has no cement. Placement of these specimens in this taxon is based on the absence of crochet and no connection between the protoloph and protocone on upper cheek teeth, minimal cement in cheek teeth and brachydont dentition.

Remarks—MacFadden (1998) placed less-derived parahippines into *Desmatippus*. This includes subsuming *Parahippus avus* Marsh, 1874 into *Desmatippus* based on low-crowned molars, lack of a crochet and lack of cement. There are variable amounts of cement on the JODA referred specimens, ranging from no cement to minimal cement; however, all lack a crochet. Downs (1956) had previously synonymized *P. brevidens* and *P. avus*. YPM 11281 was originally reported by Downs (1956) as YMP 1128. Less-derived parahippine specimens that are low-crowned, lack a crochet and have minimal or no cement

Table 4. Specimen measurements of *Archaeohippus ultimus*. **ap**=anteroposterior length; **t**=transverse width.

Specimen		ap (mm)	t (mm)
JODA 41195	dp4	14.35	8.95
JODA 7010	m2	11.03	7.85
	m3	15.19	7.06
JODA 7368	p4	11.66	8.38
	m1	11.34	9.18
	m2	11.03	7.59
JODA 14141	mX	13.29	7.09
JODA 14620	mX	13.39	7.21
JODA 16555	M2	13.85	16.07

from the type area of the Mascall are placed within this species while more derived parahippine specimens are placed in *Parahippus* sp. (see below).

PARAHIPPUS Leidy, 1858
Parahippus sp.

Referred specimens—From JDNM-4*: left P2, JODA 2401; left P3, JODA 2402; left P4 or M1, JODA 2403; left M2 or M3, JODA 2404; left P4, JODA 2405; left P4, JODA 2406; right M1, JODA 2407; right P2, JODA 2408; right P4, JODA 2409; right M3, JODA 2411; left M3, JODA 2412; left p2, JODA 2413; lower left molar or premolar, JODA 2415, lower right molar or premolar, JODA 2417; right M1 through M3?. From UCMP V4941: upper right molar, UCMP 40314.

Occurrence—JDNM-4*, UCMP V4941.

Description—The protoloph does not connect to the protocone on upper cheek teeth. Some have complex crenulation patterns and/or crochets, while others lack them. The majority of specimens have at least some cement; in some cases the amount of cement is considerable (pre- and postfossettes are filled and protocone is surrounded), especially in teeth that are unworn or slightly worn. All specimens are low-crowned with heights ranging from 9.25–16.4 mm and an average of 12.5 mm. These characteristics place these specimens within parahippines and align them more closely to *Parahippus* than *Desmatippus.*

Remarks—Downs (1956) reported a small deciduous tooth (UCMP 31987) from UCMP -3059 as *P.* sp., however, this specimen is a lower molar or premolar and belongs to *Archaeohippus ultimus*. The genus *Parahippus* contains a heterogeneous assemblage representing a morphocline from low-crowned, less-derived molars to higher-crowned, more complex molars (MacFadden 1998). The specimens assigned to this genus from the type area of the Mascall Formation are distinguished from *Desmatippus* in being on the more derived end of the morphocline with the presence of crochets, cement and incipient hypsodonty. Hunt and Stepleton (2004) note the occurrence of *Parahippus pawniensis* Gidley, 1907 from the Hemingfordian age Rose Creek Member strata south of Kimberly, Oregon. *Parahippus* is also recorded from the Late Arikareean–Early Hemingfordian Warm Springs locality in central Oregon (MacFadden 1998).

cf. *Parahippus* sp.

There are several equid premolars and molars in the JODA collection that are similar to *Desmatippus avus*, except they contain a fair amount of cement and some have a crochet. Therefore, they most likely fall further along on the morphocline between *Desmatippus* and

Parahippus (Stirton 1940, MacFadden 1998). Here they are placed within cf. *Parahippus*, but a taxonomic revision of both genera may shed more light on the identification of these specimens.

EQUINAE Steinmann and Döderlein, 1890

There are two distinct morphotypes of merychippines in the type Mascall Formation (Woodburne, *pers. communication*). A thorough revision of merychippine taxonomy, which is beyond the scope of this paper, is needed before formal naming of these specimens is possible. Therefore, for the purposes of this analysis, they will be referred to as '*Acritohippus isonesus*' and 'Merychippine species A'.

ACRITOHIPPUS Kelly, 1995
Acritohippus isonesus Kelly, 1995
Fig. 14

Holotype—From UCMP V67153: skull with left I1 through 3, C, P2 through M3 and left P2 through M3, AMNH FM 8175 (holotype of *Hippotherium isonesum* Cope, 1889, which was later renamed *Acritohippus isonesus* by Kelly (1995)).

Referred specimens—From CIT 183: skull with P2 through M3, LACM (CIT) 532. From JDNM-4: skull with P2 through M3, left I1 and right I1, I2, JODA 1316; skull with P2, dP3 through erupting M3 with broken rostrum and right zygomatic arch, JODA 1317; poorly preserved partial skull with P3 through M3, JODA 1318.

Occurrence—CIT 183, UCMP V67153, JDNM-4*.

Description—Narrow preorbital bar, moderately deep lacrimal fossa, infraorbital foramen on floor of lacrimal fossa, shallow malar fossa with no foramen, malar fossa separated from lacrimal fossa by low, indistinct ridge. Cheek teeth have protoloph connected to protocone, no crochets, one medium pli caballin, simple fossette borders with occasional pli protoconule and pli postfossettes, open hypoconal groove, simple hypocone, considerable cement, and hypsodont tooth crown height.

Remarks—This is the larger of the two merychippine species present in the type Mascall Formation, which was identified by Downs (1956) as *Merychippus seversus* Cope, 1878, in part. AMNH FM 8175 from AMNH Mascall locality (=UCMP V67153) is the type specimen for *Acritohippus isonesus* (Kelly 1995), and the original type specimen for *M. isonesus* (referred to as *Stylonus isonesus* by Kelly and Lander (1988), as *Hippotherium isonesum* by Cope (1889) and as *H. seversum* by Cope (1886)). Downs (1956) synonomized that taxon with *M. seversus*. Kelly (1995) distinguished *Acritohippus* based on a shallow malar fossa only separated from the dorsal preorbital fossa (DPOF) by a low, indistinct ridge. All of the skulls
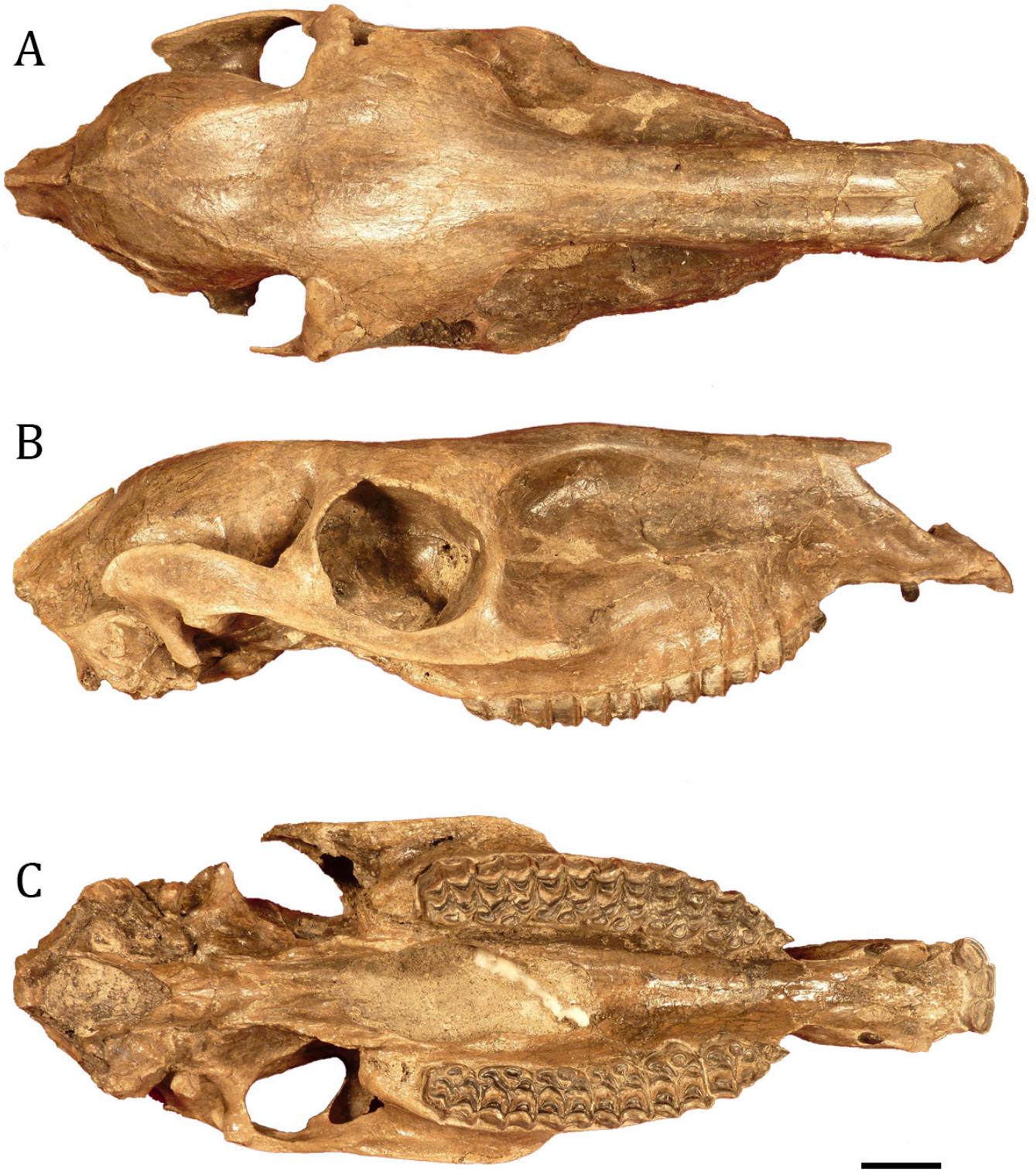
Figure 14. *Acritohippus isonesus* skull, JODA 1316. **A.** Dorsal view. **B.** Lateral view. **C.** Ventral view. Scale bar=3cm.

referred here have this feature, but a formal comparison, currently being undertaken by M.O. Woodburne (*pers. communication*), needs to be completed to confirm assignment of specimens to this taxon. There are hundreds of (>300) dental specimens collected from this taxon in the AMNH, JODA, UCMP and YPM collections, many of which Downs (1956) assigned to *M. seversus*, which are also being re-evaluated. Fragmentary enamel and postcranial material of a larger merychippine was recovered from upper Mascall deposits (JODA 15616, JODA 15617 and JODA 15630) demonstrating this species' persistence into the later part of the formation and Late Barstovian.

MERYCHIPPINE SPECIES A

Referred specimens—From "Lake deposits of eastern Oregon": Left M1 and unworn right M2(?), AMNH FM 8673. From UCMP V4942: upper molar, UCMP 23090. From UCMP V4827: upper molar, UCMP 23096. From UCMP V4825(?): lower molar, UCMP 499. From UCMP V4824: lower molar, UCMP 39101. From UCMP V67153: upper molar, UCMP 27237; upper molar, UCMP 27238. From CIT 113: right dP4, CIT 4004.

Occurrence—"Lake deposits of eastern Oregon", UCMP V4942, UCMP V4827, V4825(?), V4824 UCMP V67153, CIT 113.

Description—This species is represented only by cheek teeth, which are smaller than those of *Acritohippus isonesus*. Upper cheek teeth also have a rounded protocone that is isolated and does not have a spur, a simple and relatively long hypocone, and an open and narrow hypoconal groove. The teeth typically have one medium pli caballin, one pli protoconule and one to two pli foessettes, and hyposodont tooth crown height.

Remarks—These upper cheek teeth were identified by Downs (1956) as *Merychippus relictus* Cope, 1889. This species is smaller and rarer than *Acritohippus isonesus*. Two lower teeth of this taxon have also been recovered from Mascall deposits. UCMP 499 was recovered from old UCMP locality -884, which Downs (1956) suggests is the same as UCMP V4825. These are also smaller than lower cheek teeth of *A. isonesus*. M.O. Woodburne is currently revising this taxon and determining its classification (Woodburne, *pers. communication*).

An additional third species of a merychippine, assigned to *M. seversus* by Downs (1956), is present from the Mascall equivalent Gateway Locality (LACM (CIT) 2929 and 2930) and not included in this study. That species has a wider post-orbital bar, a deeper lacrimal fossa, no malar fossa, and the infraorbital foramen is outside of the lacrimal fossa.

RHINOCEROTIDAE Gray, 1821

Referred specimens—From -884: podial, UCMP 475; cuneiform(?), UCMP 35669. From -903: pisiform, UCMP

2176. From JDNM-70: partial tooth, JODA 4275; enamel fragments, JODA 15303. From JDNM-71A,B,D: enamel fragments, JODA 10314 and JODA 15677; molar fragment, JODA 15555 and 15644. From JDNM-4: tooth fragments; JODA 15326, JODA 15341, JODA 15612, JODA 15613, JODA 15615, JODA 15631, JODA 15678, JODA 15720, JODA 15790, JODA 15792, JODA 16124.

Occurrence—UCMP -884, UCMP -903, JDNM-4, JDNM-70, JDNM-71A, JDNM-71B, JDNM-71D.

Description and Remarks—Specimens of Rhinocerotidae are very rare in the Mascall type area but fragmentary postcranial elements and pieces of enamel have been found in all units of the Mascall Formation. Tooth material is fragmentary but contains the typical Hunter-Schreger bands characteristic of Rhinocerotidae (Rensberger and von Koenigswald 1980). To the south, by the Crooked River, rhinocerotid material is more abundant, but still mainly represented by fragmentary postcranial material. A calcaneum (UCMP 1682) from the Beaver Creek locality (UCMP -895) is assigned to *Teloceras medicornutum* Osborn, 1904 (Prothero 2005). A partial maxilla with P2 and P3 (UCMP 41121 from V4948) most likely belongs to *Aphelops* Cope, 1874 because the teeth are brachydont and lack an antecrochet; however, they have a well-developed crochet. Although fragmentary and rare, the rhinocerotid material from the type Mascall demonstrate the persistence of this family throughout the Mascall Formation.

ARTIODACTYLA Owen, 1848
TAYASSUIDAE Palmer, 1897
CYNORCA Cope, 1867
"Cynorca" hesperia Marsh, 1871
Figs. 15, 16

Holotype—From UCMP V67153: right maxilla with P4 through M3, YPM 11899.

Referred specimens—From JDNM-4*: cranium with rostrum missing but containing right and left P4 through M3, JODA 1320; partial maxilla with M2 and M3, JODA 2229; right M1 or M2 in maxillary fragment, JODA 2241. From UCMP V4945: partial cranium with incomplete palate containing left P2 through P4, M1, M3, partial left M2 and partial left and right canines, mandible with left i1, i2, canine, alveoli of p2 and p3, p4 through m3 and right i1 through 3, canine, alveoli of p2 and p3, p4 through partial m2, m3, distal right humerus, and right proximal ulna and radius, JODA 3773.

Occurrence—UCMP V67153, UCMP V4945, JDNM-4*.

Description—YPM 11899, JODA 1320, and JODA 3773 all have upper fourth premolars with a "deep trenchant groove that passes lingually between protocone and metaconule" (Woodburne 1969, p.304) and unreduced M3, placing them in "*Cynorca" hesperia* (Figs. 15, 16).
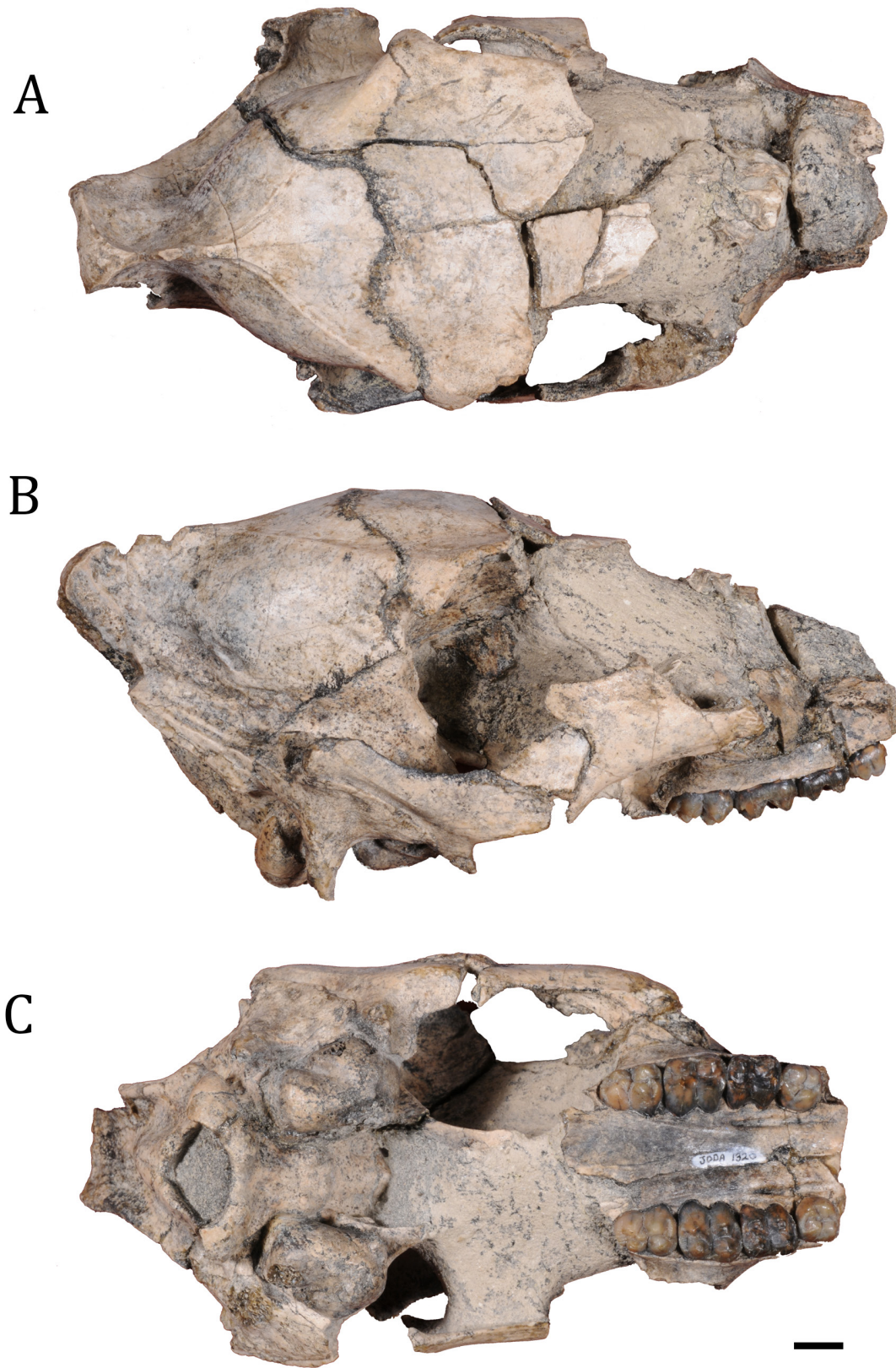
Figure 15. "*Cynorca*" hesperia skull, JODA 1320. **A.** Dorsal view. **B.** Lateral view. **C.** Ventral view. Scale bar=1cm.
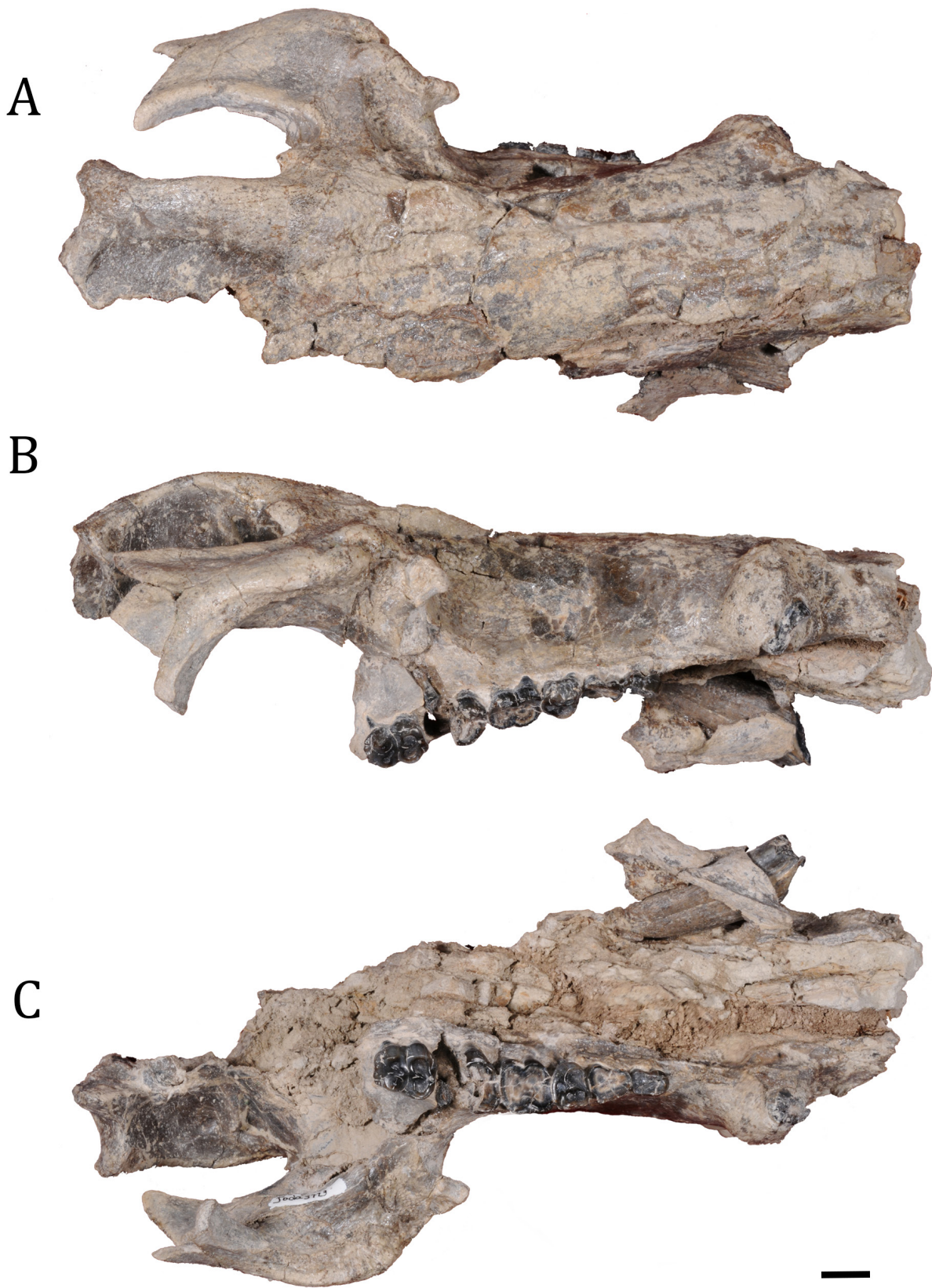
Figure 16. "*Cynorca*" *hesperia* skull, JODA 3773. **A.** Dorsal view. **B.** Lateral view. **C.** Ventral view of mandible. Scale bar=1cm.

JODA 2229 also has an unreduced M3. JODA 1320 is the most complete specimen of "*C.*" *hesperia* containing the palate and most of the braincase with well-preserved auditory bullae; however, most of the rostrum is missing (Fig. 15). The zygomatic arch of JODA 1320 does not flare, resulting in a narrow cranium shape. JODA 3773 contains most of the rostrum, part of the frontals, anterior portion of the left zygomatic arch and palate with left dentition (Fig. 16). The zygomatic arch of JODA 3773 flares laterally causing a wing like projection and broader cranium shape than JODA 1320.

Remarks—YPM 11899 is the type specimen of "*Cynorca*" *hesperia* (Woodburne 1969). It was collected by Thomas Condon, from the upper John Day River, OR. Marsh (1871) reported it from "the Pliocene beds of Oregon," however Woodburne (1969) interpreted the locality as probably the Mascall. Wright (1998) identifies the genus as a nomen dubium and only recognizes two species of "*Cynorca*" ("*C.*" *sociale* Marsh, 1875 and "*C.*" *occidentale* Woodburne, 1969), which are paraphyletic. "*C.*" *sociale* falls outside of Tayassuinae, and was renamed *Marshochoerus socialis* Marsh, 1875 and placed in the subfamily Hesperhyinae by Prothero (2015). "*Cynorca*" *occidentale* falls within the Tayassuinae. A character that is shared between "*C.*" *occidentale* and YPM 11899 is the presence of a metaconule on the P4 and the trenchant groove that passes lingually between the protocone and metaconule of P4. However, the two differ in that the M3 of YPM 11899 is not significantly smaller than the M1 or M2. The presence of the metaconule of the P4 places YPM 11899 within Tayassuinae; however, this specimen does not belong to "*C.*" *occidentale.* This specimen is similar to "*M.*" *sociale* in having an unreduced M3, length of m2 is 10.87 mm (near the average of 11.2 mm reported in Wright (1998)); however, it does not belong to that species because of morphology of the P4 discussed above. Given this, we retain YPM 11899 as "*C.*" *hesperia* and await further reclassification of the remaining species within "*Cynorca*" discussed in Prothero (2015). Because all of the other specimens listed above share the same P4 and M3 morphology as well as size range (Table 5), they are also assigned to "*C.*" *hesperia*. The difference in zygomatic arch shape of JODA 1320 and 3773 may be due to sexual dimorphism or cranial ontogeny; however, their tooth morphology and size are identical. Wright (1993) demonstrated that zygomatic arches are a sexually dimorphic character in Tayassuidae and that some Miocene and Pliocene female peccaries have smaller zygomatic arches.

"*Cynorca*" sp. Cope, 1867
Fig.17
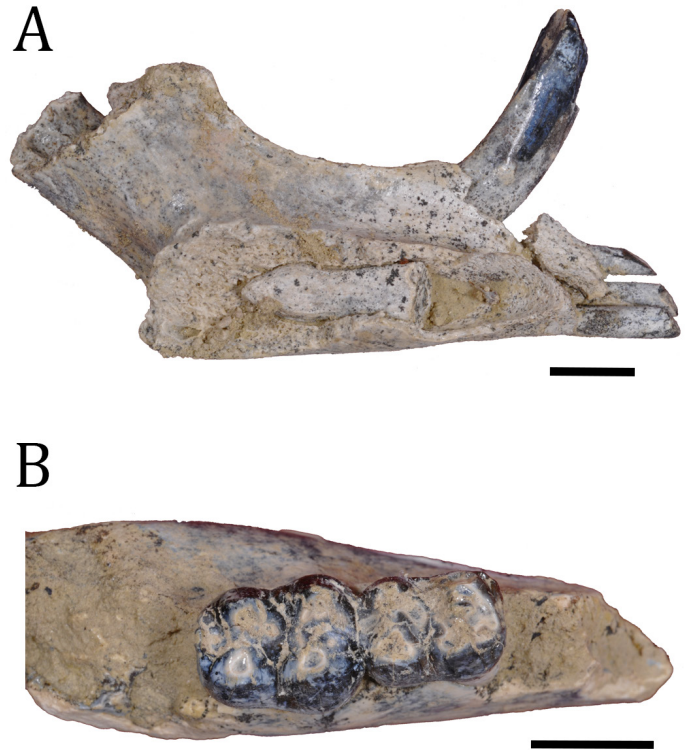
Figure 17. "*Cynorca*" sp. **A.** Partial mandible with complete left canine, left i1, i2, right i1 and partial right canine; JODA 4250. **B.** Right partial denary with m1 and m2, JODA 4258. Scale bar=1cm.

Table 5. Specimen measurements of *"Cynorca" hesperia*. If two measurements are listed, the first measurement is the right side and the second measurement is the left side. **ap**=anteroposterior length; **t**=transverse width.

Specimen		ap (mm)	t (mm)
JODA 2229	M2	12.57	10.68
	M3	11.20	9.62
JODA 2241	M1/M2	11.08	9.95
JODA 1320	P4	8.44, 8.42	9.18, 9.33
	M1	10.45, 10.43	9.72, 10.286
	M2	12.05, 12.37	10.68, 10.58
	M3	11.53, 11.97	9.50, 10.11
JODA 3773	P2	7.22	5.02
	P3	7.80	7.20
	P4	7.60	8.69
	M1	9.90	10.27
	M3	11.71	10.43

Referred specimens—UCMP V4834: partial mandible with complete left canine, left i1, i2, right i1 and partial right canine, JODA 4250; right partial dentary with m1 and m2, JODA 4258. From CIT 1869: P4, LACM 5964.

Occurrence—UCMP V4834, CIT 1869.

Description—JODA 4258 is a right dentary with m1 and m2. The m1 of JODA 4258 measures 11.02 mm anteroposteriorally and 7.78 mm transversally. The m2 of JODA 4258 measure 11.75 mm anteroposteriorally and 10.03 transversally. The simple morphology of the m1 and m2 is similar to "*C.*" *occidentale* and *Marshochoerus sociale*. JODA 4250 belongs to "*Cynorca*" based on i2 lying posterolateral to i1, i1 and i2 being subconical and the canine having lateral ridges and a lingual groove developed half way up the tooth from the jaw.

Remarks—These specimens are attributed to "*Cynorca*", but are not assigned to a species because of limited diagnostic material. "*Cynorca*", as mentioned above, is a nomen dubium, but we await further reclassification of the remaining species within "*Cynorca*" discussed in Prothero (2015). The type specimen for "*C.*" *hesperia* is a partial maxilla and does not contain comparable lower dentition. JODA 3773, assigned above to "*C.*" *hesperia*, has a comparable lower jaw; however, the m1 and m2 are too worn for morphological comparison. The m1 and m2 of JODA 4258 are the same size as the m1 and m2 of JODA 3773 suggesting that they belong to the same taxon. No other small tayassuid has been recovered from the Mascall Formation. JODA 4250 and 4258 may belong to the same individual. They have similar preservation and were found at the same site. LACM 5964 was collected by Bode in 1929. It is highly worn, so it is impossible to determine if there is a metaconule present or not, and is therefore unidentifiable to the species level.

TAYASSUIDAE INDET.

Referred specimens—Partial dentary with m1, m2, JODA 301; partial molar, JODA 302; partial dentary with p2 and p3(?), JODA 2230; molar, JODA 2238; molar, JODA 2239; molar, JODA 2240; premolar, JODA 2241; premolar, JODA 2242; deciduous premolar, JODA 2244; partial molar, JODA 2245; partial molar, JODA 2246; p2, JODA 2324; premolar, JODA 2341; M3, JODA 2342; premolar, JODA 2349; premolar, JODA 2391. From JDNM-71: molar fragment, JODA 13946. From UCMP -884: m3, UCMP 1628.

Occurrence—JDNM-4*, JDNM-71, UCMP -884.

Remarks—These specimens can be attributed to Tayassuidae; however, there is no locality information because they were collected by the Weatherfords or park rangers during the first years of JODA or are assigned to a general locality number. Therefore, it is unclear which formation they are from. The specimens are all too big to belong to "*Cynorca*," as described above, but lack the diagnostic characters that would be required to assign them to another genus. They fall within the size range of *Dyseohyus fricki* Stock, 1937 and "*Prosthennops*" *xiphidonticus* Barbour, 1925, two Barstovian species (Wright 1998); however, they also fall within the size range of Hemphillian peccaries such as *Platygonus oregonensis* Colbert, 1938, which is known from and common in the Rattlesnake Formation (Merriam et al. 1925). A lower right m3, UCMP 1628, was collected from locality -884 (Mascall Misc. 2). It has an anteroposterior length of 16.48 mm and a transverse width of 10.87 mm, the same size as *D. fricki,* the locality information is minimal and it is unclear if the specimen was found in the Mascall Formation or the Rattlesnake Formation.

A small tayassuid molar fragment (JODA 13946) was collected at JDNM-71 Rock Creek locality from the lower Mascall unit, demonstrating the stratigraphic persistence of peccaries throughout the lower and middle units of the formation.

DROMOMERYCIDAE Frick, 1937
DROMOMERYCINAE Frick, 1937
DROMOMERYCINI Frick, 1937
PALEOMERYCIDAE Lydekker, 1883
DROMOMERYX Douglass, 1909
Dromomeryx borealis Cope, 1878

Referred specimens—From UCMP -3059: partial skull with complete horns and post cranial elements, UCMP 1486; P4, UCMP 29985. From V4835: left partial dentary with p2 through m2 and parts of three lumbar vertebrae, UCMP 39185; P4, UCMP 39301. From V4831: m1, UCMP 39293. From V4832: partial calcaneum and distal tibia, UCMP 39305. From JDNM-4*: right m3, JODA 2262. From CIT 184: horn with partial cranium and orbit, CIT 799. From Cottonwood Creek: right P3 and M3, USNM 5515; left P2 through M3, right P3 through M3, left p3 through m1, m3 and postcranial material, USNM 5516; i1 through i3, canine, partial dentary with right p2 through m3 and postcranial material, USNM 5517.

Occurrence—UCMP -3059, V4835, V4831, V4832, JDNM-4*, CIT 184, Cottonwood Creek.

Remarks—All specimens are described in Downs (1956). Downs (1956) also lists several specimens assigned to this taxon that have uncertain provenance, but states they are most likely from the Mascall.

Figure 18. *Rakomeryx sinclairi.* **A**. Left and right p4, JODA 7195. **B.** Left p4-m3, JODA 2362. Scale bars=1cm.

Rakomeryx sinclairi Matthew, 1918
Fig. 18, a, b

Referred specimens—From UCMP V4831: left p3, p4, and m1 or m2, and right p4, JODA 7195; right p3; JODA 3682. From JDNM-4*: left p4 through m3, JODA 2362.

Table 6. Specimen measurements of *Rakomeryx sinclairi.* If two measurements are listed, the first measurement is the right side and the second measurement is the left side. **ap**=anteroposterior length; **t**=transverse width.

Specimen		ap (mm)	t (mm)
JODA 7195	p3	12.93	6.28
	p4	16.73, 16.49	8.7, 8.55
	m1/m2	18.99	11.5
JODA 2362	p4	15.26	8.79
	m1	17.17	12.35
	m2	19.68	12.72
	m3	27.64	12.97
	m1–m3	63.79	--
JODA 3682	p3	12.94	6.53

Occurrence—UCMP V4831, JDNM-4*.

Description—Specimen measurements are included in Table 6. Anterior fossette on the p4 of JODA 7195 is not closed by the anterior extension of the metaconid. The anterior fossette on the p4 of JODA 2362 is closed by the anterior extension of the metaconid, but not more so than AMNH FM 31782, which Frick identified as *R. raki* (Frick 1937). Prothero and Liter (2008) and Janis and Manning (1998) mentioned that the p4 may lack closure of the anterior fossette for this taxon. JODA 3682 is the same size and has the same preservation as the p3 of JODA 7195 and because they were collected in the same area, they probably belong to the same individual. These specimens are assigned to this taxon based on reduced premolars compared to *Dromomeryx* (Table 6) and morphology of the p4 (Janis and Manning 1998)

Remarks—Prothero (2008) places all species of the genus into *R. sinclairi*. There is another specimen at LACM (with no specimen number) that may be attributed to this species; however, additional preparation is needed for identification. JODA 7195 and 2362 further confirm the presence of *Rakomeryx* in the early Barstovian, as argued in Janis and Manning (1998).

TICHOLEPTUS Cope, 1878
Ticholeptus zygomaticus Cope, 1878

Referred specimens—From UCMP V67153: right i3, UCMP 35670; left p2 and p3, deciduous p4, m1 or m2, UCMP 95757; maxilla fragment with partial P4 and M1, JODA 3776; right M1 and M2, JODA 6604. From JDNM-4*: upper dentition including right P1 through M3 and left I1 though M3, JODA 1327; lower dentition including right p2 through m3 and left i3 through m3, JODA 1328; dentary with erupting i3 through p3, dp4, m1 through m2 and erupting m3, JODA 1329. From UCMP V4834: left P4, UCMP 39298. From UCMP V4835: left P4, UCMP 39301; right P1 and tooth fragment, UCMP 39302. From CIT 113: p4 and m1, CIT 1730. From JDMN-71D: right c1 through p3 in dentary fragment, JODA 295. From: JDNM-179 partial right lower canine, JODA 6509.

Occurrence—UCMP V67153, JDNM-4*, UCMP V4834, UCMP V4835, CIT 113, JDNM-71D, JDNM-179.

Description and Remarks—Cope (1886) described *Ticholeptus* from the Cottonwood Creek beds (AMNH FM 8192) and named a new species (*T. obliquidens*) from a mandibular ramus with an entire tooth series. Lander (1998) synonymized all species in the genus to one species, *T. zygomaticus*, but based on the description in Cope (1886), it is unclear whether AMNH FM 8192 belongs to *T. zygomaticus*. Scharf (1935) identified *Ticholeptus* from Mascall deposits (CIT 113, specimen CIT 1730). More recent collections confirm the occurrence of this genus, as well as identification of the species *T. zygomaticus*, in the Mascall Formation based on the following: P1–P3 are elongate, rectangular and the anterior intermediate crest does not form a cusp (unlike in *Merychyus* Leidy, 1858); larger in size than *Merychyus* (average P1–M3 length 59–152 mm); smaller in size than other contemporaneous ticholeptines; p2–p4 complexly crested (Lander 1998). All new material assigned to this taxon is dental material. JODA 1327 and 1328 were collected by the Weatherfords as individual teeth and then plastered together into a tooth row. Therefore, toothrow measurements are inexact, but the individual tooth measurements are given in Table 7. JODA 1329 is a dentary also collected by the Weatherfords with all teeth *in situ*. The remaining material consists of isolated teeth referred to this species based on size. The lower premolars of UCMP 95857, JODA 295, and JODA 1328 are complexly crested, even more complex than the lower premolars of *T. zygomaticus* from Massacre Lake (UCMP V6160 and V6161). JODA 6509, a partial canine, and the canine of JODA 1328, are similar

Table 7. Specimen measurements of *Ticholeptus zygomaticus*. **ap**=anteroposterior length; **t**=transverse width. ***** = deciduous; **'** = m1 or m2.

Specimen		C	P1	P2	P3	P4	M1	M2	M3
JODA 1327	**ap**	9.18	10.48	10.97	11.61	10.07	12.42	17.16	20.20
	t		5.51	6.97	8.84	11.03	13.29	14.84	15.89
UCMP 39298	**ap**					10.40			
	t					12.85			
UCMP 39301	**ap**					9.51			
	t					12.88			
UCMP 39302	**ap**		9.85						
	t		5.36						
		c	p1	p2	p3	p4	m1	m2	m3
JODA 1328	**ap**	12.58		10.83	12.94	12.38	12.41	14.51	23.52
	t			5.07	8.08	9.25	9.96	11.29	10.19
UCMP 95857	**ap**			9.64	11.79	17.19*	17.74'		
	t			4.56	5.78	7.27*	9.35'		
CIT 1730	**ap**					12.92	13.37		
	t					10.06	9.29		
JODA 6509	**ap**	12.06							

in size, have a worn surface on the anterior portion of the tooth and are flat posteriorly. Two additional specimens are tentatively placed in the genus, JODA 3776, an upper left M1 and partial P4 in a maxilla fragment, and JODA 6604, an upper M1 and M2. The first molar of JODA 3776 is larger (ap=13.96 mm) than JODA 1327 (M1 is broken down the midline and split, therefore a transverse width could not be measured). JODA 6604 is an unworn smaller individual (M1: ap=n/a, t=11.07 mm; M2: ap=12.32 mm, t=10.49 mm).

MERYCOIDODONTIDAE INDET.

Referred specimens—From JDNM-4*: left m1 and partial m2 in dentary fragment, JODA 2361. From V4834: left canine, JODA 4254; astragalus, UCMP 39313.

Occurrence—JDNM-4*, V4834 Mascall 20

Remarks—JODA 2361 is too large for *Ticholeptus* and lacks significant diagnostic material (ap=18.09 mm, t=12.59 mm). JODA 4264 is a complete canine, but not diagnosable to genus or species. UCMP 39313 was reported by Downs (1956) (ap=33.8 mm and t=22.0 mm).

CAMELIDAE Gray, 1821
MIOLABIS Hay, 1899
Miolabis transmontanus Cope, 1879

Referred specimens—Cottonwood Creek: nearly complete cranium, AMNH FM 8196; JDNM-4*: nearly complete mandible, JODA 1326.

Occurrence—Cottonwood Creek, JDNM-4*

Comments—AMNH FM 8196 is the type specimen for *Miolabis transmontanus* named by Cope (=*Protolabis transmontanus*). Honey et al. (1998) used this specimen as the type for the genus. The skull was found by Charles Sternberg in the Cottonwood Creek area near Dayville, OR. Measurements for AMNH FM 8196 are presented in Cope (1879) and Downs (1956), and figured in Cope (1886). JODA 1326 is assigned to this species based on the following: no p1, premolars stouter and less compressed than *Protolabis* Cope, 1876, p2 shortened and simplified, p3 is shortened with a high, central protoconid, p4 has enlarged hypoconid, molars low-crowned, but they do not have strong metastylids (this may be due to the extreme wear of the teeth), m3 less anteroposteriorly expanded relative to m2 than in *Protolabis*. Measurements for JODA 1326 are included in Table 8. JODA 1326 may be the mandible to the skull found by Sternberg. Both specimens have heavily worn teeth, however, it is unclear where JODA 1326 was found.

PROCAMELUS Leidy, 1858
cf. *Procamelus sp.*
Fig. 19

Referred specimens—Left dentary with anterior portion of p2 and p3, alveoli of p4, complete m2 and partial m3, right m1, CIT 4003.

Occurrence—UCMP V67153.

Description—The m2 of CIT 4003 has an anteroexternal stylid and measures 24 mm in anteroposterior length and 13.5 mm in transverse width. Cheek teeth are more hypsodont than in protolabines.

Remarks—The size, presence of the anteroexternal stylid and presence of the second premolar place this specimen within *Procamelus* (Honey et al. 1998), but because the posterior portions of the p2 and p3 are missing as well as the p4, the specimen is only tentatively placed in this genus. This represents the earliest occurrence of *Procamelus* in Oregon and one of the earliest records of Camelini (Honey et al. 1998). *Procamelus* cf. *grandis* Gregory, 1939 is also known from the Clarendonian age Black Butte Local fauna (Shotwell and Russell 1963).

CAMELIDAE INDET.
Fig. 20

Referred specimens—From UCMP -3043: right external acoustic meatus, JODA 15592. From UCMP -3059: right partial dentary with p3(?) and m1(?) alveoli, JODA 15560. From UCMP V4827: molar enamel fragment, JODA 4685. From UCMP -882: astragalus, UCMP 553; metapodial, UCMP 1604. From UCMP -884: phalanx, UCMP 472; astraglus, UCMP 503. From UCMP -886: calcaneum, UCMP 723.

Occurrence—UCMP -3043, UCMP -3059, UCMP

Table 8. Specimen measurements of *Miolabis transmontanus*, JODA 1326. **ap**=anteroposterior length; **t**=transverse width; **dia** =diastema.

	ap (mm)	t (mm)
i1	8.04	5.35
i2	8.45	5.16
i3	7.03	5.22
c	8.91	--
dia	39.76	--
p2	9.18	4.94
p3	13.47	5.87
p4	13.37	7.290
m1	15.14	12.31
m2	18.98	14.90
m3	28.24	13.70
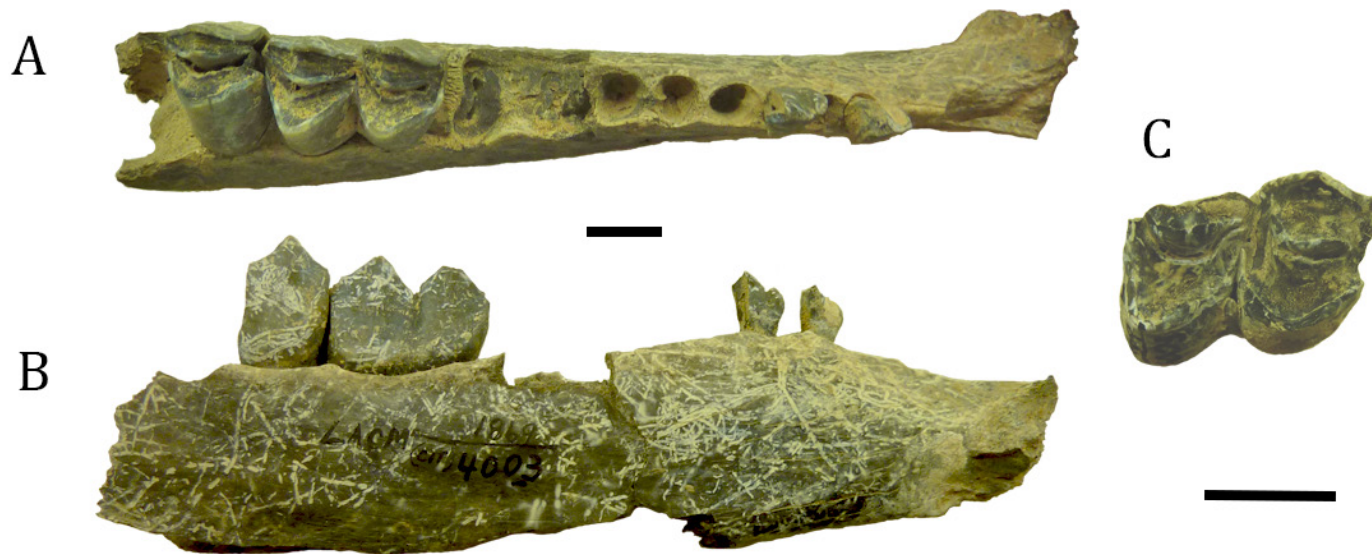
Figure 19. cf. *Procamelus* sp. left dentary with partial p2 and p3, alveoli of p4 and m1, complete m2 and partial m3, CIT 4003. **A.** Occlusal view. **B.** Lateral view. **C.** Right m1 in occlusal view. Scale bars=1cm.

Figure 20. Camelidae right partial dentary with p3 (?), JODA 15560. **A.** Occlusal view. **B.** Lateral view. Scale bar=1cm.

Figure 21. *Blastomeryx gemmifer* left dentary fragment with p3-m3 in occlusal view, JODA 2359. Scale bar=1cm.

V4827.

Description and Remarks—JODA 15560 is a small camel, the dentary is gracile and the premolar has an anteroposterior length of 9.85 mm and a transverse width of 4.49 mm. JODA 4685 is high-crowned (height=25.12 mm) and from the lower unit of the Mascall Formation. This specimen demonstrates not only the presence of camels in the lower unit of the Mascall Formation, but also demonstrates hypsodonty in the family in the earliest deposits of the Mascall fauna.

MOSCHIDAE GRAY, 1821
BLASTOMERYCINAE FRICK, 1937
BLASTOMERYX COPE, 1877
Blastomeryx gemmifer COPE, 1874
FIG. 21

Referred specimens—From UCMP -3043: right dentary fragment with m2 and m3, UCMP 39309. From JDNM-4*: lower left premolar, JODA 2256; m2, JODA 2257; left dentary with p3 through m3, JODA 2359; right M3, 2376; right M1, JODA 2377; left dentary fragment with m2 and m3, LACM 5934. From UCMP V4823: left p2, JODA 6623. From UCMP V4835: right maxilla fragment with P4 and M1, UCMP 39310.

Occurrence—JDNM-4*, UCMP -3043, UCMP V4823, UCMP V4835.

Description—Specimens are attributed to this taxon based on slightly reduced premolars, brachydont molars, and size (Prothero 2008). Referred specimens with m2 have anteroposterior length of 8.5–9.4 mm. JODA 2359 has an m1–m3 length of 30.32 mm. Specimens from the Mascall Formation are on the larger spectrum of specimens assigned to this species; however, they are smaller than *Parablastomeryx* Frick, 1937 specimens from Virgin Valley, as well as those reported here from the Mascall fauna.

Remarks—Prothero (2008) placed all species of *Blastomeryx* into a single species, *B. gemmifer,* based on size comparisons. The size of postcranial material such as astragali and podials (i.e., UCMP 496, 1730, 1746) indicates

they are referable to *Blastomeryx* (Prothero 2008). One fragmentary tooth specimen, JODA 6503, collected at JDNM-71 in the lower unit of the Mascall Formation is most likely *Blastomeryx*, but because of its fragmentary nature, it is only assigned to Blastomerycinae here. Its presence, along with *Parablastomeryx*, suggests the clade was present and diverse in the lower unit of the Mascall Formation. Downs (1956) mentions YPM 14314, a partial maxilla with P4–M2 attributed to Blastomerycini and as possibly belonging to the Mascall; however, the original locality description says "down river from the cove", meaning down river from Turtle Cove in the John Day Formation, yet there are no Mascall deposits down river from Turtle Cove. Downs (1956) also mentions USNM 7720, a lower molar, which is now attributed to the Arikareean of the John Day Formation. Moschids have
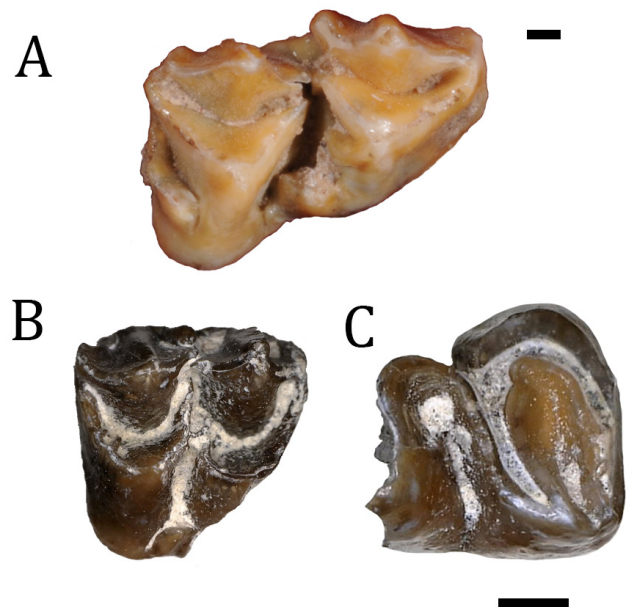
Figure 22. *Parablastomeryx* sp. **A.** Left m1 in occlusal view, JODA 2255. **B.** Left M1 or M2, JODA 17389. **C.** p4, JODA 17437. Scale bar=1mm.

been found from the upper John Day Formation strata south of Kimberly, OR (Hunt and Stepleton 2004); thus, the specimens mentioned by Downs (1956) may have come from those strata.

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PARABLASTOMERYX FRICK, 1937
Parablastomeryx sp. FRICK, 1937
FIG. 22

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Referred specimens—From JDNM-4*: Left m1, JODA 2255; From JDNM-71A: Left M1 or M2, JODA 17389; p4, JODA 17437.

Occurrence—JDNM-4*, JDNM-71A.

Description—JODA 2255 is a brachydont lower molar with the *Palaeomeryx* fold, anteroposterior length of 10.27 mm and transverse width of 5.81 mm. JODA 17389 is also brachydont with a broken protocone, anteroposterior length of 8.62 mm and transverse width of 8.14 mm.

Remarks—This is the largest genus of blastomerycine (Prothero 2008). JODA 2255 falls within the size range of *Parablastomeryx* from Virgin Valley (UCMP 10661, 11564–11567) and presence of the *Palaeomeryx* fold and brachydont molars places it within this taxon (Prothero 2008). Two species (*P. gregorii* Frick, 1937 and *P. floridanus* White, 1940) are recognized in the genus during the Miocene; however, the material is not sufficient for species level identification (Prothero 2008). Hunt and Stepleton (2004) note two species of *Parablastomeryx* from Upper John Day Formation strata: *Parablastomeryx* cf. *advena* Matthew, 1907 from the late Arikareean age Johnson Canyon Member, and *Parablastomeryx schultzi* Frick, 1937 from the Hemingfordian age Rose Creek Member. The new records from the Mascall fauna indicate this genus persisted in Oregon from the late Arikareean (earliest Miocene) to early Barstovian (middle Miocene).

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PROBOSCIDEA ILLIGER, 1811
PRODOSCIDEA INDET.

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Referred specimens—From: JDNM-266: fragmentary tooth material, JODA 2475, JODA 3754, JODA 3756, JODA 12898, JODA 15328, JODA 15346, JODA 15795; partial molar, JODA 7192. From JDNM-71D: fragmentary tooth material, JODA 15554. From UCMP V4834: fragmentary tooth material, JODA 15628.

Occurrence—JDNM-266, JDNM-71D, UCMP V4834.

Description—JODA 7192 is the anterior portion of a molar with one full loph and half of the second loph. It is smaller than the m3 of JODA 1321, which is assigned to *Mammut* sp. in the Rattlesnake Formation. JODA 7192 has a medial sulcus and lacks central conules. Approximate transverse width of the first loph is 44.39 mm and approximate width of second loph is 53.06 mm.

Remarks—Fragmentary material of proboscideans

has been collected from the lower and middle units of the Mascall Formation. Specimens collected from JDNM-266 were float material and may have weathered from the upper Mascall units above JDNM-266. The medial sulcus and lack of central conules in JODA 7192 suggest that it may be attributable to *Zygolophodon* Vacek, 1877. *Zygolophodon* is one of the taxa Tedford et al. (2004) lists as characterizing early Barstovian faunas; however, it is also present in the Hemingfordian age Massacre Lake fauna in Nevada (Lambert and Shoshani 1998). *Zygolophodon* has also been recovered from the early Barstovian Sucker Creek and Skull Springs faunas of Oregon, and the Virgin Valley and High Rock Canyon faunas of Nevada (Tedford et al. 2004). Earlier work on the Mascall deposits has reported the presence of *Gomphotherium* Burmeister, 1837 in the formation (e.g., Fremd et al. 1994, Prothero et al. 2006), but this study cannot find evidence for this genus in the type Mascall area.

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DISCUSSION

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Radioisotopic Age

Previously reported dates of 16.2±1.4 Ma for the top of the Dayville Basalt (uppermost part of the Columbia River Basalt Group, Feibelkorn et al. 1983, Bailey 1989), and 15.77±0.07 for unit 2 of Downs (1956) as dated by Swisher (1992), when combined with the current report of the Mascall Tuff at 15.122±0.017 Ma, indicate that the lower unit of the Mascall Formation in the type area is about one million years in duration. Recently reported ages of 16.44±0.05 Ma and 16.26±0.02 Ma for tuffs at Hawk Rim (McLaughlin et al. 2016) belonging to the Mascall Formation indicate the formation starts in the Late Hemingfordian outside the type area. Because the Dreamtime Tuff was not datable, the length of the Middle Mascall is unclear. The upper date of 13.564±0.018 Ma provided by the Kangaroo Tuff indicates the Upper Mascall extends into the Late Barstovian. Therefore, the Mascall Formation in the type area spans the latest Hemingfordian and almost the entire Barstovian, from >16.2 to <13.56 Ma (Woodburne, 2004) and as a whole (including Hawk Rim) from >16.44 to <13.56 Ma. However, as mentioned above, the majority of the fossils in the type area are collected in the lower and middle units of the formation, which correlate with the Early Barstovian.

Bestland et al. (2008) hypothesized that all of the paleosols of the Mascall formation represented the mid-Miocene Climatic Optimum because they all have the same degree of weathering; however, the dates presented here demonstrate that the deposits span through the end of the warming event. This suggests that the precipitation regime did not change after the mid-Miocene Climatic Optimum in the Pacific Northwest. And it further demonstrates that the Pacific Northwest had more

mesic conditions than the Great Plains during the middle Miocene and after the mid-Miocene Climatic Optimum (Bestland et al. 2008).

Faunal Turnover

Patterns of faunal turnover are difficult to assess due to the unknown provenance of many specimens, specifically those collected by the Weatherfords, and low specimen counts for small-bodied taxa; however, some general trends for specific taxa can be discerned. Within Equidae, the low-crowned genera, *Archaeohippus*, *Desmatippus* and *Parahippus* are only present in the lower and middle members of the formation, while the high-crowned *Acritohippus* persists throughout. This shift from an equid fauna that includes both low- and high-crowned equids initially, to exclusively high-crowned equids is observed throughout North American faunas. Leporidae, represented by multiple species, sciurids, and rhinoceroses span all three units of the formation; however, the presence of these taxa in the upper unit is most likely a taphonomic artifact, especially so for the durable enamel specimens of equids and rhinocerids. All species but three (*Pseudotrimylus mawbyi*, *Archaeolagus* sp., *Protospermophilus oregonensis*) are found in the middle unit. The Mascall Tuff is in the middle unit; therefore, high diversity of the middle unit most likely reflects the fact that the tuff layer yields the most fossils. The majority of species are also present in the lower unit; and absences may well be due to taphonomic or sampling issues, especially for small bodied mammals.

Local and Regional Comparisons

Overall, the fauna from the Mascall type area is similar to other early and late Barstovian sites in Oregon. The Mascall equivalent beds to the south, in the Crooked River area (UCMP V4948-V4951), differ only in the presence of *Hypohippus*, *Teleoceras medicornutum* Osborn, 1904 and *Alphagaulus vetus* Matthew, 1924. The late Hemingfordian Hawk Rim localities (JDNM 267–272, OU 4360), also in the Crooked River area, have faunal similarities to the type Mascall area with some noteworthy differences, especially among carnivorans. Hawk Rim has a different amphicyonid (*Amphicyon* cf. *frendens* Matthew, 1924), two additional dogs (*Cynarctoides arcridens* Barbour and Cook, 1914, *Paratomarctus temerarius* Leidy, 1858) along with *Tephrocyon rurestris*, and a new mustelid (*Watay tabutsigwii*). In addition, the Hawk Rim localities have antilocaprids, a chalicothere, two different beavers (*Anchitheriomys*, *Monosaulax*) that are not in the type area, and a definite identification of *Alphagaulus vetus*. The limited material from the Mascall-equivalent beds to the west of the John Day Basin in the Simtustus Formation

Gateway localities (UCMP V3427) likewise resembles the type Mascall fauna with the only exception being the addition of the distinctive "*Merychippus*" [LACM (CIT) 2929] skull discussed previously.

The several Barstovian faunas in southern and southeastern Oregon (Early Barstovian: Beatty Buttes, Red Basin, Skull Springs; Early and Late Barstovian: Sucker Creek; Late Barstovian: Quartz Basin) are all generally similar to the Mascall Type fauna. The differences between these other Oregon Barstovian faunas and the Mascall fauna is that: 1) they contain more species of talpids and soricids (most likely due to preservational reasons as discussed earlier, 2) have *Hypohippus* instead of *Kalobatippus*, 3) have aplodontiids (e.g., *Liodontia alexandrae* Furlong, 1910) and antilocaprids (e.g., *Merycodus* Leidy, 1854 and *Paracosoryx* Janis and Manning, 1998), 4) have fewer or no moschids, 5) and have fewer camels. Other fauna-specific differences in comparison to the Mascall are as follows: Early Barstovian Sucker Creek has a chalicothere; early Barstovian Beatty Buttes has *Amphicyon frendens*, *Oreolagus wallacei* Dawson, 1965, and *Pliohippus mirabilis* Leidy, 1858; Late Barstovian Quartz Basin has a greater diversity of cricetids and mustelids, fewer canids, has *Monosaulax* rather than *Euroxenomys*, and contains eomyids (*Pseudadjidaumo quartzi* Shotwell, 1967 and *Pseudotheridomys pagei* Shotwell, 1967) and an erinaceid; the Late Barstovian Skull Springs fauna has two additional amphicyonids (*Amphicyon* Lartet, 1836 and *Pliocyon* Matthew, 1918), two different canids (*Euoplocyon brachygnathus* Douglass, 1903 and *Paratomarctus temerarius* Leidy, 1858), a mustelid (*Plionictis gazini* Hall, 1931), and a chalicothere; the Late Barstovian Red Basin has *Amphicyon*, an eomyid (*Pseudotheridomys pagei*), a cricetid (*Copemys pagei* Shotwell, 1967), an erinaceid, the rhinocerotids *Aphelops* and *Teleoceras*, and higher squirrel diversity.

The Mascall fauna is also similar to the early Barstovian Virgin Valley fauna of Nevada and like other Barstovian sites in Oregon, the Virgin Valley fauna differs from the Mascall by containing the aplodontiid *Liodontia* Miller and Gidley, 1918, different canids (*Paracynarctus* Wang, Tedford and Taylor, 1999 and *Protomarctus* Wang, Tedford and Taylor, 1999), *Oreolagus* Dice, 1917, the chalicothere *Moropus* Marsh 1877, *Hypohippus*, and a more diverse rhinocerotid fauna (*Aphelops*, *Peraceras* Cope, 1880, and *Teleoceras*).

There was higher provinciality across the American West during the mid-Miocene (Barnosky and Carrasco 2002, Tedford et al. 2004) attributed to climatic changes associated with the MMCO, combined with tectonic changes related to extension of the Basin and Range

Province, uplift of the Rocky Mountains (Barnosky and Carrasco 2002, Badgley and Fineralli 2013, Badgley et al. 2017), and inception of the migration of the Yellowstone hotspot (Kent-Corson et al. 2013). The Mascall fauna, although similar to other Barstovian faunas in the Northwest, shares fewer taxa in common with more distant Barstovian localities such as those to the south (the Barstow, Green Hills, and Second Division faunas) and to the east in the Great Plains (Valentine and Lower Snake Creek), with the exception of the Pawnee Creek fauna in Colorado. The Mascall is similar to the Pawnee Creek fauna, but that fauna is more diverse, only contains large mammals, has significantly more equid taxa, contains different peccaries, and does not have *Tephrocyon*, *Rakomeryx*, *Parablastomeryx* or *Procamelus.*

CONCLUSIONS

The Mascall type area contains an early Barstovian fauna with a diverse assemblage. The following taxa are added to the mammalian faunal list at the type Mascall area from Downs (1956): *Pseudotrimylus mawbyi*, *Mioscalops* cf. *ripafodiator, Leptocyon* sp., *Pseudaelurus* sp., *Archaeolagus* sp., *Hypolagus fontinalus*, *Hypolagus parviplicatus, Euroxenomys* sp., *Hesperogaulus gazini*, *Protospermophilus malheurensis*, cf. *Kalobatippus* sp., "*Cynorca*" *hesperia*, "*Cynorca*" sp., *Rakomeryx sinclairi,* cf. *Protocamelus* sp., *Blastomeryx gemnifer*, and *Parablastomeryx* sp. *Hypolagus vetus* is removed from the list because the specimens Downs (1956) assigned to this taxon are identified as *H. parviplicatus* or Leporidae indet. *Mylagaulus* sp. is no longer confirmed in the type area because the material Downs (1956) assigned to this taxon either belongs to *Alphalaugus vetus* or *Hesperogaulus gazini* according to Calede and Hopkins (2012), therefore it is placed in Mylagaulidae. Three families are added to the list: Talpidae, Cricetidae, and Rhinocerotidae. A preliminary reevaluation of the merychippine horses concludes that there are at least two species: *Acritohippus isonesus* and a second smaller morphotype. Relative to Downs (1956), the following synonymies are updated for the Mascall fauna: *Tephrocyon rurestris* (=*Tomarctus rurestris*), *Cynelos sinapius* (=*Amphicyon sinapius*), *Balantiomys oregonensis* (=*Peridiomys oregonensis*), *Desmatippus avus* (=*Parahippus avus*), *Protospermophilus oregonensis* (=*Arctomyoides oregonensis)*, *Ticholeptus zygomaticus* (=*Ticholeptus obliquidens*).

The deposits range from approximately 16 Ma to 13 Ma, although the majority of the fossils are recovered from or stratigraphically close to the Mascall Tuff, dated here at 15.122±0.017 Ma. Assigning the fossiliferous part of the Mascall Formation to the Early Barstovian

is supported by the presence of *Tephrocyon* and *Hesperogaulus*, which have first occurrences during the Early Barstovian, and *Euroxenomys*, *Desmatippus*, *Parahippus*, "*Cynorca,"*and *Rakomeryx,* which have their last occurrence during the Early Barstovian. The Kangaroo Tuff in the upper unit of the Mascall Formation is dated here at 13.564±0.018Ma. There are 90 m of unfossiliferous Mascall deposits above the Kangaroo Tuff, leaving the upper age of the formation unknown. The date on the Kangaroo Tuff indicates that the Mascall Formation extends into the Late Barstovian; however, the fossils collected from these deposits are fragmentary and few. This updated faunal list placed into a stratigraphic framework, with more precise new ages for tuff deposits, allows for more direct comparisons of the Mascall fauna with other Barstovian sites that have also been recently updated and placed in a stratigraphic framework (e.g., Pagnac, 2005).

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Appendix 1. CA-IDTIMS U-Pb isotopic ratio and age results for zircon crystals from the Mascall and Kangaroo Tuffs.

Grain (a)	$\frac{Th}{U}$ (b)	$^{206}Pb^*$ x10⁻¹³ mol (c)	mol % $^{206}Pb^*$ (c)	$\frac{Pb^*}{Pbc}$ (c)	Pbc (pg) (c)	$\frac{^{206}Pb}{^{204}Pb}$ (d)	$\frac{^{208}Pb}{^{206}Pb}$ (e)	$\frac{^{207}Pb}{^{206}Pb}$ (e)	% err (f)	$\frac{^{207}Pb}{^{235}U}$ (e)	% err (f)	$\frac{^{206}Pb}{^{238}U}$ (e)	% err (f)	corr. coef.	$\frac{^{207}Pb}{^{206}Pb}$ (g)	± (f)	$\frac{^{207}Pb}{^{235}U}$ (g)	± (f)	$\frac{^{206}Pb}{^{238}U}$ (g)	± (f)
Kangaroo Tuff (KCM61023a)																				
z2	0.785	0.0291	85.5%	2.0	0.41	127	0.271	0.04946	9.6	0.014452	10.09	0.002119	0.559	0.858	170	224	14.57	1.46	**13.648**	0.076
z6	0.691	0.0356	90.7%	3.1	0.30	196	0.244	0.05076	5.5	0.014792	5.85	0.002113	0.355	0.881	230	128	14.91	0.87	**13.610**	0.048
z5	0.753	0.0637	94.8%	5.9	0.29	351	0.253	0.04818	2.9	0.014023	3.06	0.002111	0.196	0.919	108	68	14.14	0.43	**13.595**	0.026
z4	0.667	0.0263	81.9%	1.5	0.48	102	0.235	0.05056	13.5	0.014716	14.07	0.002111	0.735	0.794	221	311	14.83	2.07	**13.595**	0.099
z3	0.743	0.0497	93.2%	4.5	0.30	269	0.256	0.04934	3.8	0.014346	4.04	0.002109	0.254	0.920	164	89	14.46	0.58	**13.578**	0.034
z8	0.965	0.0804	94.6%	6.0	0.38	342	0.320	0.04762	3.1	0.013825	3.24	0.002106	0.211	0.896	80	72	13.94	0.45	**13.560**	0.028
z1	0.597	0.1153	97.2%	10.8	0.27	655	0.196	0.04709	1.5	0.013669	1.60	0.002105	0.115	0.871	54	36	13.79	0.22	**13.557**	0.015
z7	0.585	0.2190	97.7%	13.4	0.42	814	0.191	0.04682	1.2	0.013584	1.30	0.002104	0.103	0.809	40	29	13.70	0.18	**13.551**	0.014
Mascall Tuff (KCM1121-120)																				
z6	0.456	0.0202	84.6%	1.6	0.31	117	0.147	0.047165	13.2	0.015413	13.36	0.002370	0.469	0.360	58	314	15.53	2.06	15.261	0.072
z2	0.516	0.0585	86.6%	1.9	0.75	134	0.167	0.046902	3.7	0.015220	3.95	0.002354	0.353	0.737	44	88	15.34	0.60	**15.154**	0.053
z12	0.580	0.0368	90.4%	2.9	0.33	187	0.187	0.045130	2.7	0.014643	2.91	0.002353	0.258	0.731	-49	66	14.76	0.43	**15.152**	0.039
z4	0.625	0.0364	89.8%	2.7	0.34	177	0.202	0.044541	6.4	0.014434	6.58	0.002350	0.369	0.527	-81	156	14.55	0.95	**15.133**	0.056
z9	0.635	0.1906	96.1%	7.7	0.64	467	0.205	0.046634	0.9	0.015110	1.02	0.002350	0.117	0.734	31	23	15.23	0.15	**15.132**	0.018
z7	0.496	0.0212	79.8%	1.2	0.45	90	0.160	0.044313	11.8	0.014357	12.1	0.002350	0.575	0.455	-93	290	14.47	1.74	**15.130**	0.087
z5	0.553	0.0435	91.8%	3.4	0.32	220	0.179	0.045906	3.0	0.014856	3.13	0.002347	0.235	0.631	-7	72	14.97	0.47	**15.113**	0.036
z1	0.484	0.1379	96.1%	7.3	0.47	458	0.156	0.046618	1.0	0.015077	1.1	0.002346	0.118	0.733	30	24	15.19	0.16	**15.103**	0.018

Notes:

(a) z1, z2, etc. are labels for single zircon grains or fragments chemically abraded at 190°C; analyses in bold used in the weighted mean calculations.

(b) Model Th/U ratio calculated from radiogenic $^{208}Pb/^{206}Pb$ ratio and $^{207}Pb/^{235}U$ date.

(c) Pb* and Pbc are radiogenic and common Pb, respectively. mol % $^{206}Pb^*$ is with respect to radiogenic and blank Pb.

(d) Measured ratio corrected for spike and fractionation only. Samples spiked with the ET535 tracer, with an external Pb fractionation correction of 0.16 ± 0.02 (1-sigma) %/amu (atomic mass unit), based on analysis of NBS-981 and NBS-982.

(e) Corrected for fractionation, spike, common Pb, and initial disequilibrium in $^{230}Th/^{238}U$. All common Pb is assigned to procedural blank with composition of $^{206}Pb/^{204}Pb = 18.042 \pm 0.61\%$; $^{207}Pb/^{204}Pb = 15.537 \pm 0.52\%$, $^{208}Pb/^{204}Pb = 37.686 \pm 0.63\%$ (1-sigma).

(f) Errors are 2-sigma, propagated using algorithms of Schmitz and Schoene (2007).

(g) Calculations based on the decay constants of Jaffey et al. (1971). $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ratios and dates corrected for initial disequilibrium in $^{230}Th/^{238}U$ using Th/U [magma] = 3.

Appendix 2. LA-ICPMS U-Pb isotopic ratio, age, and trace element concentrations for zircon crystals from the Mascall and Kangaroo Tuffs.

Analysis	207Pb*/235U*	±2s (%)	206Pb*/238U	±2s (%)	error corr.	238U/206Pb*	±2s (%)	207Pb*/206Pb*	±2s (%)	error corr.	206Pb*/238U* (Age Ma)	±2s (Ma)	P	Ti	Y	Nb	La	Ce
Kangaroo Tuff (KCM61023a)																		
KCM61023a_8 12/2/2011 1:42:35 PM	0.1403	11.9	0.003087	5.9	0.5	324.0	5.9	0.3297	10.3	0.00	19.9	1.2	21745	19.43	4182	8.50	336.34	647.11
KCM61023a_9 12/2/2011 1:44:20 PM	0.0434	17.3	0.002242	4.5	0.26	446.1	4.5	0.1405	16.7	0.00	14.4	0.7	3315	18.51	2169	4.07	55.89	133.60
KCM61023a_10 12/2/2011 1:46:05 PM	0.0249	9.0	0.002084	4.9	0.54	479.9	4.9	0.0867	7.6	0.00	13.4	0.7	696	7.22	3672	13.90	0.16	53.67
KCM61023a_12 12/2/2011 1:49:37 PM	0.0109	17.0	0.002059	5.1	0.3	485.6	5.1	0.0384	16.2	0.00	13.3	0.7	976	3.62	4912	13.03		44.16
KCM61023a_4 12/2/2011 1:35:30 PM	0.0126	19.9	0.002054	7.5	0.38	486.8	7.5	0.0443	18.4	0.00	13.2	1.0	792	5.89	2716	5.13	0.03	22.01
KCM61023a_7 12/2/2011 1:40:48 PM	0.0134	48.3	0.002025	4.6	0.1	493.7	4.6	0.0479	48.0	0.00	13.0	0.6	1599	8.80	2501	6.25	14.96	81.40
KCM61023a_11 12/2/2011 1:47:51 PM	0.0134	12.3	0.00195	4.9	0.4	512.8	4.9	0.0497	11.2	0.00	12.6	0.6	544	3.43	2634	9.50	0.37	38.10
KCM61023a_6 12/2/2011 1:39:03 PM	0.0107	41.7	0.001924	4.1	0.1	519.7	4.1	0.0402	41.5	0.00	12.4	0.5	380	4.67	1685	4.18		41.79
KCM61023a_5 12/2/2011 1:37:16 PM	0.0100	24.6	0.001849	4.1	0.17	540.8	4.1	0.0392	24.2	0.00	11.9	0.5	626	1.78	2740	5.59	0.37	20.11
Mascall Tuff (KCM11121-120)																		
KCM1211-120L_37 8/23/2013 1:09:44 PM (Run: 1)	0.3278	16.0	0.005345	11.3	0.71	187.1	11.3	0.4448	11.2	0.00	34.4	3.9	464	45.93	2162	6.03	6.46	21.17
KCM1211-120L_27 8/23/2013 12:45:43 PM (Run: 1)	0.0310	5.6	0.00458	4.1	0.73	218.3	4.1	0.0490	3.8	0.00	29.5	1.2	1007	12.21	10939	195.48	2.61	33.90
KCM1211-120L_34 8/23/2013 1:04:38 PM (Run: 1)	0.0438	42.6	0.003714	27.1	0.64	269.3	27.1	0.0856	32.9	0.00	23.9	6.5	293	11.79	3594	2.48	34.85	26.57
KCM1211-120L_04 8/23/2013 11:45:36 AM (Run: 1)	0.1113	26.8	0.003279	8.8	0.33	305.0	8.8	0.2463	25.3	0.00	21.1	1.9	1996	31.68	3420	14.96	61.53	156.81
KCM1211-120L_23 8/23/2013 12:31:54 PM (Run: 1)	0.0608	47.8	0.00291	11.7	0.25	343.6	11.7	0.1515	46.4	0.00	18.7	2.2	216	7.64	651	2.04		12.89
KCM1211-120L_06 8/23/2013 11:49:00 AM (Run: 1)	0.0336	54.9	0.002902	29.9	0.54	344.6	29.9	0.0840	46.1	0.00	18.7	5.6	781	5.83	3014	4.57	31.02	64.72
KCM1211-120L_30 8/23/2013 12:50:49 PM (Run: 1)	0.0092	37.8	0.002546	10.8	0.28	392.8	10.8	0.0261	36.2	0.00	16.4	1.8	1016	10.26	1839	5.78	20.32	61.96
KCM1211-120L_17 8/23/2013 12:21:42 PM (Run: 1)	0.0394	30.8	0.002462	10.1	0.33	406.2	10.1	0.1160	29.1	0.00	15.8	1.6	2344	8.73	1020	3.96	42.02	93.12
KCM1211-120L_13 8/23/2013 12:07:54 PM (Run: 1)	0.0244	42.9	0.002453	9.1	0.21	407.7	9.1	0.0723	42.0	0.00	15.8	1.4	304	8.07	2393	5.60	0.64	12.47
KCM1211-120L_11 8/23/2013 12:04:30 PM (Run: 1)	0.0162	65.2	0.002333	12.3	0.19	428.7	12.3	0.0503	64.0	0.00	15.0	1.8	195	8.36	966	1.03		5.92
KCM1211-120L_28 8/23/2013 12:47:25 PM (Run: 1)	0.0176	26.8	0.002322	7.5	0.28	430.7	7.5	0.0551	25.7	0.00	15.0	1.1	227	6.10	1003	3.24		12.18
KCM1211-120L_45 8/23/2013 1:30:22 PM (Run: 1)	0.0131	24.6	0.002322	9.4	0.38	432.6	9.4	0.0410	22.7	0.00	14.9	1.4	532	10.88	5791	6.58		42.32
KCM1211-120L_44 8/23/2013 1:28:39 PM (Run: 1)	0.0146	13.2	0.002307	5.9	0.45	433.6	5.9	0.0461	11.8	0.00	14.9	0.9	770	11.02	9770	10.17	0.15	72.76
KCM1211-120L_20 8/23/2013 12:26:48 PM (Run: 1)	0.0174	31.6	0.002303	9.3	0.29	434.3	9.3	0.0547	30.2	0.00	14.8	1.4	345	16.15	2442	4.46	0.05	14.67
KCM1211-120L_29 8/23/2013 12:49:08 PM (Run: 1)	0.0233	54.5	0.002282	9.1	0.17	438.2	9.1	0.0741	53.7	0.00	14.7	1.3	241	5.47	913	2.84		17.15
KCM1211-120L_09 8/23/2013 12:01:06 PM (Run: 1)	0.0172	20.4	0.002275	7.0	0.34	439.5	7.0	0.0549	19.2	0.00	14.7	1.0	759	7.71	1590	6.09	29.82	65.56
KCM1211-120L_05 8/23/2013 11:47:18 AM (Run: 1)	0.0079	48.5	0.002254	8.0	0.16	443.7	8.0	0.0255	47.9	0.00	14.5	1.2	228	9.61	1894	5.93	0.10	11.96
KCM1211-120L_12 8/23/2013 12:06:12 PM (Run: 1)	0.0122	76.4	0.00223	7.5	0.1	448.4	7.5	0.0397	76.0	0.00	14.4	1.1	281	7.14	3966	3.45	0.08	9.68
KCM1211-120L_15 8/23/2013 12:11:18 PM (Run: 1)	0.0154	29.0	0.002228	9.0	0.31	448.9	9.0	0.0501	27.6	0.00	14.3	1.3	2753	12.83	3796	16.97	153.78	324.27
KCM1211-120L_07 8/23/2013 11:50:42 AM (Run: 1)	0.0350	80.6	0.002197	11.5	0.14	455.1	11.5	0.1156	79.7	0.00	14.2	1.6	215	6.51	866	2.00		6.71
KCM1211-120L_24 8/23/2013 12:33:36 PM (Run: 1)	0.0144	26.8	0.002193	7.3	0.27	456.0	7.3	0.0476	25.8	0.00	14.1	1.0	429	8.03	3333	3.82	2.90	15.49
KCM1211-120L_36 8/23/2013 1:08:03 PM (Run: 1)	0.0131	43.8	0.00218	7.0	0.16	458.7	7.0	0.0436	43.2	0.00	14.0	1.0	434	6.13	5527	11.28	0.06	63.63
KCM1211-120L_39 8/23/2013 1:13:08 PM (Run: 1)	0.0568	124.2	0.002174	8.9	0.07	459.9	8.9	0.1895	123.9	0.00	14.0	1.2	1998	8.76	1765	5.93	139.81	314.71
KCM1211-120L_10 8/23/2013 12:02:48 PM (Run: 1)	0.0141	20.3	0.002131	6.6	0.33	469.3	6.6	0.0480	19.2	0.00	13.7	0.9	491	10.50	3624	15.46	6.84	48.48
KCM1211-120L_25 8/23/2013 12:42:19 PM (Run: 1)	0.0154	10.5	0.002124	4.6	0.44	470.8	4.6	0.0525	9.4	0.00	13.7	0.6	756	9.18	9535	39.94	12.35	124.64
KCM1211-120L_02 8/23/2013 11:42:12 AM (Run: 1)	0.0147	24.4	0.002109	7.2	0.3	474.2	7.2	0.0505	23.3	0.00	13.6	1.0	344	6.63	2138	9.05		31.32
KCM1211-120L_40 8/23/2013 1:14:51 PM (Run: 1)	0.0143	15.8	0.002101	6.5	0.26	475.9	6.5	0.0493	14.4	0.00	13.5	0.9	463	5.57	3866	15.20	0.39	42.62
KCM1211-120L_14 8/23/2013 12:09:36 PM (Run: 1)	0.1600	1341	0.002096	11.8	0.01	477.2	11.8	0.5536	1341	0.00	13.5	1.6	216	5.72	957	3.94	0.07	13.81
KCM1211-120L_16 8/23/2013 12:13:00 PM (Run: 1)	0.0148	10.6	0.002091	4.3	0.41	478.2	4.3	0.0513	9.6	0.00	13.5	0.6	730	7.48	10815	57.89	0.38	140.13
KCM1211-120L_22 8/23/2013 12:30:12 PM (Run: 1)	0.0167	21.8	0.002085	8.7	0.4	479.7	8.7	0.0582	20.0	0.00	13.4	1.2	227	5.58	2842	5.98	0.11	18.12
KCM1211-120L_08 8/23/2013 11:52:24 AM (Run: 1)	0.0090	23.4	0.002082	6.4	0.27	480.3	6.4	0.0312	22.5	0.00	13.4	0.9	429	8.75	4318	7.85	0.09	20.70
KCM1211-120L_38 8/23/2013 1:11:26 PM (Run: 1)	0.0139	11.0	0.002081	6.0	0.54	480.6	6.0	0.0486	9.3	0.00	13.4	0.8	1016	4.87	10515	40.86	36.21	156.15
KCM1211-120L_43 8/23/2013 1:26:58 PM (Run: 1)	0.0153	94.6	0.002077	6.5	0.07	481.4	6.5	0.0533	94.4	0.00	13.3	0.9	257	4.75	1174	6.57	16.13	42.20
KCM1211-120L_01 8/23/2013 11:40:30 AM (Run: 1)	0.0162	17.6	0.002072	4.6	0.26	482.5	4.6	0.0567	17.0	0.00	13.3	0.6	1561	5.41	6795	23.41	115.07	265.48
KCM1211-120L_42 8/23/2013 1:25:16 PM (Run: 1)	0.0121	27.8	0.002058	5.1	0.18	485.9	5.1	0.0428	27.4	0.00	13.3	0.7	488	11.50	4825	11.96	0.03	31.85
KCM1211-120L_18 8/23/2013 12:23:24 PM (Run: 1)	0.0130	18.4	0.002037	6.0	0.35	490.9	6.0	0.0462	17.2	0.00	13.1	0.8	502	8.25	5039	12.54	0.09	35.24
KCM1211-120L_33 8/23/2013 1:02:56 PM (Run: 1)	0.0128	19.5	0.00203	7.7	0.39	492.6	7.7	0.0457	17.9	0.00	13.1	1.0	546	10.50	5198	6.76	1.33	22.32
KCM1211-120L_31 8/23/2013 12:52:31 PM (Run: 1)	0.0130	15.2	0.002023	4.9	0.32	494.3	4.9	0.0467	14.4	0.00	13.0	0.6	763	5.75	7079	52.09	4.47	104.19
KCM1211-120L_03 8/23/2013 11:43:54 AM (Run: 1)	0.0148	15.3	0.002005	4.7	0.31	498.8	4.7	0.0535	14.6	0.00	12.9	0.6	726	7.84	4980	12.38	24.75	74.18
KCM1211-120L_19 8/23/2013 12:25:06 PM (Run: 1)	0.0218	30.6	0.002004	10.3	0.34	499.1	10.3	0.0789	28.9	0.00	12.9	1.3	239	7.76	1167	2.72		10.20
KCM1211-120L_26 8/23/2013 12:44:01 PM (Run: 1)	0.0136	14.4	0.001998	4.8	0.33	500.5	4.8	0.0493	13.5	0.00	12.9	0.6	732	13.00	4744	11.28	4.13	65.66

Notes:
Radiogenic isotope ratios and ages; uncertainties do not include systematic calibration errors of 0.5% (207Pb/206Pb) and 1% (206Pb/238U).
Trace element concentrations in ppm.

Appendix 2. LA-ICPMS U-Pb isotopic ratio, age, and trace element concentrations for zircon crystals from the Mascall and Kangaroo Tuffs (continued).

Analysis	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Th	U
Kangaroo Tuff (KCM61023a)																
KCM61023a_8 12/2/2011 1:42:35 PM	86.57	428.64	98.75	8.79	136.87	34.90	385	142	644	156	1609	247	10808	2.65	766	876
KCM61023a_9 12/2/2011 1:44:20 PM	12.71	59.08	20.26	3.20	54.49	17.09	196	73	329	82	845	131	10051	1.40	529	411
KCM61023a_10 12/2/2011 1:46:05 PM	0.08	2.61	7.11	1.79	61.10	24.59	339	129	584	146	1529	237	12289	5.00	1500	1395
KCM61023a_12 12/2/2011 1:49:37 PM	0.13	2.46	11.94	1.41	75.69	31.12	413	172	790	194	2060	297	12929	3.91	1194	1325
KCM61023a_4 12/2/2011 1:35:30 PM	0.18	1.85	4.83	1.09	39.69	16.65	229	95	431	113	1250	175	10590	1.65	413	596
KCM61023a_7 12/2/2011 1:40:48 PM	5.14	26.12	11.49	3.08	51.60	18.19	223	89	402	98	1034	157	10475	1.82	603	471
KCM61023a_11 12/2/2011 1:47:51 PM	0.12	1.46	4.62	1.29	37.85	16.08	219	89	417	107	1139	174	12248	3.34	876	943
KCM61023a_6 12/2/2011 1:39:03 PM	0.06	1.71	4.17	1.82	33.90	11.85	146	57	259	67	692	108	10437	1.39	887	520
KCM61023a_5 12/2/2011 1:37:16 PM	0.04	1.03	5.49	0.84	36.74	15.73	226	93	428	111	1205	174	12191	2.00	459	644
Mascall Tuff (KCM1121-120)																
KCM1211-120L_37 8/23/2013 1:09:44 PM (Run: 1)	1.44	10.02	13.63	1.27	53.07	19.00	232	80	338	81	857	104	7902	2.00	173	217
KCM1211-120L_27 8/23/2013 12:45:43 PM (Run: 1)	1.39	9.34	23.04	2.01	196.93	82.24	1071	413	1670	389	4004	397	13231	34.84	1810	3541
KCM1211-120L_34 8/23/2013 1:04:38 PM (Run: 1)	8.14	41.00	31.05	4.37	106.64	34.94	396	137	561	132	1363	161	8260	0.75	89	134
KCM1211-120L_04 8/23/2013 11:45:36 AM (Run: 1)	17.92	106.44	44.49	2.80	113.73	35.40	401	132	527	127	1350	143	6473	4.58	410	496
KCM1211-120L_23 8/23/2013 12:31:54 PM (Run: 1)	0.00	0.80	2.61	0.77	13.49	4.52	63	22	104	31	358	40	8201	1.17	59	95
KCM1211-120L_06 8/23/2013 11:49:00 AM (Run: 1)	9.56	59.00	26.50	1.52	89.95	30.88	353	118	472	113	1174	121	7125	1.47	100	194
KCM1211-120L_30 8/23/2013 12:50:49 PM (Run: 1)	4.91	28.83	11.66	2.73	41.94	14.82	176	65	289	79	920	105	9008	1.87	135	158
KCM1211-120L_17 8/23/2013 12:21:42 PM (Run: 1)	11.69	65.12	17.57	1.95	30.00	8.97	105	38	172	44	509	58	9438	1.95	104	123
KCM1211-120L_13 8/23/2013 12:07:54 PM (Run: 1)	0.79	7.91	10.45	1.64	54.65	19.89	252	92	379	91	943	107	8274	2.06	64	143
KCM1211-120L_11 8/23/2013 12:04:30 PM (Run: 1)	0.03	2.04	3.69	1.41	21.32	7.01	90	34	147	41	471	61	8934	0.64	58	93
KCM1211-120L_28 8/23/2013 12:47:25 PM (Run: 1)	0.09	1.48	4.58	0.83	17.67	6.83	93	35	159	42	546	65	8368	1.43	75	130
KCM1211-120L_45 8/23/2013 1:30:22 PM (Run: 1)	0.67	15.23	36.26	5.42	184.66	58.35	684	226	895	217	2240	218	6934	2.20	354	361
KCM1211-120L_44 8/23/2013 1:28:39 PM (Run: 1)	1.05	26.05	61.34	9.69	297.70	95.76	1071	347	1347	318	3239	315	6451	2.43	614	545
KCM1211-120L_20 8/23/2013 12:26:48 PM (Run: 1)	0.21	5.00	11.62	3.05	59.74	20.74	254	94	404	98	1118	121	6850	1.67	202	221
KCM1211-120L_29 8/23/2013 12:49:08 PM (Run: 1)	0.06	0.93	3.01	0.81	16.86	6.16	87	33	153	41	469	55	9538	1.75	91	142
KCM1211-120L_09 8/23/2013 12:01:06 PM (Run: 1)	9.05	50.37	19.51	0.84	45.54	13.69	173	62	256	65	701	76	7553	2.26	87	171
KCM1211-120L_05 8/23/2013 11:47:18 AM (Run: 1)	0.23	4.30	8.99	0.84	47.30	16.38	193	73	307	77	841	92	7237	2.10	66	155
KCM1211-120L_12 8/23/2013 12:06:12 PM (Run: 1)	0.61	10.75	24.93	3.48	111.61	39.82	453	154	612	148	1541	174	7241	1.18	110	162
KCM1211-120L_15 8/23/2013 12:11:18 PM (Run: 1)	46.04	265.26	81.55	3.34	148.40	40.19	434	147	574	137	1419	150	8036	5.44	388	481
KCM1211-120L_07 8/23/2013 11:50:42 AM (Run: 1)		0.68	1.57	0.54	14.27	5.63	77	31	142	40	499	59	8758	0.82	31	71
KCM1211-120L_24 8/23/2013 12:33:36 PM (Run: 1)	1.38	15.11	23.58	2.60	102.42	33.10	381	135	523	125	1315	140	7161	1.50	115	197
KCM1211-120L_36 8/23/2013 1:08:03 PM (Run: 1)	0.79	16.90	33.00	2.62	156.47	51.19	618	212	843	191	1911	213	9417	3.24	305	293
KCM1211-120L_39 8/23/2013 1:13:08 PM (Run: 1)	36.81	244.52	64.94	2.55	85.95	19.98	212	71	284	68	722	79	7767	1.82	94	172
KCM1211-120L_10 8/23/2013 12:02:48 PM (Run: 1)	2.20	18.47	21.16	1.59	104.76	35.21	396	135	536	126	1306	143	7440	4.87	387	442
KCM1211-120L_25 8/23/2013 12:42:19 PM (Run: 1)	5.34	46.98	70.42	3.32	308.01	97.65	1090	365	1399	318	3137	316	6795	7.65	784	888
KCM1211-120L_02 8/23/2013 11:42:12 AM (Run: 1)	0.28	4.17	9.84	0.74	50.52	18.86	228	84	343	83	890	94	7605	3.16	158	238
KCM1211-120L_40 8/23/2013 1:14:51 PM (Run: 1)	0.56	8.83	18.45	0.65	96.87	33.80	413	149	605	149	1592	170	9615	4.63	309	442
KCM1211-120L_14 8/23/2013 12:09:36 PM (Run: 1)	0.04	1.09	2.76	0.64	17.51	6.33	83	33	156	45	544	68	9601	1.96	68	121
KCM1211-120L_16 8/23/2013 12:13:00 PM (Run: 1)	1.60	33.77	73.88	3.89	335.37	105.97	1205	397	1502	344	3419	337	6933	7.91	1182	1033
KCM1211-120L_22 8/23/2013 12:30:12 PM (Run: 1)	0.35	8.33	17.89	1.14	83.02	27.86	332	115	430	110	1117	110	7198	1.87	113	216
KCM1211-120L_08 8/23/2013 11:52:24 AM (Run: 1)	0.56	12.72	30.29	1.42	133.96	43.37	509	173	693	167	1850	185	6932	2.38	251	363
KCM1211-120L_38 8/23/2013 1:11:26 PM (Run: 1)	13.06	94.85	74.35	1.60	279.89	96.39	1114	379	1538	353	3497	372	10257	8.30	1051	1234
KCM1211-120L_43 8/23/2013 1:26:58 PM (Run: 1)	1.68	6.86	3.56	1.09	24.86	8.32	108	42	191	54	655	69	8506	2.82	134	253
KCM1211-120L_01 8/23/2013 11:40:30 AM (Run: 1)	38.99	202.00	84.92	2.70	232.39	69.64	782	258	977	233	2529	238	7512	4.98	386	609
KCM1211-120L_42 8/23/2013 1:25:16 PM (Run: 1)	0.55	11.93	29.45	3.78	146.46	47.20	553	189	729	179	1933	197	6357	3.56	488	505
KCM1211-120L_18 8/23/2013 12:23:24 PM (Run: 1)	0.55	13.22	34.29	2.22	146.44	47.53	574	196	788	195	2057	197	8002	2.71	329	430
KCM1211-120L_33 8/23/2013 1:02:56 PM (Run: 1)	1.21	17.31	34.63	2.48	160.95	49.82	575	199	785	188	1941	215	7862	1.79	260	325
KCM1211-120L_31 8/23/2013 12:52:31 PM (Run: 1)	2.39	21.84	40.08	1.16	201.31	69.82	803	282	1161	273	2861	290	9686	11.10	880	1231
KCM1211-120L_03 8/23/2013 11:43:54 AM (Run: 1)	7.01	51.74	45.79	2.56	159.42	51.74	586	198	772	177	1848	193	7085	3.16	290	390
KCM1211-120L_19 8/23/2013 12:25:06 PM (Run: 1)	0.11	2.81	5.41	1.28	25.88	9.33	109	43	191	51	635	73	8178	1.50	61	101
KCM1211-120L_26 8/23/2013 12:44:01 PM (Run: 1)	1.61	16.11	26.25	5.24	125.04	45.64	529	181	739	188	2025	209	7321	3.20	676	499

Concentrations (ppm)

Notes:
Radiogenic isotope ratios and ages; uncertainties do not include systematic calibration errors of 0.5% (207Pb/206Pb) and 1% (206Pb/238U).
Trace element concentrations in ppm.

Appendix 2. LA-ICPMS U-Pb isotopic ratio, age, and trace element concentrations for zircon crystals from the Mascall and Kangaroo Tuffs (continued).

Analysis	0.237 La	0.612 Ce	0.095 Pr	0.467 Nd	Pm	0.153 Sm	0.058 Eu	0.206 Gd	0.037 Tb	0.254 Dy	0.057 Ho	0.166 Er	0.026 Tm
Kangaroo Tuff (KCM61023a)													
KCM61023a_8 12/2/2011 1:42:35 PM	1419.2	1057.4	911.27	917.86		645.4	151.48	666.04	933.24	1515.9	2515.2	3890.6	6115.8
KCM61023a_9 12/2/2011 1:44:20 PM	235.82	218.29	133.75	126.52		132.42	55.195	265.16	457.04	769.69	1296.9	1990.4	3202.9
KCM61023a_10 12/2/2011 1:46:05 PM	0.685	87.689	0.871	5.5992		46.469	30.922	297.3	657.49	1334.9	2286	3530.5	5714.4
KCM61023a_12 12/2/2011 1:49:37 PM	0.0338	72.157	1.3495	5.2585		78.063	24.391	368.33	832.05	1625.4	3041	4775	7601.9
KCM61023a_4 12/2/2011 1:35:30 PM	0.1178	35.96	1.8645	3.9622		31.581	18.732	193.14	445.11	902.11	1672.6	2603.7	4438.1
KCM61023a_7 12/2/2011 1:40:48 PM	63.117	133.01	54.076	55.936		75.084	53.019	251.1	486.24	877.2	1580.9	2429.5	3826.5
KCM61023a_11 12/2/2011 1:47:51 PM	1.5405	62.261	1.298	3.1195		30.179	22.318	184.19	429.94	860.66	1573.8	2521.6	4199.6
KCM61023a_6 12/2/2011 1:39:03 PM	0.0156	68.281	0.6209	3.6647		27.244	31.427	164.97	316.72	575.07	1007.3	1565.7	2609.8
KCM61023a_5 12/2/2011 1:37:16 PM	0.0096	32.862	0.3822	2.2121		35.87	14.469	178.79	420.55	891.14	1639.7	2588.5	4354.5
Mascall Tuff (KCM1121-120)													
KCM1211-120L_37 8/23/2013 1:09:44 PM (Run: 1)	27.247	34.593	15.123	21.449		89.087	21.894	258.27	508.01	911.79	1411.3	2044.8	3164.8
KCM1211-120L_27 8/23/2013 12:45:43 PM (Run: 1)	11.026	55.391	14.581	20.008		150.62	34.597	958.32	2198.9	4217.5	7291	10092	15267
KCM1211-120L_34 8/23/2013 1:04:38 PM (Run: 1)	147.06	43.408	85.7	87.789		202.92	75.306	518.93	934.23	1558.3	2413.8	3390.3	5193.1
KCM1211-120L_04 8/23/2013 11:45:36 AM (Run: 1)	259.62	256.23	188.66	227.92		290.81	48.268	553.43	946.49	1577.3	2333.6	3181.8	4965.1
KCM1211-120L_23 8/23/2013 12:31:54 PM (Run: 1)	0.0009	21.055	0.0352	1.7226		17.033	13.192	65.663	120.8	249.14	393.26	626.17	1210.2
KCM1211-120L_06 8/23/2013 11:49:00 AM (Run: 1)	130.89	105.74	100.59	126.33		173.23	26.232	437.73	825.57	1388.8	2087.8	2853.5	4448.6
KCM1211-120L_30 8/23/2013 12:50:49 PM (Run: 1)	85.745	101.25	51.652	61.724		76.225	47.12	204.1	396.32	694.47	1155.6	1744.9	3099.3
KCM1211-120L_17 8/23/2013 12:21:42 PM (Run: 1)	177.28	152.16	123.01	139.44		114.81	33.677	145.97	239.79	413.4	665.38	1037.4	1714.7
KCM1211-120L_13 8/23/2013 12:07:54 PM (Run: 1)	2.716	20.376	8.3674	16.948		68.319	28.308	265.91	531.95	992.97	1632.8	2288.1	3573
KCM1211-120L_11 8/23/2013 12:04:30 PM (Run: 1)	0.0068	9.6731	0.2726	4.3663		24.149	24.318	103.75	187.53	354.44	609.11	887.42	1597.2
KCM1211-120L_28 8/23/2013 12:47:25 PM (Run: 1)	0.0227	19.897	0.906	3.1773		29.91	14.321	85.982	182.64	364.57	611.7	960.79	1662.4
KCM1211-120L_45 8/23/2013 1:30:22 PM (Run: 1)	0.1763	69.152	7.0383	32.611		237.02	93.434	898.6	1560.2	2692	3991.5	5408	8502.8
KCM1211-120L_44 8/23/2013 1:28:39 PM (Run: 1)	0.6294	118.89	11.094	55.789		400.94	166.99	1448.7	2560.5	4218.2	6133.6	8140.6	12466
KCM1211-120L_20 8/23/2013 12:26:48 PM (Run: 1)	0.219	23.972	2.1949	10.704		75.953	52.659	290.68	554.53	999.6	1659.8	2438.3	3857.5
KCM1211-120L_29 8/23/2013 12:49:08 PM (Run: 1)	0.0166	28.023	0.6642	1.993		19.676	13.906	82.022	164.78	344.1	579.94	921.81	1594.4
KCM1211-120L_09 8/23/2013 12:01:06 PM (Run: 1)	125.83	107.12	95.307	107.86		127.53	14.532	221.62	366.09	681.7	1091.2	1549	2555.4
KCM1211-120L_05 8/23/2013 11:47:18 AM (Run: 1)	0.408	19.546	2.4193	9.2007		58.743	14.486	230.17	438.07	760.85	1289.4	1855.4	3019.3
KCM1211-120L_12 8/23/2013 12:06:12 PM (Run: 1)	0.3545	15.822	6.4596	23.024		162.96	60.016	543.1	1064.6	1782.8	2717.1	3698.2	5819.8
KCM1211-120L_15 8/23/2013 12:11:18 PM (Run: 1)	648.87	529.86	484.66	568		533	57.591	722.14	1074.6	1708.4	2593.1	3466.3	5355.1
KCM1211-120L_07 8/23/2013 11:50:42 AM (Run: 1)		10.971	0.3254	1.4563		10.287	9.248	69.449	150.47	302.74	549.95	856.91	1580.9
KCM1211-120L_24 8/23/2013 12:33:36 PM (Run: 1)	12.252	25.318	14.498	32.351		154.15	44.844	498.38	884.96	1498.2	2377.2	3159.2	4904.1
KCM1211-120L_36 8/23/2013 1:08:03 PM (Run: 1)	0.2511	103.97	8.2671	36.184		215.68	45.173	761.39	1368.7	2431.8	3739.4	5095.8	7488.5
KCM1211-120L_39 8/23/2013 1:13:08 PM (Run: 1)	589.91	514.24	387.44	523.59		424.46	44.002	418.25	534.19	832.81	1252.2	1717.2	2671.3
KCM1211-120L_10 8/23/2013 12:02:48 PM (Run: 1)	28.853	79.212	23.159	39.549		138.32	27.375	509.77	941.57	1557.8	2389.2	3239.9	4953.5
KCM1211-120L_25 8/23/2013 12:42:19 PM (Run: 1)	52.107	203.66	56.191	100.61		460.28	57.276	1498.8	2611	4291.8	6441.2	8454.8	12473
KCM1211-120L_02 8/23/2013 11:42:12 AM (Run: 1)	0.0734	51.175	2.9294	8.9187		64.312	12.742	245.86	504.33	897.73	1488.3	2072.7	3260.9
KCM1211-120L_40 8/23/2013 1:14:51 PM (Run: 1)	1.6407	69.634	5.9085	18.905		120.56	11.131	471.41	903.86	1625.7	2630.5	3656.3	5848.6
KCM1211-120L_14 8/23/2013 12:09:36 PM (Run: 1)	0.2792	22.561	0.4455	2.3437		18.067	11.025	85.194	169.27	327.58	586.13	940.78	1746.3
KCM1211-120L_16 8/23/2013 12:13:00 PM (Run: 1)	1.5833	228.98	16.883	72.317		482.84	67.082	1632	2833.5	4745.2	7008.8	9076.5	13508
KCM1211-120L_22 8/23/2013 12:30:12 PM (Run: 1)	0.4664	29.601	3.6852	17.838		116.94	19.689	403.98	744.95	1306	2029.6	2595.4	4308.1
KCM1211-120L_08 8/23/2013 11:52:24 AM (Run: 1)	0.3922	33.823	5.9117	27.241		197.97	24.52	651.87	1159.7	2002.3	3053.3	4190	6564.3
KCM1211-120L_38 8/23/2013 1:11:26 PM (Run: 1)	152.77	255.15	137.52	203.12		485.92	27.657	1362	2577.2	4385	6696.8	9291.9	13827
KCM1211-120L_43 8/23/2013 1:26:58 PM (Run: 1)	68.064	68.955	17.649	14.68		23.257	18.833	120.97	222.57	426.71	740.55	1156.5	2122
KCM1211-120L_01 8/23/2013 11:40:30 AM (Run: 1)	485.53	433.79	410.4	432.55		555.04	46.562	1130.8	1862.1	3079.5	4566.8	5903.2	9140.7
KCM1211-120L_42 8/23/2013 1:25:16 PM (Run: 1)	0.133	52.047	5.8338	25.549		192.46	65.163	712.72	1262.1	2177.5	3336.9	4404.2	7021.3
KCM1211-120L_18 8/23/2013 12:23:24 PM (Run: 1)	0.3653	57.579	5.782	28.304		224.1	38.353	712.61	1270.9	2259.4	3458.8	4761.7	7637.6
KCM1211-120L_33 8/23/2013 1:02:56 PM (Run: 1)	5.6161	36.474	12.695	37.076		226.31	42.836	783.22	1332.2	2261.9	3514.1	4745.5	7365.9
KCM1211-120L_31 8/23/2013 12:52:31 PM (Run: 1)	18.874	170.25	25.152	46.76		261.99	20.035	979.6	1867	3159.9	4984.4	7017	10696
KCM1211-120L_03 8/23/2013 11:43:54 AM (Run: 1)	104.43	121.2	73.755	110.78		299.29	44.146	775.79	1383.5	2308.8	3491.1	4665.2	6948.9
KCM1211-120L_19 8/23/2013 12:25:06 PM (Run: 1)	0.0294	16.659	1.1751	6.027		35.333	21.99	125.93	249.38	430.4	762.45	1151.3	2018
KCM1211-120L_26 8/23/2013 12:44:01 PM (Run: 1)	17.431	107.3	16.998	34.506		171.6	90.352	608.45	1220.3	2082.3	3200.2	4465.2	7387.4

Notes:
Radiogenic isotope ratios and ages; uncertainties do not include systematic calibration errors of 0.5% (207Pb/206Pb) and 1% (206Pb/238U).
Trace element concentrations in ppm.

Appendix 2. LA-ICPMS U-Pb isotopic ratio, age, and trace element concentrations for zircon crystals from the Mascall and Kangaroo Tuffs (continued).

Analysis	0.170 Yb	0.025 Lu	Ti-in-zircon T(°C)	Eu/Eu*	ΣREE	(Gd/Yb)cn	Lu/Hf	Nb/Ta	Nb/U	Nb/Th	Th/U	Th/Y	Hf/Y
Kangaroo Tuff (KCM61023a)													
KCM61023a_8 12/2/2011 1:42:35 PM	9466.4	9708.8	870	0.91	0.23	0.70	10.58	0.0228	3.215	0.010	0.875	0.183	0.387
KCM61023a_9 12/2/2011 1:44:20 PM	4972.8	5160.8	864	1.18	0.28	1.05	40.79	0.0130	2.895	0.010	1.289	0.244	0.216
KCM61023a_10 12/2/2011 1:46:05 PM	8993	9349.4	764	112.72	0.18	8.30	1669.78	0.0193	2.781	0.010	1.076	0.409	0.299
KCM61023a_12 12/2/2011 1:49:37 PM	12118	11709	701	104.33	0.11	14.84	2226.61	0.0230	3.331	0.010	0.901	0.243	0.380
KCM61023a_4 12/2/2011 1:35:30 PM	7353.3	6887.3	744	36.28	0.17	7.97	1738.24	0.0165	3.102	0.009	0.692	0.152	0.257
KCM61023a_7 12/2/2011 1:40:48 PM	6079.5	6162.7	783	2.27	0.33	1.34	110.17	0.0149	3.427	0.013	1.280	0.241	0.239
KCM61023a_11 12/2/2011 1:47:51 PM	6701.7	6831.5	696	43.87	0.21	9.67	2189.97	0.0142	2.844	0.010	0.929	0.333	0.215
KCM61023a_6 12/2/2011 1:39:03 PM	4069.8	4241	723	214.55	0.33	7.43	1157.25	0.0103	3.006	0.008	1.707	0.526	0.161
KCM61023a_5 12/2/2011 1:37:16 PM	7089.9	6846.3	643	167.75	0.13	16.22	3094.97	0.0143	2.791	0.009	0.713	0.168	0.225
Mascall Tuff (KCM1121-120)													
KCM1211-120L_37 8/23/2013 1:09:44 PM (Run: 1)	5042.1	4090.6	981	0.14	1817.70	0.05	0.01	3.0146	0.028	0.035	0.797	0.080	3.655
KCM1211-120L_27 8/23/2013 12:45:43 PM (Run: 1)	23554	15642	817	0.09	8296.36	0.04	0.03	5.6107	0.055	0.108	0.511	0.165	1.209
KCM1211-120L_34 8/23/2013 1:04:38 PM (Run: 1)	8018.7	6342.6	814	0.23	3037.78	0.06	0.02	3.2970	0.019	0.028	0.670	0.025	2.298
KCM1211-120L_04 8/23/2013 11:45:36 AM (Run: 1)	7943.3	5622.2	931	0.12	3218.19	0.07	0.02	3.2675	0.030	0.036	0.827	0.120	1.893
KCM1211-120L_23 8/23/2013 12:31:54 PM (Run: 1)	2104	1592.7	769	0.39	653.24	0.03	0.00	1.7438	0.021	0.035	0.620	0.091	12.590
KCM1211-120L_06 8/23/2013 11:49:00 AM (Run: 1)	6903.6	4774.4	743	0.10	2664.66	0.06	0.02	3.1160	0.024	0.046	0.515	0.033	2.364
KCM1211-120L_30 8/23/2013 12:50:49 PM (Run: 1)	5409.6	4127.9	799	0.38	1821.27	0.04	0.01	3.0823	0.037	0.043	0.854	0.073	4.898
KCM1211-120L_17 8/23/2013 12:21:42 PM (Run: 1)	2992.4	2280.3	782	0.26	1195.14	0.05	0.01	2.0337	0.032	0.038	0.845	0.102	9.252
KCM1211-120L_13 8/23/2013 12:07:54 PM (Run: 1)	5545.9	4225.9	775	0.21	1973.02	0.05	0.01	2.7180	0.039	0.087	0.449	0.027	3.458
KCM1211-120L_11 8/23/2013 12:04:30 PM (Run: 1)	2769.6	2398.2	778	0.49	885.28	0.04	0.01	1.6108	0.011	0.018	0.623	0.060	9.246
KCM1211-120L_28 8/23/2013 12:47:25 PM (Run: 1)	3209.8	2552.4	747	0.28	982.77	0.03	0.01	2.2647	0.025	0.043	0.575	0.074	8.346
KCM1211-120L_45 8/23/2013 1:30:22 PM (Run: 1)	13179	8578.3	805	0.20	4822.68	0.07	0.03	2.9897	0.018	0.019	0.980	0.061	1.197
KCM1211-120L_44 8/23/2013 1:28:39 PM (Run: 1)	19053	12402	806	0.22	7202.21	0.08	0.05	4.1932	0.019	0.017	1.127	0.063	0.660
KCM1211-120L_20 8/23/2013 12:26:48 PM (Run: 1)	6574.2	4773.7	848	0.35	2203.71	0.04	0.02	2.6766	0.020	0.022	0.914	0.083	2.805
KCM1211-120L_29 8/23/2013 12:49:08 PM (Run: 1)	2760.3	2170.2	737	0.35	882.79	0.03	0.01	1.6270	0.020	0.031	0.644	0.100	10.446
KCM1211-120L_09 8/23/2013 12:01:06 PM (Run: 1)	4121.6	2973.1	770	0.09	1567.02	0.05	0.01	2.6907	0.036	0.070	0.509	0.055	4.749
KCM1211-120L_05 8/23/2013 11:47:18 AM (Run: 1)	4949.1	3615.4	792	0.12	1673.59	0.05	0.01	2.8153	0.038	0.089	0.427	0.035	3.821
KCM1211-120L_12 8/23/2013 12:06:12 PM (Run: 1)	9066.7	6868.1	762	0.20	3283.84	0.06	0.02	2.9245	0.021	0.031	0.677	0.028	1.826
KCM1211-120L_15 8/23/2013 12:11:18 PM (Run: 1)	8348.8	5892.3	823	0.09	3922.70	0.09	0.02	3.1175	0.035	0.044	0.807	0.102	2.117
KCM1211-120L_07 8/23/2013 11:50:42 AM (Run: 1)	2933.3	2307.7	754	0.35	876.84	0.02	0.01	2.4405	0.028	0.064	0.435	0.036	10.118
KCM1211-120L_24 8/23/2013 12:33:36 PM (Run: 1)	7733.2	5503.6	774	0.16	2814.02	0.06	0.02	2.5550	0.019	0.033	0.583	0.034	2.149
KCM1211-120L_36 8/23/2013 1:08:03 PM (Run: 1)	11240	8395.5	748	0.11	4312.27	0.07	0.02	3.4837	0.039	0.037	1.043	0.055	1.704
KCM1211-120L_39 8/23/2013 1:13:08 PM (Run: 1)	4249.6	3121.5	783	0.10	2345.71	0.10	0.01	3.2627	0.034	0.063	0.548	0.053	4.401
KCM1211-120L_10 8/23/2013 12:02:48 PM (Run: 1)	7680.8	5642.4	801	0.10	2881.18	0.07	0.02	3.1735	0.035	0.040	0.875	0.107	2.053
KCM1211-120L_25 8/23/2013 12:42:19 PM (Run: 1)	18452	12454	788	0.07	7293.88	0.08	0.05	5.2209	0.045	0.051	0.883	0.082	0.713
KCM1211-120L_02 8/23/2013 11:42:12 AM (Run: 1)	5237.1	3684.8	755	0.10	1838.07	0.05	0.01	2.8612	0.038	0.057	0.662	0.074	3.557
KCM1211-120L_40 8/23/2013 1:14:51 PM (Run: 1)	9366.2	6706.6	739	0.05	3280.84	0.05	0.02	3.2790	0.034	0.049	0.698	0.080	2.487
KCM1211-120L_14 8/23/2013 12:09:36 PM (Run: 1)	3199.3	2672.5	741	0.28	970.63	0.03	0.01	2.0085	0.032	0.058	0.560	0.071	10.037
KCM1211-120L_16 8/23/2013 12:13:00 PM (Run: 1)	20112	13261	767	0.08	7899.40	0.08	0.05	7.3174	0.056	0.049	1.143	0.109	0.641
KCM1211-120L_22 8/23/2013 12:30:12 PM (Run: 1)	6569.9	4322.1	739	0.09	2369.49	0.06	0.02	3.1920	0.028	0.053	0.522	0.040	2.533
KCM1211-120L_08 8/23/2013 11:52:24 AM (Run: 1)	10884	7299.2	783	0.07	3821.00	0.06	0.03	3.2953	0.022	0.031	0.691	0.058	1.605
KCM1211-120L_38 8/23/2013 1:11:26 PM (Run: 1)	20570	14643	727	0.03	8004.61	0.07	0.04	4.9246	0.033	0.039	0.852	0.100	0.976
KCM1211-120L_43 8/23/2013 1:26:58 PM (Run: 1)	3852.4	2708.9	724	0.36	1224.23	0.03	0.01	2.3310	0.026	0.049	0.531	0.114	7.243
KCM1211-120L_01 8/23/2013 11:40:30 AM (Run: 1)	14878	9368.7	736	0.06	6029.16	0.08	0.03	4.7033	0.038	0.061	0.633	0.057	1.105
KCM1211-120L_42 8/23/2013 1:25:16 PM (Run: 1)	11371	7761.1	811	0.18	4051.28	0.06	0.03	3.3578	0.024	0.025	0.966	0.101	1.318
KCM1211-120L_18 8/23/2013 12:23:24 PM (Run: 1)	12101	7758.3	777	0.10	4286.29	0.06	0.02	4.6278	0.029	0.038	0.767	0.065	1.588
KCM1211-120L_33 8/23/2013 1:02:56 PM (Run: 1)	11417	8469	801	0.10	4192.73	0.07	0.03	3.7785	0.021	0.026	0.801	0.050	1.512
KCM1211-120L_31 8/23/2013 12:52:31 PM (Run: 1)	16832	11434	742	0.04	6115.91	0.06	0.03	4.6942	0.042	0.059	0.715	0.124	1.368
KCM1211-120L_03 8/23/2013 11:43:54 AM (Run: 1)	10868	7611.3	772	0.09	4191.35	0.07	0.03	3.9199	0.032	0.043	0.744	0.058	1.422
KCM1211-120L_19 8/23/2013 12:25:06 PM (Run: 1)	3736.2	2881.1	771	0.33	1157.81	0.03	0.01	1.8151	0.027	0.045	0.607	0.052	7.008
KCM1211-120L_26 8/23/2013 12:44:01 PM (Run: 1)	11913	8209.7	824	0.28	4160.76	0.05	0.03	3.5194	0.023	0.017	1.355	0.143	1.543

Notes:

Radiogenic isotope ratios and ages; uncertainties do not include systematic calibration errors of 0.5% (207Pb/206Pb) and 1% (206Pb/238U).

Trace element concentrations in ppm.

Ti-in-zircon temperatures calculated with activity(SiO2)=1 and activity(TiO2)=0.6, using the algorithms of Ferry and Watson (2007).