HAWK RIM: A GEOLOGIC AND PALEONTOLOGICAL DESCRIPTION OF A NEW BARSTOVIAN LOCALITY IN CENTRAL OREGON

by

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DISSERTATION ABSTRACT

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Hawk Rim represents a new mid-Miocene site in Eastern Oregon. This time period offers a rare chance to observe dramatic climatic changes, such as sudden warming trends. The site is sedimentologically and stratigraphically consistent with the Mascall Formation of the John Day Basin to the north and east of Hawk Rim. Hawk Rim preserves taxa such as canids *Cynarctoides acridens* and *Paratomarctus temerarius,* the felid *Pseudaelurus skinneri*, castorids *Anchitheriomys* and *Monosaulax*, tortoises and the remains of both cormorants and owls. Hawk Rim has yielded a new genus and species of mustelid. As individuals these taxa are of interest, but the real story is told by the paleoecology. The lower reaches of the section have lacustrine diatomite layers as well as preserved logs, suggesting the presence of a wet, forested ecosystem as conformed by the structure of the paleosols. Climate data allow us to make analyses of large-scale ecological trends in mid-Miocene Oregon.

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CHAPTER I

INTRODUCTION

Fifteen million years ago, the earth was recovering from a sudden change in climate: the Mid Miocene Thermal Optimum. After a drastic warm spike, the Mid Miocene Thermal Optimum, the climate had cooled somewhat again (Zachos *et al.*, 2001). However, the hotter climate set the stage for the continued expansion of grasslands and the resulting faunal turnover. Grasslands reshaped the landscape, by replacing the previous vegetation, providing a new food source for the rapidly evolving grazing ungulates as well as altering the climate still further (Edwards *et al.*, 2010). With the biological advent of sod, moisture was trapped in the soil and removed from the air (Retallack, 2008). Forests were gradually displaced by grasses, creating more open habitats and drastically effecting ecology. Yet the ecology of terrestrial habitats, especially the intermontane West, was far from a simple linear progression from one biome to another. With greater topographic relief than other regions, in the West the picture is complicated by extreme elevation gradients and climatic patterns exacerbated by effects such as rain shadows. With all these confounding factors the Middle Miocene is a critical time to our understanding of how climate and tectonics interact in generating biodiversity (Finarelli and Badgley, 2010), particularly in the Western United States. The Mid Miocene Thermal Optimum is one of the sharpest increases in temperature recorded since the Mesozoic and is observed in both oceanic and local terrestrial climatic proxies (Zachos *et al.*, 2001, Sheldon and Retallack, 2004). Additionally, this time period is characterized by a variety of major tectonic events in the Northwest, including Great Basin extension, Columbia River Flood basalt eruptions, and the initiation of

Yellowstone Hotspot Activity (Anders and Sleep, 1992). Hence, a detailed record of the distribution of fossil animals across the Northwest during this interval offers the opportunity to study how mammals react to the combination of climatic and tectonic changes in the context of local climate and topography.

The Northwest in general and Oregon specifically provides an excellent location for observing biotic reactions to the combined effects of climate change and tectonics. With regional climate proxies from paleosols (Retallack, 2004), a detailed enough record is available to facilitate the observation of biotic responses on a fine temporal scale. The Mascall Formation is among the better known faunas from the John Day Fossil Beds National Monument. This extensive formation has yielded fossils to paleontologists for well over 150 years; horses from the Mascall collected by Thomas Condon were used by Cope to support the then-controversial theory of evolution. While less well known, the Simtustus Formation to the west, eastern Sucker Creek Formation, and the fauna of the Butte Creek Volcanic Sandstone to the east and south are similar in age and all three formations span the Early Barstovian North American Land Mammal Age (NALMA) (Tedford *et al.*, 2007). With this rich diversity of sites, concurrent in time, distinct sites in Oregon allow for the rare opportunity to observe ecological change over a broad, but well constrained, geographic gradient. The combination of high resolution climate proxies from a variety of available sources including paleosols, floras, diatoms, and stable isotope analysis, with well sampled faunas facilitates the understanding of climate and tectonics on the evolution of both landscapes and their inhabitants.

Oregon may provide a relatively robust sampling of the early Barstovian, yet the terrestrial fossil record in particular, by its nature, still has many gaps. Environments lacking high sedimentation rates, unlike those such as flood plains and fluvial and laucustrine margins, are usually not preserved in the fossil record and are thus undersampling actual diversity (Behrensmeyer and Hill, 1988). This issue is further confounded by the rugged topography of the region, partitioning habitats into smaller and smaller microcosms. Think of a transect from the Oregon coast, through the Willamette Valley, over the High Cascades, and onto the High Desert of Central Oregon. Without even venturing into the multitude of smaller more fractionated habitats like alpine meadows, bogs and wetlands, or dry forests, one crosses four very distinct environments in a relatively small distance. This level of ecological diversity was certainly at play during the Mid Miocene, yet the relative paucity of fossils the world over often prevents our observation and understanding of environmental diversity and ecological heterogeneity.

Hawk Rim, a newly discovered Early Barstovian site in central Oregon, provides an excellent opportunity to begin to fill in some of the gaps in our understanding. Located in a geographic gap between other localities (Figure 1), Hawk Rim serves as a stepping stone to observe change across space, but also presents a concise time sample to broaden our temporal understanding of ecological change. Discovered in 2008 through a collaborative effort between the Park Service and the Bureau of Land

Figure 1: Map of Oregon showing location of Hawk Rim as a solid star and other Oregon Barstovian localities as open stars. Green stars from left to right: Simtustus Formation, Mascall type area, Red and Quartz Basins, and Sucker Creek.

Management (BLM), the site is located in Central Oregon on BLM land. One of the most readily apparent indications of the fossil-bearing potential is the abundant petrified wood. As one hikes across the locality, entire fossil logs are evident throughout the site, attesting to the presence of an ancient forest. Within a few moments of arrival, one fact becomes apparent: Hawk Rim preserves a forest, one of the ecosystems less frequently sampled in the Miocene fossil record (Behrensmeyer and Hill, 1988). Because Hawk Rim preserves a pocket of this different ecosystem, the site offers the exciting possibility to enhance not only the regional beta diversity, or species level sampling differences between sites, but the overall understanding of how biotic components of environments responded to geologic change. Hawk Rim will contribute knowledge to the process of ecological change through time and the role ecological heterogeneity, driven by tectonics, plays in shaping an evolutionary response.

CHAPTER II

BACKGROUND

Biostratigraphic context

Oregon possesses a remarkably complete Miocene fossil record paired with a diversity of climatic proxies lacking in many other regions. Hawk Rim, in particular, presents an ideal location to add to our understanding of the Barstovian, allowing for gradients to be observed across the region by filling in some of the existing gaps. Identification of key biostratigraphic marker taxa allows for assignment to individual NALMAs or even subsections of NALMAs. The site is consistent with an Early Barstovian NALMA as indicated by the presence of several key taxa (Wang *et al.*, 1999, Woodburne, 2004, Tedford *et al.*, 2004).

Hawk Rim falls west and slightly south of the type locality of the Mascall Formation, which is observed across much of the central part of Eastern Oregon. (Figure 1) To the northwest is the Simtustus Formation, outcropping near and on the Warm Springs Indian Reservation, also of Barstovian age. To the southeast, the Owyhee Basin contains excellent faunas spanning the Barstovian including the Red Basin and Quartz Basin faunas. Both of these faunas sample the Early Barstovian and are likely representative of both the ecological and biological diversity occurring in the region with their markedly different faunal compositions (Shotwell, 1968). Farther south, the Succor Creek Formation also yields a fauna of Early Barstovian age. While outside of Oregon, the Virgin Valley fauna of northern Nevada, near the southeast cornor of Oregon, is also Early Barstovian and within the greater regional trends, as is the Railroad Canyon fauna of Montana (Barnosky *et al.*, 2007). Lying on the central western edge of the distribution of northwest Barstovian sites, Hawk Rim adds increased ecological diversity and a more complete sampling of the time period to the datum. While Hawk Rim sub-samples the existing Early Barstovian regional fauna to some extent, it adds several taxa previously not known from the Northwest and exhibits species abundances different from those observed in many coeval sites in the region.

Lithostratigraphic context

The Mascall Formation has been rudimentarily mapped (Walker and MacLeod, 1991) over large portions of central and eastern Oregon, and despite a paleontological collecting history lasting well over 150 years, there is little comprehensive lithostratigraphic work that has been done (Downs, 1956). The formation spans a wide range of time, beginning at approximately 16 million years ago (Ma), but is as yet poorly constrained by radiometric dating. The upper terminus is an unconformity with the Late Miocene Rattlesnake Formation. The Rattlesnake Ashflow Tuff (RAFT) is ^{40}Ar/^{39}Ardated at 7.093 ± 0.015Ma (Jordan *et al.*, 2004) and is thus considerably younger than the age estimates for the fossiliferous deposites. In many localities, the base of the Mascall Formation is deposited directly onto the Columbia River Basalts (CRBs). Due to differences in timing of the CRBs, some contemporaneous Early Barstovian deposits, such as Succor Creek, fall in between CRB eruptive events. Typically, the Mascall Formation consists of alluvial floodplain deposits, which are eroded from source rock rhyodacitic in composition (Bestland, 1998). The sediments are typically shades of cream, brown and yellow, making the formation distinct from other nearby sedimentary formations such as the blue-green of the Turtle Cove Member of the John Day

Formation. Deposition of the formation corresponds to continued uplift in the Cascades and increased levels of local volcanism (unrelated to the Cascades) supplying sediment (McBirney, 1978). Traditionally the formation has been divided into the Upper and Lower Mascall because of the broad range of time covered and lithological differences (Bestland, 1998). Upper Mascall consists of clayey siltstones, extensive tuff strata, and conglomeritic deposits. While paleosols are present, the Upper Mascall is characterized by lesser development of soils. The lower Mascall consists of diatomite, clayey siltstones, and less abundant tuff strata, although it contains the thickest tuff deposit in the Formation, the Mascall Tuff. The fossil soils are generally much better developed, representing a longer time inbetween the deposition on new sediments. The lower Mascall records deposition during a period of Mediterranean-like climate (Chaney and Axelrod, 1959). In the Upper Mascall the depositional environment was a slightly dryer, less humid environment, although still forested (Chaney and Axelrod, 1959). With the Lower Mascall predominantly siltstones and ash developed into soils, there are also strata interbedded with lacustrine deposits including diatomite and lignite. This depositional environment is warmer and more humid then the Upper Mascall and dominated by deciduous hardwood forests, as opposed to the more mixed forests found in the Upper Mascall (Chaney and Axelrod, 1959).

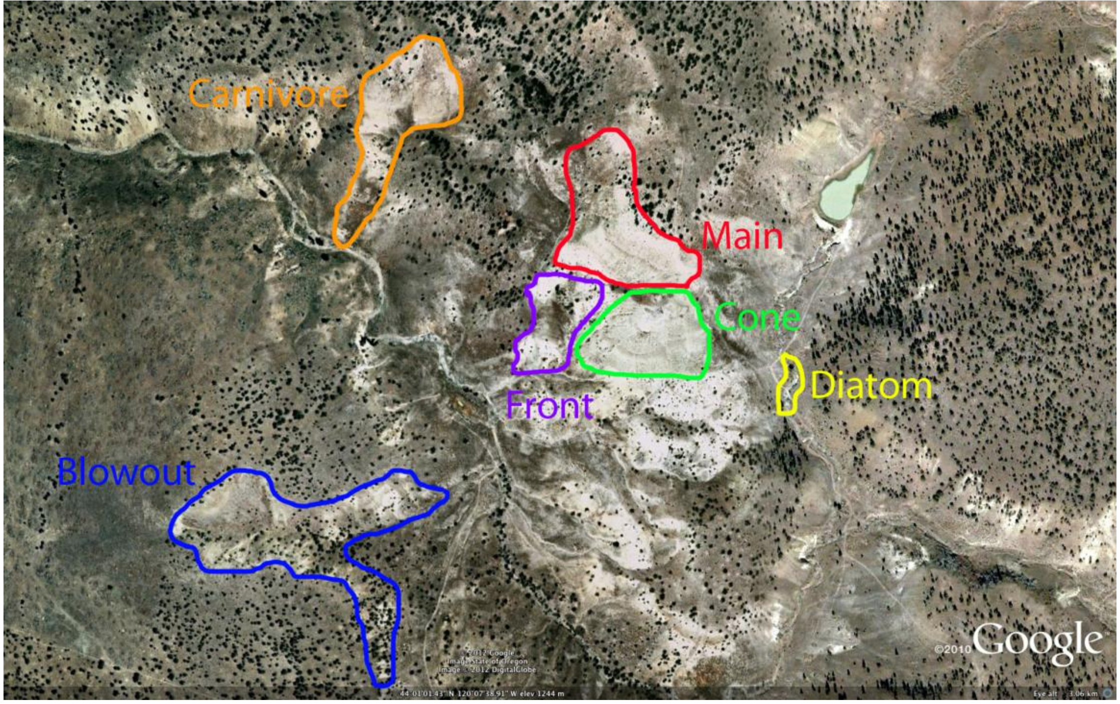
CHAPTER III

METHODS

Geology

Outcrops at Hawk Rim were located through surface surveys, aerial photography, and consultation with John Zancanella of the Bureau of Land Management Prineville District. Preliminary investigations occurred over one day of field investigations in 2008, conducted by staff from the John Day Fossil Beds National Monument. Limited material was collected including a *Tephrocyon rurestis* tooth and astragali and teeth from *Merychippus, Archaeohippus,* and *Desmatippus*. These finds prompted further field work, conducted by the University of Oregon Field Camp, and myself, over the 2010-2011 field seasons. The main outcrop was stratigraphically measured by first clearing weathered material from the surface, usually to a depth of 0.3 meters. With unweathered material visible, the stratigraphy was then measured with a Jacobs Staff. An Abney level was used to compensate for sub-horizontal beds. Dip direction and angle were recorded with a Brunton Compass. Rock orientation is recorded as dip direction expressed in azimuth between 0˚ and 359˚, and dip angle, in degrees the plane of the rock unit falls below horizontal, is recorded at three points near the stratigraphic column location in the main section. Because dip did not change significantly through the main outcrop section (Figure 2), the measurements were averaged to achieve a consensus used to set the Abney level for section measuring. The Jacobs Staff and Abney level were used to measure the thickness of each stratum, and detailed descriptions were recorded including sedimentological characteristics, total thickness of each stratum, thickness of soil development layers such as the A, B, B_y, and C horizons, depth to gley, depth of leaf-bearing section within a strata, and any other visually distinct features, such as distinct color changes in otherwise continuous lithology. This detailed column (Figure 3) allows for correlation between separate outcrops, as well as corrections within each outcrop necessitated by the complex structural setting. Structure in the area is influenced by the Brothers Fault zone (Jordan *et al.* 2004); however it is dominated by anticline-related faults and folds from the Blue Mountain anticline (Meigs *et al*., 2009). More recent structure has complicated the area with a system of north-south and east-west trending faults (Meigs *et al*., 2009). Sedimentary strata were deposited over irregular topography, adding to the complexity of the site. Topographically above and below the Hawk Rim sediments are outcrops of the Clarno Formation and the John Day Formation, which are both considerably older.

Figure 2: Google Earth image of the entire Hawk Rim site. Image is aproximetly one mile in diameter. Individual outcrops are outlined and listes with names. Only localities yielding multiple fossils are named.



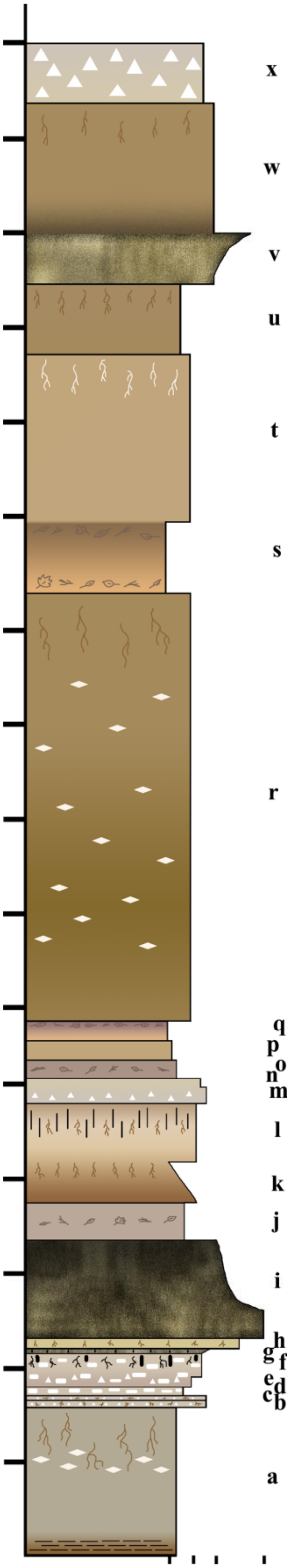


Figure 3: Stratigraphic column on main outcrop. Y axis marked in 5m increments, x axis from smallest to largest grain size. Brief description from bottom to top: a) Clayey siltstone with gypsum and well developed root traces. b) Tuff layer. c) Tuff layer, ferruginized root traces. d) Diatomite. e) Silty diatomite. f) Diatomite with burrows and root traces. g) Fine grained sandstone with burrows. h) Sandy siltstone with root traces. i) Fining upwards crossbedded sandstone. j) Siltstone grading into a lignitic shale. k) Fining upwards siltstone to claystone with ferruginized root traces. l) Sandy siltstone with ferruginized root traces and gley. m) White ash. n) ashy siltstone. o) Lignitic shale. p) Siltstone. q) Lignitic shale. r) Siltstone with abundant gypsum. Root traces near top, mollic texture throughout. s) Lignitic shale. t) Siltstone with gypsiferrous root traces. u) siltstone with ferruginized root traces. v) Coursening upwards, crossbedded sandstone. w) sandy siltstone with root traces. x) Ashflow tuff.

The Clarno Formation dates from the Eocene and ranges from approximately 37 to 49 Ma (Crane 1989), while the younger John Day Formation spans 19 to 37 MA (Robinson *et al.* 1984), several million years older then Hawk Rim. Nearby is Logan Butte, an outcrop of the Turtle Cove Member of the John Day Formation, which is well mapped and constrained biostratigraphically, compared to other elements within the John Day Basin stratigraphy. Contacts and faults were mapped onto aerial photographs and ground checked. Two sets of north-northwest trending faults shape the geology of the area. Also interacting with the site is a series of east-west trending faults, like those seen in Paulina and John Day. Higher in the sequence than the measured fossiliferous units, the RAFT unconformably caps the deposits. Material between the fossiliferous units and the cap tuff is covered by weathered soils but does not appear to have any diagnostic tuffs or fossils. At least the Clarendonian NALMA and likely the Late Barstovian are missing from the site. This distribution would be consistent with the sediments having been deposited into a topographically low-lying area within the local topography's foothills. Continued faulting and folding exposed areas to erosion and created new depositional centers within the topography.

Biostratigraphy

During field work fossils were assigned to the stratum of origin when possible. Most specimens came from float, so in many cases their stratigraphic assignment should be considered a lowest possible occurrence. Materials collected from channels and at the base of outcrops could not be assigned to an individual stratum. However, some *in situ* material was collected, and the topography of the site would have prevented much of the other material from being transported a significant distance downslope. Fossils were therefore assigned to a particular stratum or stratigraphic range of strata. Several taxa are only represented by single identifiable specimens, for which a stratigraphic range could not be generated. Known biostratigraphic ranges for each taxon present at the site were generated from the existing literature (Tedford *et al.*, 2007). The co-occurence of taxa was then used to generate age and NALMA estimates for Hawk Rim, as well as a better understanding of the range of time covered by deposition at the site (Figure 4).

Radiometric age determinations

Two tuffs from the main outcrop were sampled for radiometric dating analysis (Figure 5) from horizons that bracket the vertebrate fauna above and below. Samples were sent to the Boise State University Isotope Geology Laboratory (BSU IGL) for Ar^{40}-Ar^{39} dating. Results are currently pending further analysis.

Paleopedology

Within the measured section, paleopedological data were recorded for all strata with soil development. Completely undeveloped sediments received only a lithological description. For paleosol strata (fossil soils), a more extensive set of observations and measurements, in addition to the lithological descriptions, were recorded for use in environmental interpretations and reconstructions. For each stratum, color was recorded using a Munsell Soil Chart to maintain consistency between descriptions and generate reproducible results. Ped (soil clods) and cutan (soil clod skin) descriptions were recorded to infer general constraints on climatic and biotic depositional settings.

Figure 4: Known biostratigraphic ranges of key taxa present at Hawk Rim.

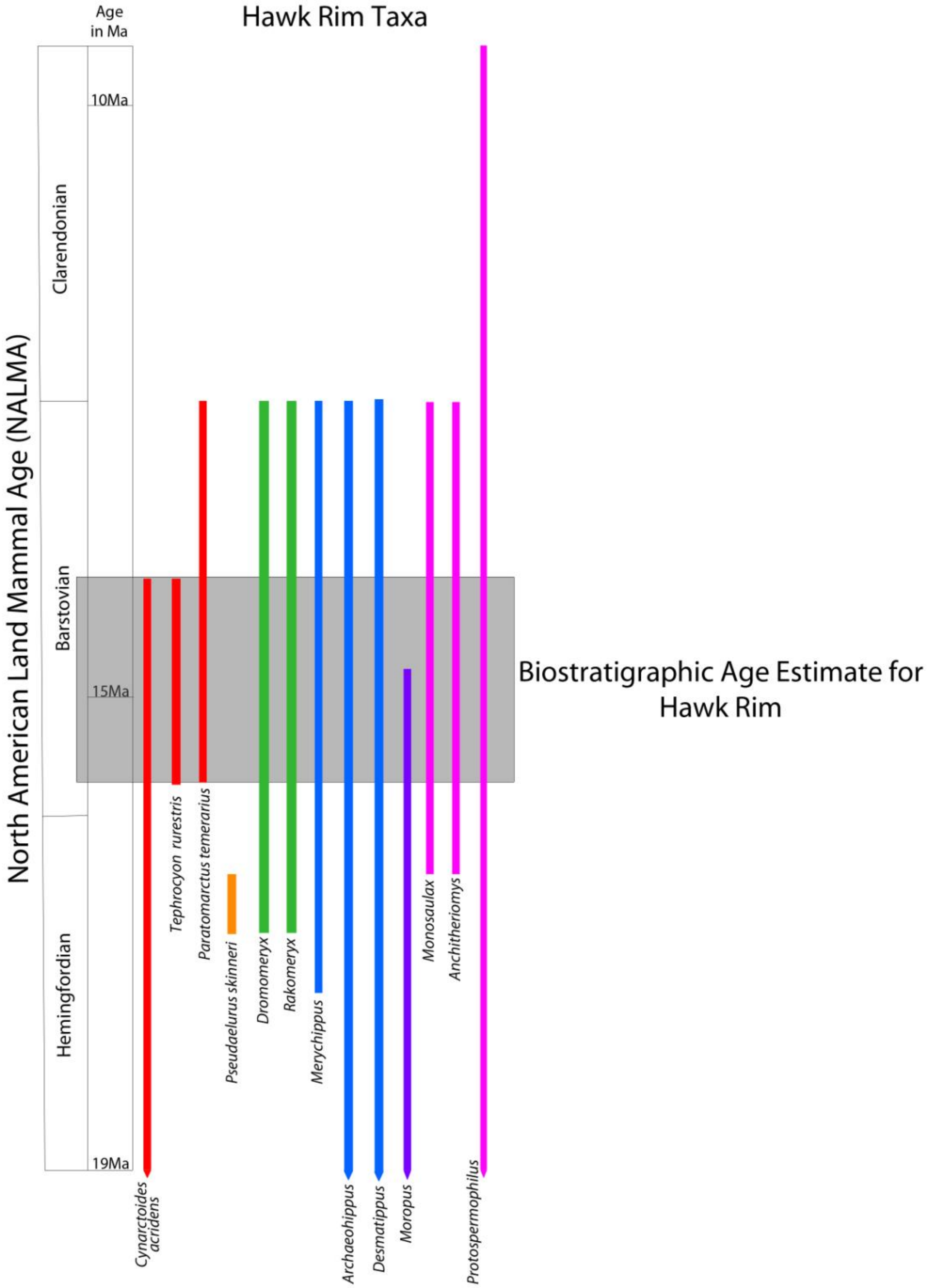
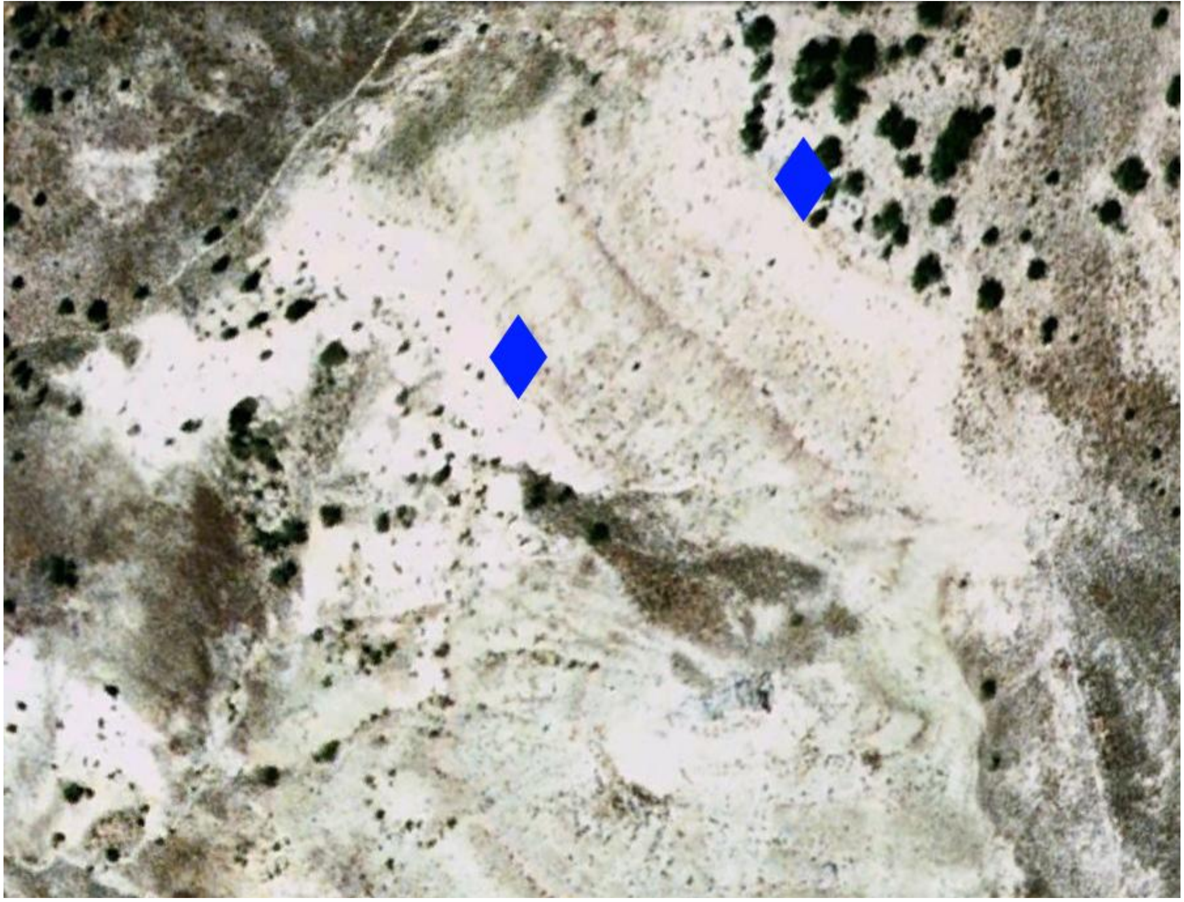


Figure 5: Google Earth image of main outcrop showing location of samples collected for radiometric dating (shown with blue diamond)



In well-developed soils, distances between soil horizons were recorded and used to help infer parent material and depositional setting. Finally, organic, carbonate, and gypsum content and the presence or absence of burrows and root trances were also recorded. Comparisons to pedotypes from the type area of the Mascall Formation were made based on visual comparisons and not chemical analyses (Bestland, 1998). I therefore only offer assignments to pedotypes on a tentative basis to facilitate comparisons and these finding should not be taken as conclusive evidence of the same depositional and environmental settings.

CHAPTER IV

RESULTS

Site geology

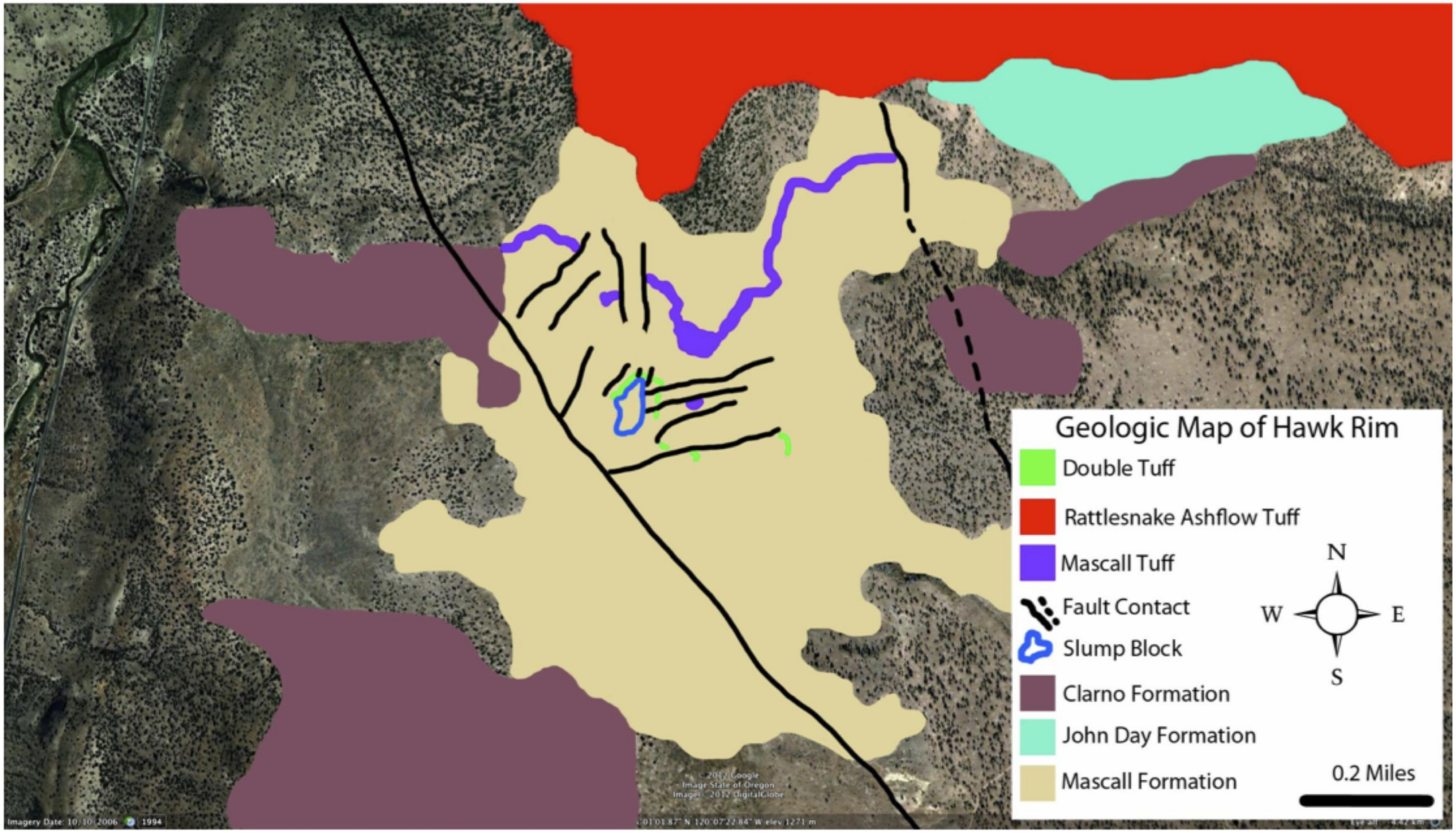
The most detailed stratigraphic column, measured and described where weathered material was cleared from the surface, yielded a 90m section (Figure 2). A large ashflow tuff caps the measured portion of the outcrop. This capping tuff I infer to be consistent with the Mascall Tuff, mapped in the type area of the Mascall Formation. While many other tuffs exist in the region, most can be ruled out based on age and physical characteristics. Other regional tuffs include Rattlesnake Ashflow Tuff (RAFT), Divine Canyon Tuff, Prater Creek Tuff, and several smaller ashy deposits. The RAFT lies stratigraphically above the Hawk Rim deposits, radiometric dating on both the Divine Canyon (9.74±0.02 Ma) and Prater Creek (8.41±0.16 Ma) tuffs is inconsistent with the biostratigraphic dating results. Both dates placing these candidate tuffs much later in time than the Mascall Formation or Hawk Rim (Jordan *et al.*, 2004). Unlike the Mascall Tuff as known from the type section of the Mascall Formation (Bestland, 1998), the Hawk Rim capping tuff has undergone minimal reworking. Some grains show a small degree of rounding suggesting slight reworking. However, the Hawk Rim Mascall Tuff strata are divided into two separate ash flow events and are completely massively bedded. The Mascall Tuff from the Mascall Formation type section is also characterized by a resistant, highly burrowed horizon capping the unit which develops a dirty yellow color with weathering. The Hawk Rim tuff lacks this extensive reworking and coloring, likely due to differences in the depositional setting leading to less reworking before burial. Both upper and lower contacts are very sharp. Lithologically, the composition is very similar to the Mascall Tuff, with pumice clasts and similar mafic grains. The tuff is primarily vitric material with some lithic fragment components. Of note is the occasional preservation of leaves in the lower 15cm of the tuff. Leaf-bearing localities within the tuff may represent wet depositional settings, such as a pond, over which the tuff was emplaced. This would allow for the preservation of the leaves in the base of the rapidly cooled ash, as evidenced by higher vitiric content from quenching. Emplacement mechanisms for the Mascall Tuff have been debated and include gravity flows, ashy slurry floods similar to the Pinatubo floods (Bestland, 1994, Scott *et al*., 1999), or several years of ashy flood deposits weakly-developed into thick soil horizons (Bestland 1998). The lack of reworking and relatively fresh grain surfaces in the Hawk Rim deposits would preclude the possibility of weakly-developed soil horizons. The high degree of welding present in the tuff suggests direct air fall emplacement, or a gravity flow. If any remobilization occurred it would have been redeposited very soon after initial eplacments or the tuff wouldn’t be so thoroughly welded. The capping tuff is present only in the “Main”, “Cone”, and “Carnivore” outcrops (Figure 2).

Despite faulting, the dip of the beds is largely consistent across the site. Average dip angle is 5˚NE and never gets above 15˚. Overall, the beds are subhorizontal, with little tilting after deposition. However, different tilt directions due to faulting and variation in strike in subhorizontal beds along fault blocks caused the strike to vary from N39W to N81W. The main north-northwest trending fault, along the valley floor, resulted in the northern side of the valley being significantly higher than the southern. Slump blocks, some tens of meters in heights, have further modified the surface makeup of the main outcrop. The main valley-forming faults trace trends northeast-southwest while secondary smaller faults are also oriented roughly east-west (Figure 6). A second set of faults trace trends northwest to southeast and appear to impact mostly older sediments than the Mascall. Faulting is largely extensional, resulting in horst-graben topography. Along with aforementioned volcanic tuffs, the stratigraphy is composed of sequences of fluvial sandstones, lacustrine diatomites, mudstones, lignitic shales, and siltstones exhibiting soil development. Some fluvial sequences and parent material in paleosol strata suggest a relatively high-energy environment, with pebble-sized clastic input and large-scale cross-bedding. Deposition at the site occurred in a foothill environment, driven by local topographic highs. At the lowest exposed areas of section, distinct contacts are visible between the Mascall Formation and the much older Clarno Formation. One outcrop reveals a channel incised into the Clarno, with a fluvial sandstone from the Mascall deposited into the area of topographic low. Prior to renewed deposition within in a small foothills basin, the Clarno was being uplifted and eroded in the area, with younger sediments only being deposited into isolated regions of low relief. A comparison of energy indicators between Hawk Rim and the type area of the Mascall suggests deposition at Hawk Rim may have occurred at a higher paleotopographic elevation as evidenced by such features as braided stream deposits.

Biostratigraphy

While Hawk Rim preserves range extensions for several taxa, the majority of the fauna, as well as key diagnostic specimens, were consistent with an assignment to the Early Barstovian NALMA. Previous work on the Mascall Formation has led to its

Figure 6: Geologic Map of Hawk Rim



A comparison of energy indicators between Hawk Rim and the type area of the Mascall suggests deposition at Hawk Rim may have occurred at a higher paleotopographic elevation as evidenced by such features as braided stream deposits.

Biostratigraphy

While Hawk Rim preserves range extensions for several taxa, the majority of the fauna, as well as key diagnostic specimens, were consistent with an assignment to the Early Barstovian NALMA. Previous work on the Mascall Formation has led to its assignment to the Barstovian based on the fauna and a single radiometric date of 15.77 ± 0.07 Ma from the lower portion of the type section (Swisher 1992). Furthermore, Tedford et al.'s (1987) recommendation is to expand the definition of the Barstovian to include the Mascall Formation as one of the principal correlative faunas to the Barstow fauna. However, the Barstovian NALMA overall presents issues with assigning a tight age range across North America, as there is a high degree of endemicity and varying levels of diversity when tracked across space (Tedford et al., 2004). Due to these issues, there are fewer defining taxa appropriate for all of North America, than there are for many other biostratigraphic ages. In particular, the Barstovian contains relatively few immigrant taxa, often useful as novel defining characters of a land mammal age, compared to the Hemingfordian and Clarendonian NALMAs, (Tedford et al., 2004). Future integration of Hawk Rim's fauna into accepted biostratigraphic ranges will aid in expanding and redefining the lack of immigrant taxa with the addition of a new genus of mustelid with strong European affinities and certainly a new immigrant taxon to the region.

The chief defining taxa for the start of the Barstovian are *Plithocyon* and *Zygolophodon*, but neither of these taxa is present in any abundance in the region and therefore their absence from Hawk Rim is not of particular note. Canids are reputed to be particularly good biostratigraphic indicators in the region (Wang *et al*,. 1999) and have already been used for regional biostratigraphy (Orcutt *et al.*, 2011).The presence of the borophagine *Paratomarctus* at Hawk Rim is indicative of the Early Barstovian (Wang *et al*,.1999, Tedford, 2004). Furthermore the beaver *Monosaulax* has only been found from the beginning of the Barstovian through the end of the Barstovian (Korth, 2001), with two poorly dated sites possibly representing Hemmingfordian occurances (Bailey, 2004). The Early Barstovian marks the last occurrence of canids such as *Cynarctoides* (Wang *et al*,.1999) as well as the equid *Desmatippus* and paleomerycid *Rakomeryx* (Tedford, 2004). Other taxa, such as *Tephrocyon,* have limited biostratigraphic ranges confined to the Early Barstovian.

While some other taxa are considered indicators from an earlier NALMA, such as *Moropus*, they are mostly taxa already considered to be rare elements of most faunas, and therefore are most likely to represent temporal range expansions rather than conflicting biostratigraphic indicators or reworking. *Moropus* is considered to be a defining taxon of the earliest Late Arikareean although is documented in rare occurances through the Early Barstovian (Tedford, 2004). *Pseudaelurus skinneri* is considered indicative of the Late Hemingfordian, but only for the Great Plains region (Rothwell, 2003), and thus it is acceptable to find the taxon in a different biostratigraphic context in another region. Many of the taxa present at Hawk Rim make their last appearances in the Late Barstovian with only a few, such as *Merychippus* and *Spermophilus,* even making it into the Clarendonian (Tedford, 2004). The majority of the fauna are consistent with or unique to the Early Barstovian, and thus this should be regarded as the best estimate for the time of deposition.

Radiometric dating

Hawk Rim possesses several tuff beds containing minimally reworked sediments. Flow deposits greater then one meter in thickness potentially indicate a nearby volcanic source; however, further work matching tuffs based on physical and geochemical analyses would be necessary to understand volcanic sources and relationships in the region. Sanidine crystals within the prominent tuffs are unweathered and show minimal to no transport wear, making them excellent candidates for radiometric dating. This should allow for Ar-Ar dates to be accurately generated from the site, unlike many other attempts in the region as a whole, which failed due to the high degree of weathering present at many sites.

Paleopedology

Hawk Rim's stratigraphy is dominated by Alfisol paleosols. Alfisols are fossil soils developed in closed habitat forest environments (Bestland, 1998). Generally these soils develop in relatively humid climates, a climatic feature supported by the lack of calcareous elements in the soil profiles. Carbonates commonly form in very dry, well-drained soils in open habitats ranging from grasslands to deserts, and are far less common beneath strongly forested ecosystems such as those present at Hawk Rim. Mixed in with the Alfisols are some duric Inceptisols. These less well-developed soils are indicative of the rapid rate of sediment deposition occurring at the site. Paleosols at Hawk Rim have parent material from fluvial and lacustrine deposition as well ash deposits reworked into fertile soils (Andisols) (Retallack, 2001).

Many of the same pedotypes, or soil families, of the Mascall type area are also present at Hawk Rim. While chemical analyses were not run on samples from Hawk Rim, identification of paleosol types and relationships can shed light on the depositional environment and climatic conditions. Even broad scale environmental interpretations of the depositional conditions are useful as they help to better understand important climatic events of the past. The sequence of paleosols at Hawk Rim preserves insight into life in the region just after the Mid Miocene Climatic Optimum. In this time of rapid climatic change we have well-constrained Oxygen and Carbon isotopic data from marine sediments (Zachos *et al.*, 2001) but an understanding of terrestrial climatic variation is less well defined. Hawk Rim's paleosols are uniformly from semi-closed to closed habitats. These paleosols were forming in forests, and often dense forests with large deciduous trees. The climate was sub-humid to humid. This can be seen from the lack of calcareous material and the high degree of clay present in many of the B_y horizons forming well developed cutans, or clay skins, on the peds. Several strata also show gleying, indicative of waterlogging at least part of the year. One thick section of paleosols higher up in the section begins to develop a near mollic texture, suggesting an increase in the volume of grass within the ecosystem. However, stratigraphically higher paleosols return to closed, forested habitats, and the stratum directly under the capping tuff contains leaves from a deciduous hardwood trees.

Original environmental interpretations based on the flora of the Mascall Formation by Chaney (1938) found the Mascall to be a sub-humid moderately-closed forest environment. Subsequent floral interpretations (Chaney, 1956, Chaney and Axelrod, 1959, Krull, 1998) have found the Mascall to be, if anything, more humid and dominated by forests. However these data have rarely been incorporated into the larger view of the formation. Sedimentological data suggesting a lowland flood plain, used by Downs (1956) to suggest an open grassland habitat, and faunal analyses with a notable contingent of grazing taxa have led to other interpretations of a drier, more open, savannah-like habitat (Tedford 1987, Downs 1956). A more complete reconstruction will need to integrate all proxies including more geochemical and isotopic data. Meanwhile, Hawk Rim's flora, fauna, sediments, and paleosols point to a humid, closed habitat more consistent with floral interpretations generated by Chaney (1959). The presence of aquatic animals, such as mud turtles, cormorants, and the beaver *Monosaulax*, support the continued presence of rivers and ponds at Hawk Rim. Future exploration of the paleobotanical resources at Hawk Rim and isotopic work on the diatomite strata will enhance the climatic and habitat reconstructions done at the site.

CHAPTER V

SYSTEMATIC PALEONTOLOGY

Class AVES Linnaeus, 1758

Order PELICANIFORMES Sharpe, 1891

Family PHALACROCORACIDAE Reichenbach, 1850

Genus *PHALACROCORAX* Brisson, 1760

Referred Material – JODA 14966, proximal right humerus

Description: Preserved material is limited to a single right proximal humerus (Figure 7). The surface of the break indicates the bone was broken well after fossilization, as the fracture line is sharp and perpendicular to direction of bone growth. In addition to overall morphology and size being similar to modern comparative material, the assignment to Phalacrocoracidae was indicated by the presence of a very pronounced ligamental furrow characteristic of this family (Gilbert *et al.* 1996). The greatest width measured from the edge of the bicipital crest above the breakage point to the widest point on the deltoid crest is 24.0 mm. The dimensions of the humerus indicate the cormorant was similar in size to extant double-crested cormorants (*Phalacrocorax auritus*). An extant *Phalacrocoran auritus* (HAFO uncatalogued comparative specimen), was used as a comparison as was the nearly complete skeleton of *P. macer* (HAFO4906), from Blancan Pliocene deposits at Hagerman Fossil Beds National Monument in the Glenns Ferry Formation. While some differences in the articular surface exist, the double-crested cormorant was morphologically more similar than either the Brandt's cormorant (*P. penicillatus* HAFO uncatalogued comparative specimen) or the Pelagic cormorant (*P. pelagicus* HAFO uncatalogued comparative specimen) specifically in the shape of the bicipital crest and the deltoid crest. The bicipital crest is the only portion of the proximal end that is broken, although it appears to only be missing the distal-most portion, an estimated 5% of the width of the proximal head. Enough of this feature remains to discern it is not a pronounced feature, as in many other avian families. The pneumatic fossa is quite shallow and contains one pneumatic foramen in line with the mid-shaft of the bone. Also indicative of *Phalacrocorax* is the prominent capital groove, clearly delineating an ovoid shape at the proximal edge of the humerus.

Figure 7: JODA 14966, cormorant humerus, scale 1cm. The ligmental furrow is the pronounced indedentation in the center of the image. This feature is pronounced in cormorants because of their ability to hunt underwater, using their wings to propel themselves, unlike many diving birds which use their feet. Water provides a high degree of resistance, necessitating strong muscles and skeletal attatchments for the muscules.

Discussion: While the humerus is one of the few individual bones that permit species level diagnosis, this specimen was not assigned to a species for several reasons. First of all, the distal end of the humerus contains several features necessary for distinguishing among species, and with the limited nature of the preserved material this was impossible for the Hawk Rim specimen. Furthermore, fossil Aves material is in generally rare. While it makes this specimen scientifically valuable, it greatly diminishes the amount of reference material available for comparison. Material from Miocene cormorants was unavailable for comparison, but several sites in the region have yielded Pliocene samples. Oregon samples have been assigned to *P. macropus*, but are from a much larger species (Shufeldt, 1915). Younger material from the Intermontane West includes numerous specimens from Oregon's Fossil Lake (Late Pleistocene in age), also assigned to *P. macropus*. The Hawk Rim material is similar in size to the Hagerman fossil material, however the shapes of the ligmental and bicipital furrows are distinct. On these grounds it is unlikely the Hawk Rim specimen belongs to the same species as either regional fossil example.

Order STRIGIFORMES Wagler, 1830

Family STRIGIDAE Vigors, 1825

Referred Material – JODA 15035, distal left tarsometatarsus; JODA 15138, partial right coracoid

Description: Two specimens are assigned to the family Strigidae, a partial left tarsometatarsus (Figure 8) and a partial right coracoid (Figure 9). The tarsometatarsus preserves only the distal portion with the fourth trochlea broken off. The dorsoplantar foramen is situated equally between the trochleae of the 3rd and 4th digits, and is elongate in shape. The first metatarsal facet protrudes slightly and has a flat surface. While the trochlea of the 4th digit is missing, that of the 3rd digit is shorter than the 2nd, characteristic of birds of prey (Gilbert *et al.*, 1996). Looking at the distal end, the trochleae are slightly curved, with the 3rd digit being the highest. There is no evidence of a raptor hook on the edge of the 2nd digital trochlea. Characteristic of the Strigidae, the wings of the medial trochlea are directed posterolaterally, while those of the lateral trochlea are directed posteromedially.

The coracoid is very fragmentary; the brachial tuberosity and attachment are broken off of the anterior portion of the bone. Posteriorly, the bone is completely missing, with preserved material ending in the shaft posterior to the triosseal canal. The highly pronounced triosseal canal is the most prominent feature of this bone. The procoracoid, projecting off the canal in line with the main shaft of the coracoids, is robust and cone shaped. It does not hook back towards the main shaft of the bone, as this feature does in many other families of birds. Also characteristic of strigids is the strong semi-lunar shape the procoracoid makes in relationship to the main part of the shaft

Figure 8: JODA 15035, strigid tarsometatarsus, scale bar 1cm. Note the second and third trochlea are the same length, unlike many other Aves families, where the third trochlea is the longest.

Figure 9: JODA 15138, partial strigid coracoid, displaying the lunate shape of the triosseal canal.

(Gilbert *et al.*, 1996). The glenoid facet is reduced with hardly any scapular facet visible. The shaft of the bone narrows considerably towards the posterior end before it would have enlarged again. This feature is unusual compared to most Aves families, and is found in owls as well as a few other groups.

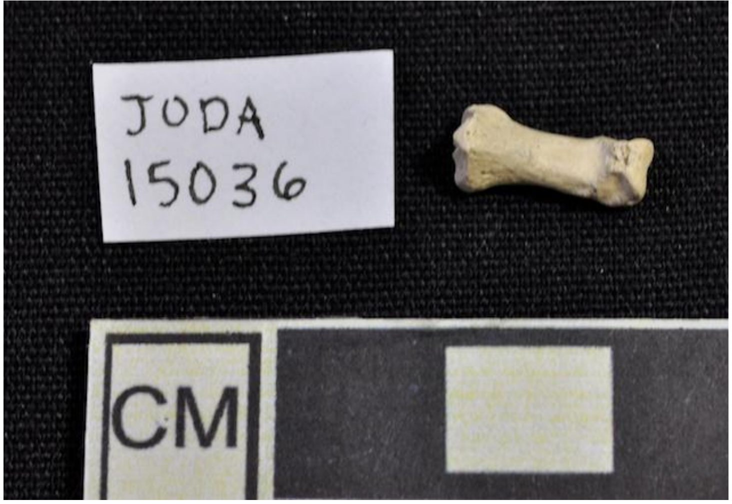
Discussion: While the tarsometatarsus is a highly diagnostic bone, its fragmentary preservation makes positive identifications difficult. Furthermore, the previously stated paucity of avian material in the fossil record provides little for comparison. Owls are even less frequently preserved than other families due to their general restriction to woodlands habitats (Lynch, 2007), further indication of the forested nature of Hawk Rim.

AVES *indeterminate*

Referred Material – JODA 15036, proximal phalanx

Description: Preserved material is limited to a single proximal phalanx (Figure 10). The material was identified as Aves by comparison with modern birds including several HAFO comparative specimens, the lightweight build and the construction of the proximal articular surface are consistant with Aves. The maximum length is 12.0 mm while the

Figure 10: JODA 15036, Aves phalanx, scale in cm. While complete and unworn, the phalanx displays little morphological variation between Aves families, and thus is of little use taxonomically.



maximum mid shaft width is 3.4 mm. Dimensions of the proximal articular surface is 5.5 mm while the distal articular surface is 4.2 mm. No part of the bone shows breakage or diagenetic wear.

Discussion: Functional morphology limits the amount of variation possible in this bone, and thus little variation exists between avian families. The phalanx was found in direct proximity to the strigid tarsometatarsus; however it is far too large to have come from that individual or species.

Class REPTILIA Laurenti, 1768

Order TESTUDINES Batsch, 1788

Family EMYDIDAE Bell, 1825

Genus *CLEMMYS* Ritgen, 1828

Referred Material – JODA 15029, postcranial material and costal carapace plates; JODA 14970 peripheral carapace plate, neural carapace plate, two costal carapace plates, JODA 14986 peripheral carapace plate; JODA 15003 nuchal carapace plate, costal carapace plate, peripheral carapace plate; JODA 15020 peripheral carapace plate; JODA 15049 two peripheral carapace plates; JODA 15056 three costal carapace plates; JODA 15129 postcranial material and costal carapace plates

Description: Abundant material from fossil emydids, more commonly called pond turtles, is present at Hawk Rim. Most material consists of carapace bones, with limited postcranial material and plastron bones. Peripheral bones were the most common, followed by fragments of costals. Assignment to the Emydidae is indicated by the distinctive scute attachment lines on the nuchal, peripherals, and pygal bones. The attachment lines for the marginal scutes occur much farther towards the proximal edge of the costal bones, leaving a wide margin between the scute lines and the distal peripheral edge, unlike the attachments characteristic of any other North American testudine family. This renders emydids easily distinguished from other genera at the site, such as those of *Xenochelys*, which have the marginal scute attachment lines quite close to the marginal edge of the peripheral bones. The peripheral bones can also be distinguished from smaller members of the Testudinidae, as testudinid peripherals are relatively wider and slightly upturned at the edge. Definitive assignment to *Clemmys* was based on a single nuchal bone as well as unique neural bones. Other material was assigned to *Clemmys* on the basis of overall similarities in morphology as well as depositional proximity to the nuchal bone. The size range for living species of *Clemmys* ranges from 8-23cm (Sobolik and Steele, 1996) for the entire shell. While only individual carapace bones are preserved, the size of said bones places the Hawk Rim specimens within the normal variation in size. Specimen JODA 15003B was the only *Clemmys* peripheral from the site. It was diagnosed as *Clemmys* because the marginal scute lines are located away from the anterior edges of the bones, and pleural scute lines are present. Neural bones (JODA 14970) were assigned to *Clemmys* because of the distinctive 6- or 8-sided shape, which is unlike that of other possible testudines. Most importantly, neurals from *Clemmys* have unique double-track vertebral attachment scars on the ventral side.

Discussion: While the Emydidae are the most speciose family of living testudines (Ernst and Barbour, 1972), many of the genera do not originate until the Pleistocene. Both *Graptemys* and *Deirochelys*, two of the most common emydid genera other than *Clemmys*, have their earliest occurrences in the Pleistocene. While *Emydoidea* occurs in the Miocene, the genus is distinct from *Clemmys* in possessing a more domed and elongate shell. Lastly, paleoenvironmental and sedimentological interpretations of the site allow for the emydid genus *Malaclemys* to be ruled out, as the genus is only recorded from brackish or saltwater deposits. Morphologically *Malaclemys* displays a vertebral keel on the neurals, unseen on any Hawk Rim specimens. Modern *Clemmys* can be quite terrestrial and are found in habitats including bogs, streams, marshy meadows, and woods (Sobolik and Steele, 1996).

Family KINOSTERNIDAE Hay, 1892

Genus *XENOCHELYS* Hay, 1906

Referred Material – JODA 15012, peripheral carapace plate, neural carapace plate; JODA 15055, costal carapace plate, two peripheral carapace plates; JODA 15074 carapace plate; JODA 15165, two peripheral carapace plates; JODA 15166, three peripheral carapace plates

Description: Kinosternida shell material consists mostly of peripherals. Peripherals from *Xenochelys* are highly diagnostic. The marginal scute outlines are distally oriented on the peripherals, which produces a “lipping” effect (Sobolik and Steele, 1996), as is seen in JODA 15012 (Figure 11). The distal marginal scute lines are also present and diagnostic on the nuchal bone, however a nuchal has not yet been recovered from Hawk Rim for this genus. The neurals assigned to the Kinosternidae are identifiable because they are very

Figure 11: Ventral and dorsal views of the kinosternid peripheral, JODA 15012

small and ovate in shape. They are thinner than the emydids and not nearly as wide as those from testudinids. Costals are long, thin, and rectangular in shape. Compared to other genera, the edges are are slightly rounded. Significantly, the 1st, 3rd, and 5th costals have a posterior vertebral scute attachment line that is rounded (Hay, 1908).

Discussion: All kinosternid material from the site likely belongs to the genus *Xenochelys*. This genus is the oldest member of the family, know in North America beginning in the Eocene (Hutchinson, 1991). This turtle possesses an ovate shell like the material from Hawk Rim, as indicated by the sweeping shape of the costal, whereas those of later genera are more rounded. Sedimentary analysis of deposits indicated this genus is found in slow-moving, freshwater deposits. This would be consistent with the lacustrine deposits common at Hawk Rim, as modern mud turtles are not usually found in the main channels of streams and rivers (Moll and Moll, 2004).

Family TESTUDINIDAE Gray, 1825

Referred Material – JODA 14965, costal carapace plate; JODA 14972, femur, plastron carapace plate fragments; JODA 15016, plastron carapace plate pieces, costal carapace plate, peripheral carapace plate; JODA 15084, costal carapace plate fragments; JODA 15088, distal phalanx, costal carapace plate ; JODA 15094; JODA 15117, peripheral carapace plate, costal carapace plate; JODA 15135, hypoplastron plate, five costal carapace plates, neural carapace plate, four costal carapace plates, two post cranial elements; JODA 15136 carapace plate; JODA 15150, first costal carapace plate; JODA 15157 carapace plate; JODA 15160 carapace plate; JODA 15163, two peripheral carapace plate; JODA 15164, two plastron plate fragments, peripheral carapace plate, costal carapace plate

Description: Tortoise material is one of the most common fossils found at Hawk Rim. The material includes both carapace and postcranial remains. The size of the material indicates it was from very large animals (Figure 12), far outside the size range attained by any other testudine in the North American Middle Miocene. While mass estimates are difficult to calculate from the limited material, the animals were likely of a similar size to living Galápagos tortoises. Postcranial material was diagnosed based on sheer size as belonging to the Testudinidae. Notably, there was a distal femur recovered (JODA 14972A) (Figure 12) and a distal phalanx (JODA 15088A). The rough size estimate was generated from the diameter of the distal femur as well as the thickness and size of the most complete carapace plates and should only be considered an approximation.

Discussion: No tortoise of this size has currently been described from the Barstovian of

Figure 12: JODA 14972A, tortoise humerus, scale in cm

the region. However, several Barstovian localities, including the Mascall type area (Samuels, pers. com.) have yielded undescribed tortoise material of comparable size. Little work has been done on tortoises limiting chances for comparison. Material, while abundant, is also rather fragmentary and has yet to yield key species-diagnostic material such as a nuchal bone.

TESTUDINES *indet.*

Referred Material – JODA 14994; JODA 15028; JODA 15068; JODA 15102; JODA 151108; JODA 15112; JODA 14969

Description: Most of the referred specimens are carapace material too fragmentary to assign to family. Thicker pieces likely belong to tortoises, but diagnosis is difficult and should not be attempted without scute attachment lines or clear bone margins.

Class MAMMALIA Linnaeus, 1758

Order ARTIODACTYLA Owen, 1848

Family ANTILOCAPRIDAE Gray, 1866

Referred Material: JODA 15018, right astragalus

Description: Preserved material is limited to a single right astragalus (Figure 13). The bone was collected from fluvial sandstone and shows some evidence of minimal transport, resulting in somewhat worn edges. For identification standard measurements were taken (DeGusta and Vrba, 2003) including total length (16.6 mm) and width (10.5 mm). While size is not generally a defining feature, the overall small dimensions precluded many of the possibilities, such as the uniformly larger paleomerycids. The

Figure 13: JODA 15018, antilocaprid astragalus, scale in cm. While incomplete, the facets characteristic of an atilocaprid are seen, as well as the overall compact shape unlike many other families of artiodactyla.

trochlear keels are oriented parallel to the overall dimensions of the bone indicating the astragalus belonged to a small artiodactyl. Both trochlear keels are of nearly the same length, ruling out artiodactyl families such as Camelidae. Overall the shape is roughly rectangular, unlike the upwards curved shapes of the Tayassuidae. Antilocaprid astragali from Red Basin (UO F-4950, UO F-30987, UO F-7459) and the type area of the Mascall Formation (UCMP 1726) were used as comparison to verify the identification.

Discussion: While astragali can be highly diagnostic in artiodactyls, the water-worn nature of the preserved specimen prohibits a positive identification. The astragalus likely belongs to *Merycodus*, as the size is consistent and the genus is known from the Mascall Formation and Red Basin (Shotwell, 1968, Downs, 1956).

Family CAMELIDAE Gray, 1821

Referred Material: JODA 14975, canine; JODA 14988, tooth fragments; JODA 15005, maxilla; JODA 15066, tooth fragment; JODA 15075, tooth fragment; JODA 15118, tooth fragments; JODA 15127, tooth fragments

Description: While numerous specimens diagnostic as camelid have been discovered at Hawk Rim (Figure 14), none of the material can be assigned to genus. All material is from a relatively small camelid and size is consistent though all samples. Dental material was assigned to the Camelidae on the grounds of the pronounced buttress in the middle of the outside portion of each tooth. The teeth are also higher-crowned and larger than many of the other artiodactyls and perissodactyls of the time. The canine is small in size (Figure 14), indicating the camelid at the site was small in stature.

Discussion: The consistency in size indicates all material likely came from the same species, which appears to be the only camelid present at the locality. The lack of llama

Figure 14: JODA 14975 camelid canine and JODA 15005 maxilla, scale in cm. The canine is the only whole tooth, limiting the ability to diagnoise the camelid material.

buttresses on the tooth fragments indicates the species was a camelin camelid. A small camelid is also present in Red Basin, but is a sparsely-represented component of the fauna and thus is also unidentified beyond Camelidae (Shotwell, 1968). Miolabine camels are found concurrently in the Mascall Formation (Downs, 1956), and represent the most likely candidate.

Family MERYCOIDODONTIDAE Thorpe, 1923

Referred Material: JODA 15065, upper left molar

Description: While a complete tooth is preserved, the fact that recovered material is limited to a single upper left molar (Figure 15) prevents a generic level identification. The upper molar is from a relatively small oreodont. The tooth is 13.3 mm long and 13.0 mm wide. Crown height, measured from the base of the enamel to the juncture between lophs is 5.8 mm. While morphologically consistent with *Ticholeptus*, it is considerably smaller than comparable specimens from Red Basin (UO F-22192).

Figure 15: JODA 15065 an upper oreodont molar. This single tooth is much smaller than specimens from Red Basin.

Discussion: Similarities to both Red Basin and Mascall specimens supports the probable diagnosis as *Ticholeptus*. However, the small size is outside of normal variation and the limited material precludes a positive diagnosis. Hawk Rim material may represent either a new species or indicate greater phenotypic variation within known species. More material would be needed to facilitate identification past family level.

Family PALAEOMERYCIDAE Lydekker, 1883

Genus *DROMOMERYX* Douglass, 1909

Referred Material: JODA 14968, distal humerus, distal metapodial; JODA 15006, astragulus; JODA 15090, tooth fragments; JODA 15145, 2nd lower premolar

Description: Most preserved material is fragmentary and does not represent one of the more common animals recovered from the site. The distal humerus and metapodial were identified by comparisons with UCMP 55916. The morphology of the articular surfaces and the size are consistent between the specimens, supporting the diagnosis as belonging to *Dromomeryx*. Red Basin specimens (UO 20695, UO 20512, UO 20673) were used as comparisons to facilitate the identification of the Hawk Rim astragalus (Figure 16). Standard measurements (DeGusta and Vrba, 2003) were taken on both the Red Basin and Hawk Rim astragali. The Hawk Rim specimen is within the variation seen at Red Basin, although it falls in the bottom 10% of observed size variation in all dimensions. Dental material was compared to specimens from both the Mascall Formation and Red Basin. Overall morphology of the lower premolar was indicative of a palaeomerycid, with the dimensions indicating the material belonged to *Dromomeryx*. While not complete, the

Figure 16: JODA 15006, *Dromomeryx* astragalus, scale in cm

width measurement for the second premolar was 7.5 mm and the projected total length was 15.0 mm.

Discussion: *Dromomeryx* represents a common member of both the Mascall Formation type area (Downs, 1956) and Red Basin (Shotwell, 1968). While overall collected material from Hawk Rim is too limited to generate robust abundance data, the percentage of ungulate material assigned to *Dromomeryx* indicates it was not a common member of the herbivore community. Furthermore, material from Hawk Rim indicates the species present was, on average, of a much smaller stature than is present in the Mascall type area or in Red Basin. This may have been an adaptation to the habitat at Hawk Rim, as it is inferred to be a more heavily forested, closed environment than the Mascall type area or Red Basin, this may have been a response to the different environment. *Dromomeryx* is currently monotypic, with only one recognized species *D. borealis* (Prothero and Liter, 2007). Considerable size variation exists within specimens assigned to this species. The

Hawk Rim specimens fall within variation seen at other sites, but are consistently in the smallest range of observed measurements. While this may reflect environmentally driven variation, a phylogenetic reevaluation is needed before more diagnostic material could be assigned to species.

Genus RAKOMERYX Frick, 1937

RAKOMERYX SINCLAIRI (Matthew, 1918)

Referred Material: JODA 15034, cannon bone; JODA 15043, lower premolar; JODA 15073, lower molar; JODA 15086, astragulus; JODA 15143, cubonavicular; JODA 15152, 1st lower molar and tooth fragments

Description: Material from *Rakomeryx* is more common than the larger *Dromomeryx* at Hawk Rim. Specimens were primarily assigned to *Rakomeryx* based on morphological similarities to *Dromomeryx*, but one half to two-thirds the size of *Dromomeryx* material. *Rakomeryx* and *Dromomeryx* are very closely related, belonging to the same subtribe, and originate from the same migratory event from Eurasia (Prothero and Liter, 2007). The only morphological differences noted are that of size and horn morphology. While *Rakomeryx* material for comparison is limited, some dental material from Red Basin was used to facilitate comparisons as well as *Dromomeryx* material from both University of Oregon and University of California. The cannon bone (Figure 17, top), or fused metatcarpal, was identified by comparison to UCMP 709 from *Dromomeryx*. All relationships between morphological dimensions, as well as the articular surface, were identical in spatial relationship to those of *Dromomeryx*, but approximately two-thirds the size. This comparison also held true for the cubonavicular. The fusion was indicative of an artiodactyl, and the size precluded several other animals. It was morphologically distinct, with a different arrangement of the articular surface than camelids, as shown by comparison to UO 8702. Dental elements (Figure 17, lower) were identified by comparison to material from Red Basin (UO 22147 and UO 22146).

Discussion: Material from Hawk Rim, while limited, seems to be of a similar size to that

Figure 17: JODA 15034, a *Rakomeryx* cannon bone, on top. Below, from left to right, JODA 15073, JODA 15043, JODA 15152, a lower molar, lower premolar, and two partial lower molars

from Red Basin. Unlike Red Basin, or the Mascall Formation type area, *Rakomeryx* represents the majority of the palaeomerycid material from the site, as opposed to the usually more common *Dromomeryx*. The genus is monotypic, and while worn, can be diagnosed based on the complete teeth discovered at Hawk Rim.

PALAEOMERYCIDAE *indet.*

Referred Material: JODA 15014, phalanx; JODA 15054, inner ear

Description: Material was compared to preexisting palaeomerycid samples to facilitate diagnosis. However, this material was of intermediate size, making it difficult to distinguish between *Rakomeryx* and *Dromomeryx*. The inner ear was identified by visual comparison to images of all identified artiodactyl inner ears (O'Leary, 2010).

Discussion: While the Mascall Formation contains both *Rakomeryx* and *Dromomeryx* in addition to *Bouromeryx*, it is unlikely Hawk Rim contains any material from the genus *Bouromeryx*. *Bouromeryx*, while intermediate in size, has much shorter and stouter limb proportions (Prothero and Liter, 2007). All material recovered from Hawk Rim came from relatively gracile individuals, with consistent morphological proportions.

Family TAYASSUIDAE Palmer, 1897

Referred Material: JODA 15042, molar, incisors, canine, jaw fragment

Description: Collected material was all from the same individual and represents the anterior portion of a mandible (Figure 18). One incisor was found still in place in an alveolus in the small jaw fragment. Other incisors were found in association, as well as the canine and molar. The molar is extremely worn, suggesting the individual may have been old at the time of death. The canine was diagnostic as belonging to the Tayassuidae because of the occlusal wear pattern, with distinct "self-sharpened" edges (Harris and Li-Ping, 2007). While heavily worn, the bunodont structure and two distinct lophs of the molar were also characteristic of a tayassuid.

Discussion: The level of wear on this specimen made identification more difficult than it would have otherwise been. Furthermore, while the canine and incisors are indicative of a tayassuid, little morphological variation exists between genera. The Mascall Formation, Railroad Canyon Sequence, and Red Basin all possess tayassuids as members of their faunal lists (Fremd 2010, Barnosky *et al.*, 2007, Shotwell, 1968). However, Railroad Canyon and the type Mascall area contain material identified as *Cynorca*, while Red Basin contains *Prosthennops*. With limited morphological variation between these genera exist, it is difficult to discriminate between the genera without more extensive material. Furthermore, recent reevaluation of Mascall material has concluded the presence of *Prosthennops* in addition to the previously identified *Cynorca* (Kaitlin Maguire, pers. comm., 2011). With only one worn molar, it is also difficult to tell its relationship in the

Figure 18: JODA 15042, peccary canine, incisors, and lower worn molar. The "self-sharpening" edge on the canine is from occlusion with the upper incisor.

jaw. In dimension the molar appears to be closer to the smaller size range observed in *Cynorca* than the larger genera such as *Prosthennops* and *Dyseohyus* (Barnosky *et al.*, 2007). This size similarity is further confounded by the suggestion that *Cynorca* is highly polyphyletic and in need of extensive phylogenetic reevaluation (Wright, 1998).

ARTIODACTYLA *indet.*

Referred Material: JODA 15009, tooth fragments; JODA 15011, tooth fragments; JODA 15038, distal tibia; JODA 15076, distal metapodial and tooth fragment; JODA 15085, tooth fragment; JODA 15091, calcanium; JODA 15105, tooth fragment; JODA 15111, distal phalanx; JODA 15122, tooth fragment; JODA 15124, metapodial

Description: While material was too fragmentary to assign to family level, all collected samples assigned to Artiodactyla contained distinctive morphological characters indicative of the order. Tooth fragments were either strongly leaf-shaped, or contained pronounced selenes. Limb and foot elements were all consistent with an even-toed ungulate. The distal tibia had grooves for two keels oriented straight with the main shaft of the bone, unlike the slanted keels of a perissodactyl.

Discussion: Morphometric analysis of some elements would possibly allow for a family-level identification, however this level of detail is outside the current scope of this study.

Order CARNIVORA Bowdich, 1821

Family AMPHICYONIDAE Haeckel, 1866

Referred Material: JODA 15058, left first metacarpal

Description: Recovered material is limited to a left first metacarpal (Figure 19). While a complete unweathered bone, this material has limited use for a generic-level taxonomic identification. The bone is extremely robust, representing a large muscular animal. The bone likely came from an older individual as the plantar surface shows evidence of low-grade arthritis, with the development of small subchondral cysts.

Discussion: The size of the bone would be consistent with *Pliocyon*, found in the Mascall Formation (Fremd, 2010), Railroad Canyon Sequence (Barnosky *et al.*, 2007), and Red Basin (Shotwell, 1968). However, *Amphicyon* also shows a range of overlapping sizes, and is found in the Mascall type area (Downs, 1956) and Red Basin (Shotwell, 1968). The Hawk Rim specimen is morphologically and morphometrically very consistent with an unpublished partial skeleton from Virgin Valley; however that material has not yet been identified to a generic level. Both of these are considered to be midsized amphicyonids (Hunt, 1998).

Figure 19: JODA 15058, beardog metacarpal, scale in cm.
Note the highly robust nature of the bone.

Family CANIDAE Fisher, 1817

Genus *CYNARCTOIDES* McGrew, 1938

CYNARCTOIDES ACRIDENS (Barbour and Cook, 1914)

Referred Material: JODA 14964, first lower molar

Description: This canid molar belonged to an animal of very small size (Figure 20). The length of the lower first molar is estimated, as one cusp is broken off, to be 8.0 mm, the trigonid width is 4.1 mm, and the talonid width is 4.5 mm, within the reported range of 6.7-10.0mm, 2.5-4.0mm, and 3.1-4.8mm respectively (Wang *et al.*, 1999). Diagnostic of the genus, the molar is relatively high crowned with a conical shape. The metaconid is high in relationship to other cusps with an enlarged prostylid. Overall, the tooth is consistent with the elongate narrow jaws found in *Cynarctoides*. Furthermore, the tooth is indicative of an animal that was quite hypocarnivorous. This trend towards increased hypocarnivory is characteristic of *Cynarctoides*, and was achieved in this genus in a quite different manner than other related genera such as *Phlaocyon* and *Cynarctus*.While still a small canid, *C. acridens* is the largest species, and type species, of the genus (Wang *et al.*, 1999). Unlike other species in the genus, *C. acridens* also displays a metastylid on the m1 and a more pronounced protostylid than species such as *C. gawnae*. Furthermore, the characteristic enlarged prostylid of the genus has been continued, resulting in the reduction of the protoconid. As the last species of the genus, the Hawk Rim specimen exhibits highly derived dental morphology.

Figure 20: Hawk Rim canid teeth, JODA 14964 (top right), JODA 14998 (bottom right), and JODA 15142 (left), scale 1 cm, showing size variation among Hawk Rim canids

Discussion: The genus is known from the Whitneyan to the Early Barstovian in both the Great Plains and the West. However, Hawk Rim represents the first occurrence of this genus in Oregon in the Early Barstovian. Previously the genus had only been collected from Early Barstovian deposits of Nebraska, New Mexico, and California (Wang *et al.*, 1999). This species was the longest-lived as well as one of the most geographically dispersed of all *Cynarctoides* species. Therefore, it is unsurprising to discover this small borophagine canid in Oregon.

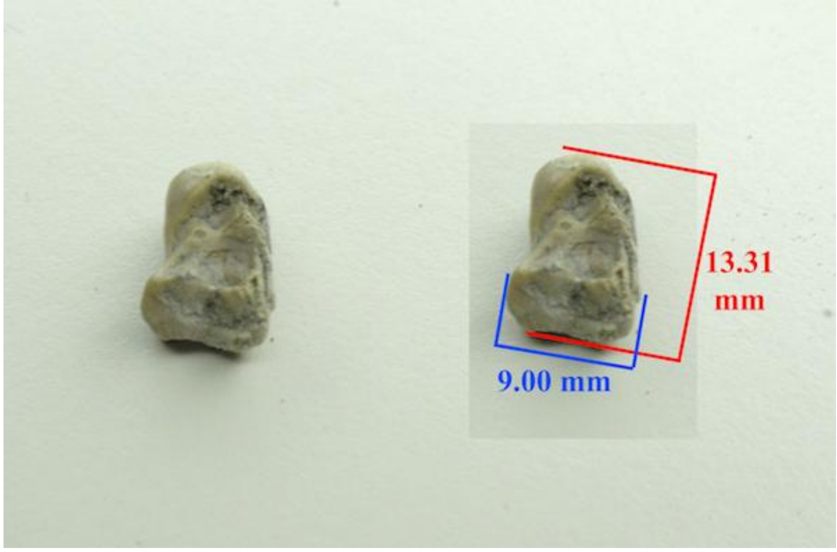
Genus *PARATOMARCTUS* Wang *et al*, 1999

PARATOMARCTUS TEMERARIUS (Leidy, 1858)

Referred Material: JODA 14998, upper left carnassial

Description: Only a single tooth has been recovered from this species; however, it is an upper left carnassial (Figure 21), a highly diagnostic element in canids. The most important feature indicating the placement into this genus is the strongly pronounced

Figure 21: JODA 14998, *Paratomarctus* upper molar



lingual cingulum, which extends much further anteriorly than in other genera. *P. temerarius* is the smaller of the two species of *Paratomarctus* (Figure 20). The Hawk Rim specimen has a length of 9.0 mm and a width of 13.3 mm, measurements consistent and within the known range of *P. temerarius* (average M1 length 11.7, average M1 width 13.8) but not *P. euthos* (Wang *et al.*, 1999).

Discussion: The genus has been recovered from the Late Hemingfordian to the Late Clarendonian (Wang *et al.*, 1999). While known from the Early Barstovian of Oregon, Hawk Rim represents the first occurrence in the Mascall Formation (Fremd, 2010). While both the length and width measurements are within the known range for the species, the length was at the known minimum while the width was at the known maximum. Dental variation does exist in this species; however the Hawk Rim specimen is more antero-posteriorly compressed that those of other samples of the species. Without more material, it is difficult to tell if the Hawk Rim material represents increased morphological variety within the species or a new species of *Paratomarctus*.

Genus *TEPHROCYON* Merriam, 1906

TEPHROCYON RURESTRIS Condon, 1896

Referred Material: JODA 15142, maxilla fragment fourth premolar and first molar; JODA 14135, upper fourth premolar

Description: The maxillary fragment with two perfectly preserved teeth facilitated a definitive identification. As a monotypic genus, *Tephrocyon* is quite distinct from all other contemporary canids (Figure 20). Much larger than its evolutionary predecessors and contemporaries (Wang *et al.*, 1999), *Tephrocyon* immediately stands out. The M1 posesses a distinct metaconule and is less high-crowned than other genera. The holotype specimen (UO F-23077), a complete skull from the Mascall Formation type area, was used for morphological comparisons. The morphology of Hawk Rim specimens was consistent not only in size, but in all observed morphological details. This comparison also holds true with Red Basin specimens published by Shotwell (1968). The teeth are robust compared to other genera and Hawk Rim canids as well. The length of the M1 is 12.2 mm while the width is 14.4 mm. This is very close to the average values reported by Wang *et al*. (1999) of 12.1 mm and 15.0 mm for length and width.

Discussion: *Tephrocyon rurestris* is the only canid previously known from the Mascall Formation (Downs, 1956, Fremd, 2010). It is also well-known from Red Basin (Shotwell, 1968). As the largest canid in the region during the Early Barstovian, it was likely a more common member of local faunas than the smaller canids, and may have played a role as one of the top predators. With its adaptations for increased bone crushing, scavenging may have constituted an important portion of its diet.

Family FELIDAE Fischer De Waldheim, 1817

Genus *PSEUDAELURUS* Gervais, 1850

PSEUDAELURUS SKINNERI Rothwell, 2003

Referred Material: JODA 14977, right mandible

Description: A nearly complete right mandible of a cat was recovered from Hawk Rim (Figure 22). The canine is broken, leaving only the root and very base of the tooth. The single rooted second premolar is missing. However, the third and fourth premolars, as well as the first molar are present and well preserved. The posterior ramus of the jaw is broken and missing. While not the earliest true cat, *Pseudaelurus* is the first cat to reach North America, and as such, still possesses several primitive felid characteristics. Characteristics generally diagnosing the genus are the absence of the first premolar and

Figure 22: JODA 14977, cat mandible, scale 1 cm. While the ramus and canine are broken, the mandible is still nearly complete. The carnassial displays two additional cusps lost in later cats, attesting to the basal nature of this felid.

the second molar. The first molar still retains a highly reduced metaconid and talonid, features lost in later genera. Unlike in later cats, the second premolar is still retained, but has undergone severe reduction as can be seen in the single-rooted alveolus on the Hawk Rim specimen. North American *Pseudaelurus* differ from European and Asian species in that they have a shorter total toothrow measurement, the first molar possesses a taller protoconid and a more reduced metaconid and talonid and the tall protoconid is consistently taller than the paraconid, as opposed to what is seen in *P. lorteti*. North American species also possesses a fourth premolar with a protocone that projects at an obtuse angle anteroligually (Rothwell, 2003). North American species can be most readily distinguished by size. The length of the first molar in the Hawk Rim jaw is 12.9 mm, within the range observed in the species of 11.5-13.8mm (Rothwell, 2003). This observed size variation is larger than *P.stouti* but smaller than *P. aeluroides*. The Hawk Rim specimen is also morphologically consistent with the species. The dentary is overall slender and gracile. There is a large mandibular foramen, positioned under the coronoid process. While the ramus is broken off, the remaining bone hints at a highly upright position of the ascending ramus. This is similar to *P. validus* as well as *P. skinneri*, but *P. validus* is a much larger species. The canine is missing the upper portion, but the remaing part of the tooth is enough to clearly show an ovate shape. This oval cross sectional area is characteristic of *P. skinneri* and is not observed in any other species of *Pseudaelurus*. The second premolar is single-rooted, a characteristic also found only in this species.

Discussion: *Pseudaelurus*, while recorded, has never been a common taxon in Oregon. Material is highly limited in the state, especially from the Barstovian. While the Mascall Formation has supposedly yielded the taxon (Fremd, 2010), no curated material was located for comparison. Material from Red Basin is fragmentary and limited to two individual teeth and some postcrania (Shotwell, 1968). As dental material preserved was limited to upper teeth, a direct comparison to the Hawk Rim specimen is difficult. However, material from Red Basin seems to be from a larger individual than the Hawk Rim material. The genus has a temporal distribution from the Hemingfordian to the Late Barstovian. All other specimens of *P. skinneri* are from the Late Hemingfordian, however the entirety of the species is represented by nine specimens from Nebraska, approximately 1,500 miles from Hawk Rim. The Hawk Rim jaw represents not only the first *Pseudaelurus* specimen from Oregon assignable to the species level, but also a huge temporal and geographic range extension for the species.

Family MUSTELIDAE Fischer, 1817

gen. et sp. nov

Referred Material: JODA 15060, partial left mandible with the canine, third and fourth premolars, and partial first molar.

Description: While fragmentary, most of a left jaw is present. The complete canine is preserved, which displays the lingual groove, or blood channel, characteristic of hypercarnivorous mustelids. Two premolars, the third and fourth, are also preserved with roots. The third premolar was found still in place in a segment of the jaw. While close, this jaw fragment does not directly attach to the distal portion of the jaw preserving the base of the ramus and the alveolus of the second molar. The posterior half of the first molar is also preserved. While the tooth is broken in half, the preserved portion is in excellent condition. Overall the individual shows only minimal wear on the teeth,

Figure 23: JODA 15060, mustelid jaw, scale in cm. The blood channel in the canine is visible on the posterior side of the tooth.

evidenced primarily in the canine. The jaw is robust with the anterior portion actually being slightly deeper than the posterior portion directly in front of the ramus and below the alveoli of the second molar. The jaw is deep as well as broad and is sturdily built. There is some shortening of the jaw, especially in comparison to *Ischyrictis*, but no evidence of the extreme shortening resulting in the crowding the premolars seen in

Figure 24: JODA 15060, oclussial view. This view shows how robust the jaw is.

several other North American ischyrictins (Baskin, 1998). Dental morphology is consistent with an extremely hypercarnivorous animal. The dentition is robust, with consistent reduction of the crushing portions of preserved teeth. The canine tooth is 9.8 mm long and 6.8 mm wide, with a crown height of 12.9 mm measured from the enamel dentine junction. There is wear along the lingual channel, as well as the point of the tooth. While robust, the canine does not broaden significantly towards the base as in *Brachypsalis* (Galbreath, 1955). The premolars posses both a cingulum and accessory cusplets, even in wear. The length, width, crown height to the highest assesory cusplet and crown height to the second accessory cusplet were measured for the premolars and are as follows: p3 L = 7.0 mm, W = 4.2 mm, CH1 = 3.9 mm, CH2 = 3.7 mm. The preserved portion of the first molar reveals a very short, highly trenchant talonid and is 5.9 mm high from the enamel dentine junction to the highest preserved portion of the crown height. The hypoconid is reduced to the point of being virtually absent. Wrapping around the tooth is a pronounced cingulum.

Discussion: While other mustelids exhibit some features, such as the trenchant talonid seen in *Sthenictis*, no described mustelid matches all characters observed in the Hawk Rim specimen. Assignment to *Sthenictis* is precluded by the very short talonid of the first molar in *Adamantictis*; *Sthenictis* is characterized by an elongate m1 talonid. *Mionictis* is equally untenable, as that genus possesses a much less pronounced cingulum and a more dominate hypoconid. *Hoplictis* lacks accessory cusps on the premolars. *Oligobunis* is unlikely not only due to its characteristic posteriorly broadening premolars and the presence of a notable hypoconid on the m1, but also the age (Oligobunis has its last appearance 2.5 to 3 million years earlier in the Hemingfordian). The European *Ischyrictis* shares the greatest number of similarities with *Adamantictis* and likely represents the parent taxon. While never actually recorded in North America, it is considered an immigrant taxon dispersing from Europe (Zhanxiang, 2003). The most similar North American mustelids are all grouped into the Ischyrictini, reflecting this relationship. *Ischyrictis,* however, never achieved the reduction of the talonid to the extent seen in *Adamantictis*. Most species also have less prominent accessory cusps on the premolar (Peter, 1963, Ginsburg, 1985), with overall more robust premolars that are also more pyramidal in shape (Ginsburg, 1992). The specimen shares strong similarities with the modern South American grisson, *Galictis*, and may represent and evolutionary stepping stone for how the lineage of animals got to South American from their European ancestry.

Order CARNIVORA *indet.*

Referred Material: JODA 15087, metacarpal; JODA 15130, metapodial

Description: Both the metacarpal and metapodial were referred to the Carnivora based on overall morphological similarities to carnivore comparative specimens. Both were more asymmetrical than is seen in ungulates.

Discussion: The material would be consistent in size with a small canid, however, the lack of relevant comparative material makes even family level identifications impractical.

Order LAGOMORPHA Brandt, 1855

Family LEPORIDAE Fischer de Waldheim, 1817

Referred Material: JODA 15044, proximal tibia; JODA 15078, calcaneum

Description: With only a water-worn calcaneum and a broken proximal tibia (Figure 25) to refer to this family. Generic level identification was not possible. Material was identified as belonging to a rabbit through morphological comparisons with modern rabbit skeletal material (UO R-8456 and UO R-8271). Both the size and shape were consistent with the assignment as a leporid, but would have been inconsistent with ochotonids.

Discussion: More material is needed, preferably dental material. Both thetype area of the Mascall Formation and Red Basin contain *Hypolagus* as the only identified rabbit present

Figure 25: top, JODA 15044 proximal rabbit tibia, bottom JODA 15078 calcaneum

(Downs, 1956, Shotwell, 1968). Likely the Hawk Rim material also belongs to this genus, and would be consistent with the observed size range for the genus.

Order PERISSODACTYLA Owen, 1848

Family CHALICOTHERIIDAE Gill, 1872

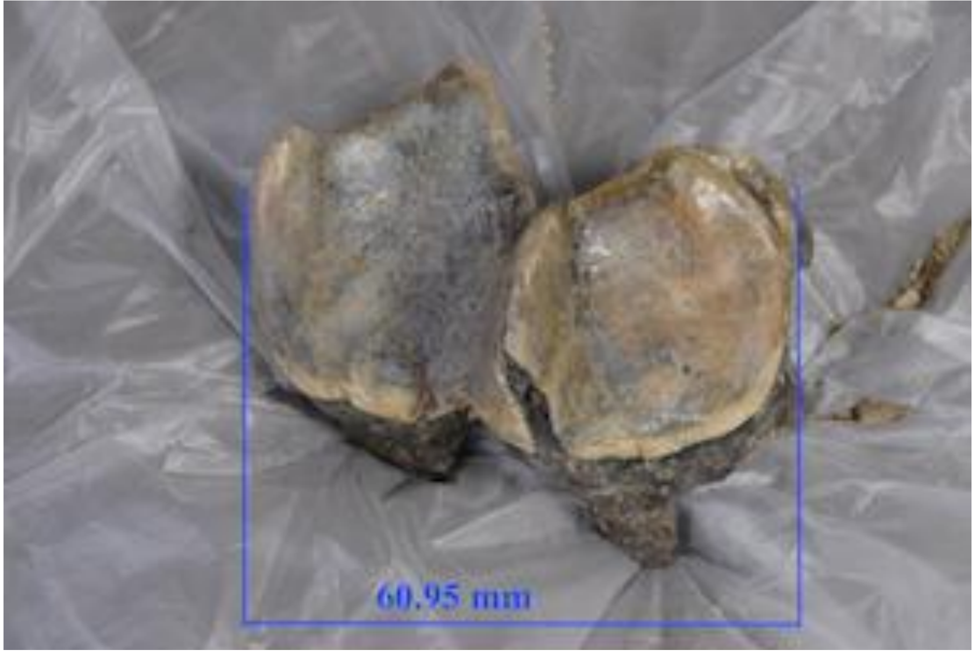
Genus *MOROPUS* Marsh, 1877

Referred Material: JODA 15059, partial first upper molar

Description: Most readily apparent is the very large size of the specimen. This immediately precluded most other mammals. Only the outside portion of the tooth is preserved, with a small portion of the infolded central enamel area on the anterior portion. The length of the tooth is 61.0mm. While much of the tooth is missing, the estimated width of the tooth is 37mm. The W-shaped ectoloph of the tooth clearly indicates a perissodactyl, however the dimensions of the tooth make it far larger than even the rhinoceroses of the time period. Furthermore the enamel edge is also lacking the prominent perykymata seen in the enamel of rhinocertids. Tooth morphology and the presence of the infolded enamel portion, or post fossette (Coombs, 1978), of the tooth allowed for it to be identified as a chalicothere and specifically *Moropus* (Coombs, 2004).

Discussion: While *Moropus* has been noted from the Mascall Formation by Marsh, the actually specimen described, a mentioned has been subsequently lost (Coombs *et al.*, 2001). All other John Day Basin material belonging to *Moropus* has been collected from the Haystack and Kimberly Members of the John Day Formation (Fremd, 2010). The Hawk Rim specimen therefore represents the youngest known specimen of the genus in

Figure 26: *Moropus* molar, JODA 15059



the area (Coombs *et al.*, 2001). The Hawk Rim specimen is also larger than any described specimen of *Moropus*. It may either represent a new species or indicate greater morphological variation within species than previously recorded. More material would be needed to make a conclusion on the phylogenetic affinities of the Hawk Rim specimen.

Family EQUIDAE Gray, 1821

Genus *ARCHAEOHIPPUS* Gidley, 1906

Referred Material: JODA 14991, metapodial; JODA 15004, cubonavicular, phalanx, upper molar; JODA 15040, first premolar; JODA 15053, phalanx; JODA 15061, tooth; JODA 15071, phalanx and tooth; JODA 15081, astragulus; JODA 15082, astragulus; JODA 15104, phalanx

Description: All listed material was easily assignable to *Archaeohippus* due to its extremely small size (Figure 27). The size, in addition to morphological modifications to

Figure 27: on left, JODA 15004, on right JODA 15082

the limb dimensions, is generally recognized as valid grounds for assigning equid material to this genus (Barnosky *et al.* 2007, MacFadden, 1999, Janis *et al*. 1994, O'Sullivan, 2003). In addition to small size, the genus possesses low-crowned teeth. The limb bones are not only small, but highly gracile (O'Sullivan, 2003), as can be seen in the delicate second and fourth toes of this genus found at Hawk Rim. The phalanges also display the reduced tridactyly linking this primitive looking horse to merychippine grade horses (O'Sullivan, 2008), with the small stature being due to phyletic dwarfism (MacFadden, 1999). The teeth of this genus are not only small and low crowned, but have black cementum and the presence of crochets in the upper teeth.

Discussion: *Archaeohippus* is known from both the Mascall Formation (Downs, 1956) and from Montana's Barstovian Railroad Canyon fauna (Barnosky *et al.* 2007), but is unrecognized in the geographically intermediate Red Basin fauna. At both other regional Barstovian sites, Railroad Canyon and the Mascall proper, the small horse is an uncommon member of the fauna. At Hawk Rim, *Archaeohippus* is the most common equid. While some of this frequency may reflect the ease in identifying its remains from more fragmentary pieces than is possible for other genera, the taxon still represents a more substantial portion of the fauna than at other sites. As *Archaeohippus* is thought to be a browsing taxon (MacFadden, 1999), this relative abundance may be due to the preservation of forested habitats represented by many of the fossil-bearing strata at Hawk Rim. *A. ultimus* is the main species described in the region (Downs, 1956), however other species cannot be ruled out. The poorly understood origins of this genus make diagnostic differences between species harder to parse (O'Sullivan, 2003).

Genus *MERYCHIPPUS* Leidy, 1858

Referred Material: JODA 14976, tooth fragments; JODA 14999, upper molar; JODA 15070, lower molar and two upper molars; JODA 15137, lower molar

Description: *Merychippus* is the most common equid at most early Barstovian sites, so ample material exists for comparison. Hawk Rim specimens were compared to *Merychippus* from the Mascall Formation (UCMP 739) and Red Basin (UO F-23322 and UO F-21038). Identification is also facilitated by several distinct features of the genus. These intermediate-sized horses exhibit mesodonty (Figure 28), being higher-crowned than most other coexistent genera (MacFadden, 1999). The lower dentition is unique among Barstovian equids in possessing a moderate to thick layer of cementum on the cheek teeth. Postcrania were difficult to assign to this genus as it is a similar size to parahippine-grade equids such as *Desmatippus* (Morris, 1965).

Figure 28: *Merychippus* molars, JODA 15070

Discussion: Of all equids present at Hawk Rim, *Merychippus* is the most difficult to assign to a particular species. Either a much larger sample or complete dentitions would be needed for a species level assignment. *Merychippus* is really more of a grade of horses than a genus, owing to the highly polyphletic nature of the taxon (Hulbert and MacFadden, 1991). The limited dental material from Hawk Rim suggests the merychippine-grade horses at the site were different from those in the type Mascall area, Red Basin, or Railroad Canyon, as the teeth are all from much smaller animals than the other sites. However, previous authors have noted the large amount of variation exhibited by this genus across the Barstovian (Barnosky *et al.*, 2007), thus Hawk Rim may only exhibit increased pheonotypic variation in response to a more closed environment.

Genus *DESMATIPPUS* Scott 1893

Referred Material: JODA 14973, lower molar; JODA 14992, tooth fragments; JODA 14996, upper molar; JODA 15025, tooth; JODA 15031, tooth; JODA 15156, upper molar fragment

Description: Like *Merychippus*, only dental material (Figure 29) could be referred definitively to this genus on the grounds of the similar size and postcranial morphology of the two larger horse genera at the site. Dental material was diagnostic in that it was considerably larger than *Archaeohippus* material, but was also low-crowned and lacked cement in the lower molars. Postcranial material could not be assigned to genus due to the similarity in size.

Discussion: Previous publications have cited the occurrence of *Parahippus* and not *Desmatippus* in the Oregon Barstovian (Downs, 1956, Shotwell, 1968, Fremd, 2010). However the material known from Oregon in the past, to which these publications referred, was referable to *Parahippus avus*, a species that has been subsequently transferred to *Desmatippus* (MacFadden, 1998). No other species of *Parahippus* have ever been recorded in the region, thus a generic assignment to *Desmatippus* in favor of *Parahippus* is consistent with the faunal record of the region.

Figure 29: *Parahippus* molars JODA 14973 on left and JODA 15025 on right

EQUIDAE *indet.*

Referred Material: JODA 14967, distal tibia; JODA 14982, tooth fragment; JODA 14985, tooth fragment; JODA 14993, astragulus and phalanx; JODA 14997, tooth fragment; JODA 15019, metapodial and tooth fragment; JODA 15021, astragulus; JODA 15022, calcaneum; JODA 15023, tooth fragments; JODA 15067, tibia fragment; JODA 15096, tooth fragment; JODA 15101, metapodial; JODA 15109, tooth fragment; JODA 15114, astragulus; JODA 15128, tooth fragment

Description: While all material was clearly equid in nature, this material was all from intermediate-sized equids. Therefore, it was impossible to determine if the postcranial material belonged to *Merychippus* or to *Desmatippus* or possibly even large specimens of *Archaeohippus*. Dental material was too fragmentary in nature to even estimate the overall size of the tooth. All astragali possessed slanted keels and the compact morphology characteristic of equids. They were within documented size variation for both merychippine- and parahippine-grade horses (Morris, 1965).

Discussion: Dental material would indicate the largest equids were generally *Merychippus* at this site. Therefore, the largest postcranial material likely belongs to this genus. However, the small sample size precludes any statistically significant analysis of mass variation in equids at the site, and size alone is poor grounds for a generic assignment.

Family RHINOCEROTIDAE Gray, 1821

Referred Material: JODA 15002, tooth fragment; JODA 15032, tooth fragment; JODA 15072, deciduous tooth; JODA 15077, tooth fragment; JODA 15083, tooth fragment; JODA 15115, tooth fragment; JODA 15120, tooth fragments; JODA 15123, tooth fragment; JODA 15146, tooth fragments

Description: It was only possible to assign dental material to the Rhinoceratidae. All dental material from rhinos has thicker enamel than any other animal found at Hawk Rim, or in the region other than Probocideans, and the presence of perpendicular banding in the enamel (Prothero, 2005). Several fragments also displayed a prominent cingulum. A nearly complete deciduous tooth (Figure 30) was identified by the wear pattern on the underside of the tooth where the roots had dissolved. Deciduous dentitions are not phylogenetically distinct between ccurrent Barstovian species.

Discussion: Both *Aphelops* and *Teleoceras* are known from the Mascall Formation

Figure 30: Rhino tooth, JODA 15072

(Fremd, 2010). However, with the highly fragmentary dental material yielded by Hawk Rim, distinguishing between these genera is impossible.

Order RODENTIA Bowdich, 1821

Family CASTORIDAE Gray, 1821

Genus *ANCHITHERIOMYS* Roger, 1885

Referred Material: JODA 15052, incisor

Description: While preserved material is limited to only a single incisor (Figure 31), the large size and crenulated enamel facilitated the identification. This genus of beaver is much larger than nearly all other contemporaneous rodent taxa. Furthermore, the crenulated enamel, with pronounced longitudinal ridges, is a trait only seen in a few taxa, with no other taxon in within several million years sharing that trait (Korth and Emry, 1997).

Figure 31: Large castorid tooth, JODA 15052

Discussion: This taxon's geographic range has been limited to primarily the Great Plains. Most known occurrences are in Nebraska, with the genus also reported from Texas, Nevada, and possibly Florida (Mors and Hubert, 2010). It is an uncommon member of all reported faunas in which it occurs. Hawk Rim represents an extension of the geographic range for the genus.

Genus *MONOSAULAX* Stirton, 1935

Referred Material: JODA 14984, molar; JODA 15030, molar; JODA 15132, molar

Description: *Monosaulax* is the only previously known beaver in the Mascall Formation (Fremd, 2010). The castorid is very small compared to other members of the family. The cheek teeth (Figure 32) are subhypsodont, unlike some later genera of the family. Overall shape of the occlusal surface is round to very slightly ovoid (Stirton, 1935). They have strongly pronounced fossettids, which tend to be oriented nearly perpendicular to the axis of the jaw (Shotwell, 1968). There are no secondary fossettids present in the teeth. All

Figure 32: *Monosaulax* tooth, JODA 15030

three individual teeth recovered are molars and do not appear to have come from the same individual, as they were collected from different strata.

Discussion: While Hawk Rim specimens differ in appearance from both *M. typicus* and *M. progressus*, which are found nearby, the level of phenotypic variability in castorids makes it difficult to assign to species. Without a much larger sample size it is impossible to determine if variation is due solely to differences in wear stages or morphological variation between individuals.

Family MYLAGAULIDAE Cope, 1881

Referred Material: JODA 15125, distal left humerus

Description: Preserved material identified as mylagaulid is limited to a single distal left humerus (Figure 33). Preservation is quite good and there is no water wear or other damage to the fossil. Consistent with a burrowing rodent, the distal portion of the humerus is broad and quite robust (Barnosky *et al.* 2007). The epicondylar process is broad and forms a winglike portion of the bone (Fagan, 1960). The entepicondylar foramen is small and situated above the medial epicondyle.

Figure 33: Mylagaulid humerus, JODA 15125

Discussion: The size and relative position of the entepicondylar foramen suggests the humerus may belong to the large *Ceratogaulus* or *Mylagaulus* known from rare occurrences in Oregon's Miocene (Calede and Hopkins, 2012). This taxon is previously known in the Mascall Formation (Fremd 2010) and also in Red Basin (Shotwell, 1968) as well as the Crooked River area (Calede and Hopkins, 2012). However, several other genera are also known from Oregon's early Barstovian, including *Alphagaulus* and *Hesperogaulus* (Calede and Hopkins 2012).

Family SCIURIDAE Gray, 1821

Genus *PROTOSPERMOPHILUS* Gazin, 1930

Referred Material: JODA 14979 calcaneum, JODA 15063 incisor and postcranial material, JODA 15148 metacarpal

Description: Most material consisted of postcranial remains (Figure 34). Identifications were made possible by comparison to modern squirrels (UO R-8398 and UO R-8394). The incisor is robust and has a cross-sectional shape typical of *Protospermophillus*, with the medial portion flatted and the lateral portion convex (Black, 1963). Furthermore, the

Figure 34: Sciurid material, JODA 15063

material is indicative of a larger animal than *Miospermophilus*, the only other comparable ground squirrel at the time.

Discussion: The Hawk Rim material is size consistent with intermediately-sized species of *Protospermophilus*, however some species overlap closely enough in size to prohibit a positive identification. The material clearly belongs to a ground squirrel, and while this is phylogenetically poorly understood, the ecology cannot be mistaken for any other sciurid lifestyle. Of the fragments included in JODA 15063 bears evidence of rodent modification prior to fossilization.

CHAPTER VI

CONCLUSION

While relatively few vertebrate fossils have been recovered from Hawk Rim, enough material has thus far been generated to facilitate ecological inferences and to allow comparisons to the faunal asembledges of other sites. The assemblage of taxa are indicative of particular paleoenvironments and, taken as a whole, describe the changing ecology of the site through the limited time span represented. Some material is collected from fluvial strata, and may have been transported. However, the amount of abrasion, or rounding, provides some indication of the distances transported. A completely rounded *Desmatippus* tooth (JODA 15156) is an example of a specimen transported for some distance. However the sharp edges of the large and fragile *Moropus* tooth (JODA 15059) are still present and thus was probably only transported a very short distance, despite its discovery in a cross bedded fluvial granule conglomerate. Many taxa, including all carnivore material, were recovered from paleosols, and therefore certainly represent the fauna present at the site during deposition of sediments and continued development of the soil.

Hawk Rim represents a rare glimpse into a Middle Miocene broadleaf deciduous forest. While analysis of the flora and climatic indicators continues, the locality would have been warm and reasonably wet with a Mediterranean climate. Many of the characteristic taxa, such as all three genera of horses and both genera of paleomerycids, only appear with the warmer climate of the Early Barstovian. The mean monthly cold temperature would have been above freezing all year, as indicated by the presence of giant land tortoises (McCord, 2012). Broadleaf forests predominated, with no recovered material of conifers from four leaf-bearing strata.

Paleotopographic indicators point to a depositional environment in a small foothill basin of the surrounding mountains, above the floodplain level often preserved in fossil sites (Behrensmeyer and Hill, 1988). The area would have been crosscut by rivers and streams and at times had lakes and ponds filling in the topographic lows cut into the Clarno Formation. Occasional volcanic events reshaped the landscape, providing fertile ash for new forests to colonize and develop into soil. Riparian and lacustrine animals, such as *Monosaulax*, *Anchitheriomys*, *Phalacrocorax*, *Clemmys*, and *Xenochelys* would indicate a habitat on the banks of rivers populated by flora such as *Alnus* and water lilies. Finally, forest dwelling browsing taxa like *Moropus*, *Rakomeryx* and the horses *Desmatippus* and *Archaeohippus* collarborate with the abundant deciduous tree fossils to support the presence of closed habitat forests. Strigid owls also would have roosted and nested in dense pockets of forest. Predators, such as *Cynarctoides acridens* and *Pseudaelurus skinneri*, would have likely stalked small prey, protected from larger predators by the forest. As a cat, *Pseudaelurus skinneri* would also have been an adept climber, capable of hunting birds and rodents in the lower levels of the canopy (Rothwell, 2003). *Merychippus*, the first truly grazing horse, would have likely gathered in meadows and along the bodies of water, where the rapidly spreading grasses were beginning in infiltrate the previously dense forests as the West dried out.

Many, but not all, of these taxa are shared with the other Oregon Early Barstovian sites. However, even between overlapping taxa, differences exist in the relative abundances as well as morphological characteristics. The type area for the Mascall

Formation is especially well known for its rich diversity of horses, with eight different genera present (Fremd, 2010). However, at virtually any other collected locality within the formation, *Merychippus* is far and away the most abundant horse genus. Hawk Rim does not follow that trend. Even with the difficulty in parsing postcrania from *Merychippus* and *Desmatippus*, *Archaeohippus* is still the most common equid. More material needs to be collected to lend statistical significance to that observation, but of material thus far collected this observation hold true. Furthermore this site provides an interesting comparison to the Red Basin fauna, where the equids are completely dominated by *Merychippus* and *Archaeohippus* had not been recorded, in spite of thousands of collected specimens. Interesting differences also arise in the comparative morphology of equids from the three sites. *Merychippus* from Hawk Rim is slightly smaller than members of the genus from the type area and significantly smaller than all material from Red Basin. Without more complete material, as well as a larger sample size, the morphological variation derived from species differences or environmentally-driven phenotypic plasticity is difficult to tease out. Morphological differences are noted in other taxa as well. The *Dromomeryx* and oreodont material from Hawk Rim is also notably smaller than that preserved at Red Basin. However one taxon does prove to be an exception. The single *Moropus* tooth from the site is larger than any other recorded sample from that genus. As this taxon is not found in the other Barstovian localities comparisons are impossible, other than noting it is larger than older samples from the John Day Formation.

Situated just after the Mid-Miocene Thermal Optimum, Hawk Rim adds to our understanding of how floral and faunal elements responded to climate change as an ecosystem, rather than as individuals. With modern anthropogenically-driven climatic change looming as an ever greater threat, this knowledge of past climate change becomes especially valuable. Data gathered from Hawk Rim will not only add to the overall regional understanding of biotic response to climate change, but illustrate why the issue is so complex and the need to address these problems on a fine scale. With different taxa and novel setting compared to other fossil localities, Hawk Rim displays the issues with lumping broad categories of ecosystem together and treating them as one system. With the high level of ecological heterogeneity currently in the region only being subdivided further by development and land use changes, the role of ecological heterogeneity in the past is all the more important. Ecosystems are not static entities, but are dynamic places being greatly impacted by climate, tectonics, and in turn altered and impacted by the biota. Hawk Rim adds to our understanding of these processes and may help to lend predictive power to models of future change.

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