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GEOLOGY AND PALEONTOLOGY OF THE UPPER JOHN DAY BEDS, JOHN DAY RIVER VALLEY, OREGON: LITHOSTRATIGRAPHIC AND BIOCHRONOLOGIC REVISION IN THE HAYSTACK VALLEY AND KIMBERLY AREAS (KIMBERLY AND MT. MISERY QUADRANGLES)

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The Rose Creek Member at the Picture Gorge 36 locality (at center right, geologist stands on basal fluvial facies) yields the youngest mammalian fauna (~18.2–18.8 Ma) in the John Day Formation's eastern subregion. Here the member is in angular unconformity above pinnacled gray Kimberly tuff and is overlain by Columbia flood basalts.

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ABSTRACT

The John Day Formation of north-central Oregon preserves a succession of speciose, superposed Oligocene through early Miocene mammalian faunas that establish the sequence of mid-Cenozoic mammalian evolution within the Pacific Northwest. Upper John Day rock units initially described by Merriam (1900, 1901) in the Kimberly and Haystack Valley areas were later divided into lower (Kimberly) and upper (Haystack Valley) members by Fisher and Rensberger (1972). We focused our study on the lithostratigraphic succession within the Haystack Valley Member. Rocks previously included in the Haystack Valley Member can be subdivided into four unconformity-bounded, genetic lithostratigraphic units that range in age from ~24 to ~18 Ma, three of the units incorporating age-diagnostic mammalian faunas.

We have identified two principal depositional units within the Haystack Valley Member of Fisher and Rensberger south of Kimberly: (1) Johnson Canyon Member—late or latest Arikareean tuffaceous siltstones and fine sandstones (~?19–22.6 Ma) with fluvial monomictic intraformational pebble gravels, well exposed along the west wall of the John Day valley; (2) Rose Creek Member—coarse polymictic welded tuff-bearing gravels, debris flows, coarse obsidian-shard tuffs, and fine-grained tuffaceous units, yielding early Hemingfordian mammals (~18.2–18.8 Ma), deposited in angular unconformity on lower units of the John Day Formation along the east wall of the John Day valley.

At Balm Creek in the type area of the Haystack Valley Member, the southern limb of the Balm Creek syncline exhibits the most complete local section of upper John Day rocks, here comprising three members: (1) a revised Haystack Valley Member made up of early late Arikareean ribbed tuffs (~23.5–23.8 Ma) with monomictic welded tuff conglomerate channels, overlain by a gray massive airfall marker tuff (GMAT); (2) Balm Creek Member—tuffaceous late Arikareean siltstones and fine sandstones interbedded with lacustrine tuffs, overlain by stacked fluvial fining-upward sequences and gray airfall tuffs; (3) Rose Creek Member—coarse polymictic welded tuff-bearing gravels, debris flows, lacustrine units, and fine-grained tuffaceous sediments, believed to correlate to the fossiliferous early Hemingfordian unit south of Kimberly.

The complexity of upper John Day rocks (evidenced by marked lithofacies variation within multiple unconformity-bounded subunits, punctuated by numerous paleosols) suggests an early Miocene depositional regime with more varied local environments and pronounced episodic sedimentation relative to the more uniform Oligocene environments documented by lower John Day strata. Whereas the lower John Day Formation consists of fine-grained volcaniclastic sediments that were deposited in basins with minimal topographic relief, the upper John Day Formation is characterized by a succession of increasingly coarse fluvial channel fills, as well as massive airfall and coarse-shard tuffs, well-developed paleosols, and relict topography. Regional compression appears to have triggered fluvial incision and valley filling from ~24 Ma to at least ~19 Ma. Extension in latest John Day times resulted in the development of half-grabens or grabens both in Haystack Valley and south of Kimberly, ensuring the preservation of upper John Day sediments. Significantly, a final episode of normal faulting appears to have immediately preceded the earliest eruption of Picture Gorge Basalt, as evidenced by flows of the Twickenham Member (PGBS) abutting against vertical fault scarps south of Kimberly. The faunas of the upper John Day units thus play a critical role in dating a complex sequence of tectonic events which preceded the onset of Columbia River Basalt Group flooding in the early Miocene.

INTRODUCTION

In north-central Oregon a sequence of volcanogenic rocks spanning the Eocene through late Miocene preserves a lengthy record of Cenozoic biotas, environments, and tectonism. The late Eocene–early Miocene John Day Formation is pivotal to that record: its richly speciose succession of faunas establishes the pattern of mid-Cenozoic mammalian evolution within the Pacific Northwest paleogeographic province. The John Day beds, due to their occurrence along a major river system, proximity to early military routes, and their fossil content, were among the first in the far western United States to be explored and described. During the 1860s and 1870s, Thomas Condon, Joseph Leidy, J.S. Newberry, O.C. Marsh, and E.D. Cope focused attention on the John Day fossil flora and fauna; the first geological publications formally describing the John Day sequence appeared at the turn of the century (Merriam, 1901; Calkins, 1902).

In the earliest geologic assessments, the John Day rocks were considered lacustrine deposits (Le Conte, 1874; Marsh, 1875). This was in keeping with the predominant theory of lacustrine origin of the Rocky Mountain basin fills in the western United States, advocated in the latter half of the 19th century by Clarence King, F.V. Hayden, N.H. Darton, and others. Merriam's (1901) work first challenged this view in Oregon, identifying much of the John Day sequence as airfall tuffs and fluvially worked tuffaceous sediments deposited on broad plains of low topographic relief. This view has been generally substantiated by more recent studies (Fisher and Rensberger, 1972; Fisher, 1967; Hay, 1963). The important pyroclastic contribution to the John Day Formation was explicitly recognized by Merriam and his students (Calkins, 1902) and in more recent petrographic analyses (Hay, 1963).

The formation consists of andesitic to dacitic tuffaceous sediments, airfall tuffs, ash flows, and lavas (Robinson et al., 1990; Robinson and Brem, 1981; Hay, 1963). The areal distribution of the formation was governed by the location of its source vents to the west and by local topography. In early John Day times, a topographic high was established along the axis of the Blue Mountain uplift (Robinson et al., 1990); this high and the Ochoco Mountains now divide the formation among three subregions: eastern, southern, and western (fig. 1). Following deposition of the John Day Formation in the eastern subregion, the area was inundated by lava flows of the Columbia River Basalt Group (CRBG).

The eastern subregion today is traversed by the north, middle, and main forks of the John Day River. The river and its tributaries have deeply dissected the basalt plateau to reveal extensive exposures of the John Day Formation along the course of the river beneath steep cliffs of the Picture Gorge Basalt. When traveling north (downstream) along the John Day River from Picture Gorge towards Kimberly (fig. 2), one is viewing an exposed cross section of the John Day Formation: in stratigraphic sequence, the Big Basin, Turtle Cove, and Kimberly Members, and younger units, disconformably capped by basalts of the Columbia River Group. This is the classic section and ''type area'' described by Merriam (1901), Fisher (1967), and Fisher and Rensberger (1972: 7), among others. The aggregate thickness of the John Day Formation in the eastern subregion approaches 750 m (Robinson et al., 1990).

In the type area the John Day strata are preserved in sculpted badland exposures that have some lateral continuity; additionally,

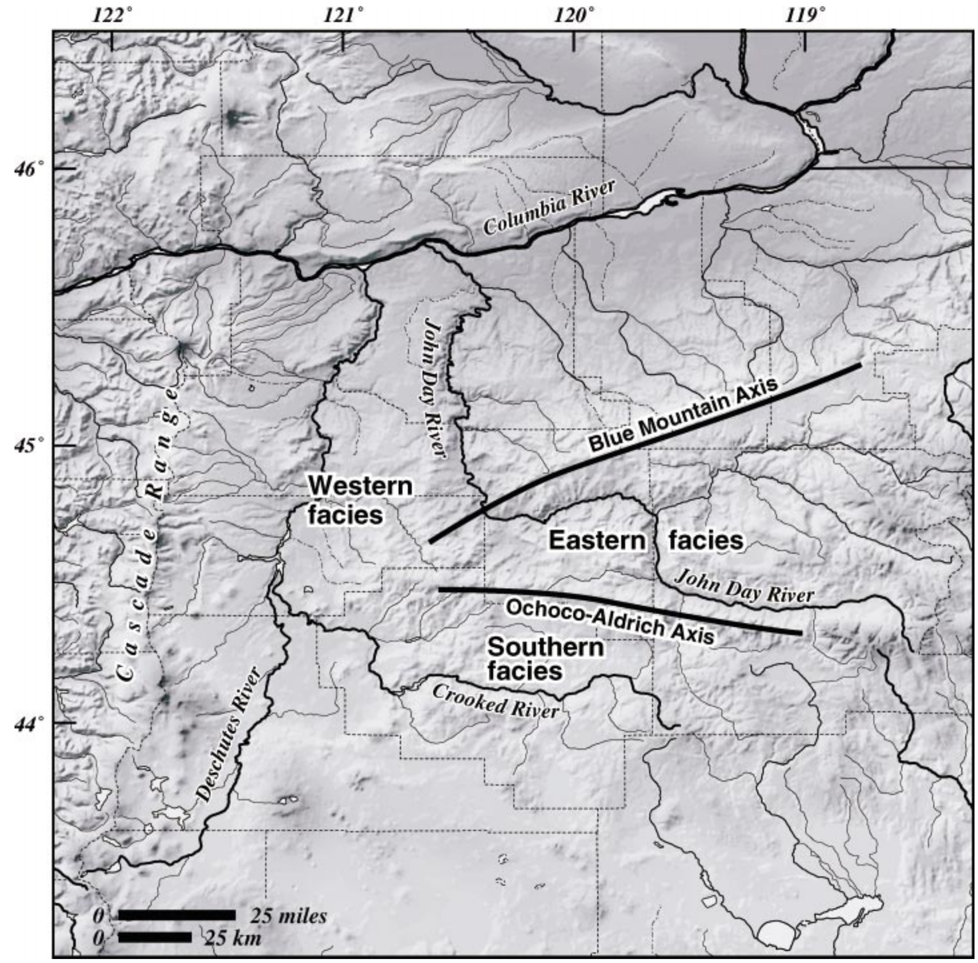


Fig. 1. The principal exposures of the John Day Formation of north-central Oregon occur along the course of the John Day River (eastern facies), Crooked River (southern facies), and Deschutes River (western facies). The eastern and southern facies have produced abundant fossil mammals that form the basis for an Oligocene and early Miocene mammalian biochronology in the Pacific Northwest. This report examines the upper John Day Formation of the eastern facies, outcropping along the John Day River, geographically situated between the Blue Mountain anticlinal uplift and the Ochoco-Aldrich Mountains axis.

conspicuous marker units such as the Blue Basin Tuff, Picture Gorge Ignimbrite, and Deep Creek Tuff correlate outcrops that are not conjoined (those on the eastern and western flanks of the river valley, for example). The lower and middle units of the formation are lithologically fairly uniform, comprised mainly of fine-grained tuffaceous sediments and airfall tuff in conformable sequence; by contrast, the upper units exhibit much greater textural and lithologic variety, as well as unconformable stratigraphic relationships. The uppermost rocks register tectonic events and episodes of stream incision and fluvial and lacustrine deposition during the last stages of John Day sedimentation prior to the outpouring of Columbia River basalts. The faunas from these rocks provide biochronologic control for dating those events.

Recent work in North America, Africa, and South America has demonstrated the importance of fine-grained pyroclastic depositional environments relative to the Cenozoic mammalian record (Pascual et al., 1985; Pickford, 1986; Hunt, 1990), particularly during the Oligocene and Miocene. Fine-grained pyroclas-

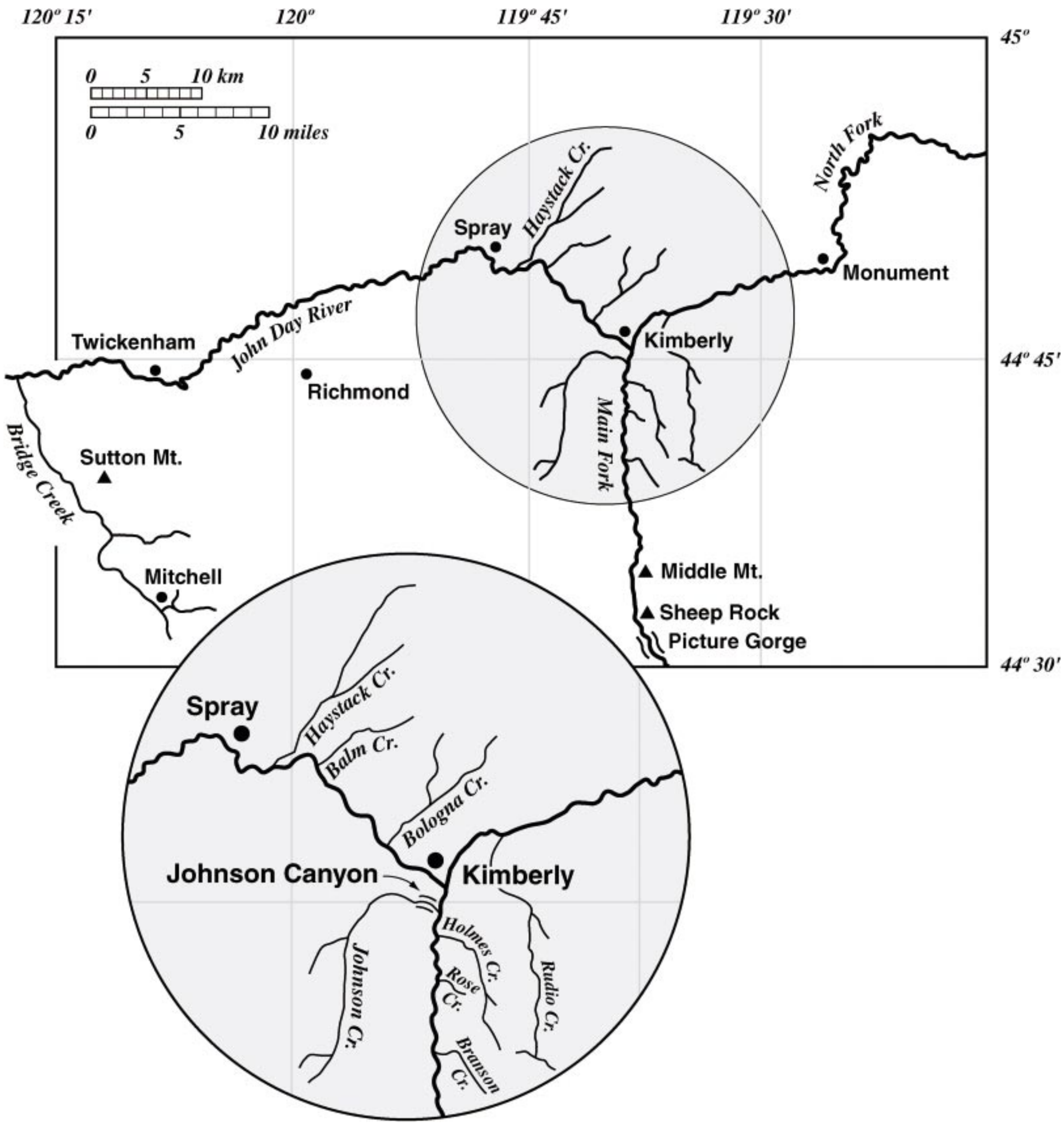


Fig. 2. Map of the John Day River valley with geographic localities discussed in this report. Our field study of upper John Day rocks was focused in the Haystack Creek-Balm Creek area in Haystack Valley east of the town of Spray; in the vicinity of Kimberly post office and for ~20 mi to the south of Kimberly along the John Day valley; and at Sutton Mountain east of Bridge Creek. The geographic area within the circle includes the classic John Day exposures studied by Merriam (1901), Hay (1963), and Fisher and Rensberger (1972).

tics blanketing large geographic areas have preserved mammalian faunas distributed across a variety of subenvironments. When regional volcanism is temporally prolonged, these volcaniclastic prisms often retain a faunal succession documenting the pattern of mammalian evolution within a major geographic province. The rift basins of East Africa, the Patagonian sequence east of the Andes, and the White River–Arikaree volcaniclastics of the North American midcontinent include thick terrestrial pyroclastic sequences, commonly reworked by fluvial, eolian, and lacustrine processes, that contain abundant mammal remains. The John Day Formation represents an additional example of an Oligo-Miocene faunal succession preserved in fine-grained pyroclastic sediments, in this instance in association with a convergent continental margin.

Our purpose in this investigation was to examine the sediments of the upper part of the John Day Formation, which have never been studied in detail, in order to interpret the lithostratigraphy, depositional environments, and biochronology of their fossil mammals, and to compare these findings with our earlier results from the North American midcontinent (Hunt, 1985, 1990).

GEOLOGY OF THE JOHN DAY BEDS: PREVIOUS WORK

As described in earlier studies (Calkins, 1902; Hay, 1963; Fisher and Rensberger, 1972, Robinson et al., 1990), the John Day Formation is a widely distributed sequence of pyroclastic sediments and flows. In most areas, it is lithologically distinct from the andesitic and basaltic rocks of the underlying Eocene Clarno Formation. The John Day sequence owes its existence to andesitic-dacitic and rhyolitic eruptions from vents in the Cascade range and its eastern outliers (Robinson et al., 1990). The formation is lithologically and texturally very uniform in its lower and middle parts; the higher units much less so.

The task of segregating the formation into mappable subunits was first attempted by J.C. Merriam (1900, 1901) who advocated a threefold division of the John Day ''series'' within its eastern subregion (fig. 3). At the base of the series, overlying deeply weathered and eroded flows, tuffs, lahars, and breccias of the Clarno Formation, are dark red tuffaceous claystones which comprise Merriam's lowest unit. These are conformably overlain by drab to bluish-green tuffaceous claystones and siltstones: a ''middle division''. The ''lower'' and ''middle'' divisions are chiefly fine-grained tuffaceous air-fall sediment that weathered on land surfaces; numerous paleosol horizons are indicated by rhizoliths, burrows, and other invertebrate traces. These rocks show almost no evidence of fluvial incision and lack deposits of coarse detritus, but were reworked by sheet floods and slope wash in some areas. Merriam also recognized an ''upper division'' of light-toned or buff-colored tuffaceous sediments with a significant fluviatile component, including coarse sands and gravels.

R.L. Hay (1963) called attention to the role of diagenesis, and especially zeolitization, in modifying the fine-grained tuffaceous sediments of the formation. Air-fall sediment had accumulated incrementally, for the most part, and weathered to montmorillonite at the land surface before burial (Hay, 1962, 1963; Fisher, 1964, 1966a, 1968). A subtropical to warm temperate climate supplied sufficient rainfall for subsurface fluid migration through the ash-rich deposits. Subsequently, ground water infiltrating the sediments at moderate depth promoted the precipitation of the zeolite clinoptilolite as a pseudomorph in cavities from which glass shards had been dissolved. In both Merriam's ''lower'' and ''middle'' divisions, glass was almost entirely replaced by zeolite and/or clay; an evident distinction between these two divisions was the occurrence of kaolinite and ferric iron oxides in the lower unit, lending a distinct reddish-maroon hue. The predominantly gray to yellow-gray tuffaceous sediments of Merriam's ''upper division'' lacked a zeolitic signature and remained in a relatively fresh, unaltered state (Hay, 1963).

At Sutton Mountain north of the town of Mitchell (fig. 2), Hay determined that the boundary between the zeolitized and nonzeolitized units was diachronous. By employing a geographically widespread rhyolitic ash flow (Picture Gorge Ignimbrite) as a synchronous horizon, he observed that the zeolitization boundary variably occurred above, below, and within the ignimbrite. Preferring to differentiate rock units by a strict lithochronologic scheme, Hay (1963) divided the formation into three members, with the lowest including all rocks that predated the ignimbrite, the second comprising the ignimbrite itself, and the third including all rocks that postdated the ignimbrite (fig. 3).

During the 1960s, geologist R.V. Fisher and paleontologist J.M. Rensberger initiated lithostratigraphic and biostratigraphic studies of the John Day Formation that included Merriam's type area of the formation from Picture Gorge north to Kimberly along the

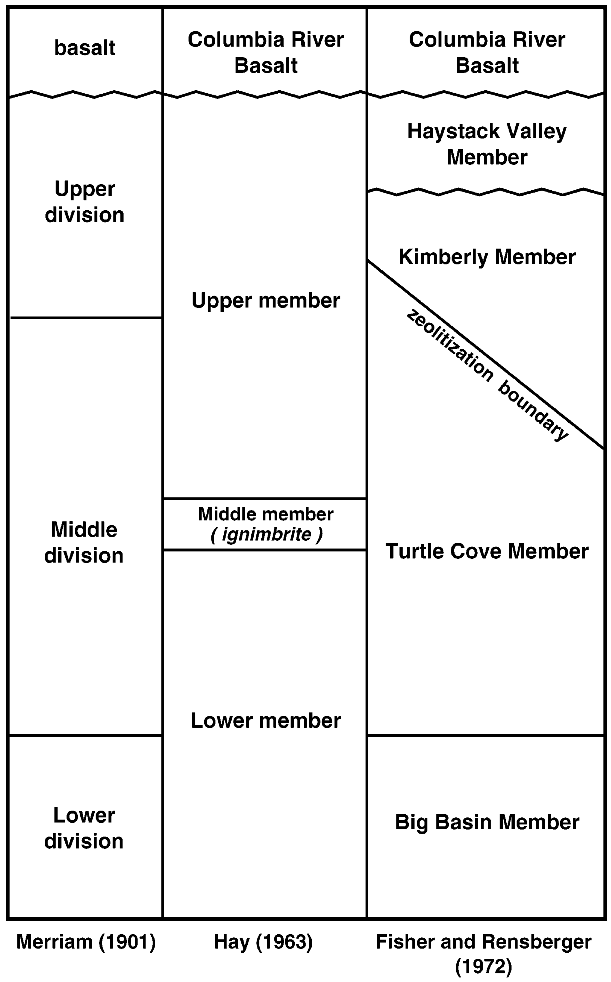


Fig. 3. Stratigraphic nomenclature applied in previous studies to Oligocene and early Miocene rocks of the John Day Formation in the eastern subregion. The ignimbrite of Hay (1963) occurs within the Turtle Cove Member of Fisher and Rensberger (1972), who recognized its importance as a regional marker unit within the John Day Formation.

John Day River (Fisher and Rensberger, 1972: 7), continuing northwest to Haystack Valley. The abundant fossil mammals, varied lithofacies (particularly in the upper units), and numerous marker tuffs in stratigraphic sequence presented suitable conditions for extracting a detailed geologic and faunal history from these rocks.

Fisher and Rensberger (1972) believed that the diagenetic boundary between zeolitized and unzeolitized rocks in the type area of the formation was a diachronous stratigraphic horizon, as Hay had demonstrated in the Mitchell area. Their conclusion rested heavily on the identification of a nonzeolitized coarse-shard tuff on Rudio Creek as the correlative of the zeolitized Deep Creek Tuff south of Kimberly, supported by coeval rodent assemblages found in proximity to both tuffs (Fisher and Rensberger, 1972: 14–15; Rensberger, 1983: 50–51, fig. 20). Also, they noted that while zeolitization was usually restricted to the lower units, in one instance 200 ft (61 m) of upper John Day rocks in the Balm Creek valley were zeolitized (secs. 33–34, T8S, R25E).

Thus, one had to be cognizant of the control that topographic position of strata had exerted over diagenesis, and to be alert to whether deformation (if any) had preceded or postdated diagenesis. Zeolitization boundaries were apt to be diachronous where folding or faulting preceded chemical alteration. Conversely, such boundaries could approximate synchronous horizons in local areas where diagenesis preceded deformation of essentially horizontally stratified beds. Rensberger (1971: 9) emphasized that, in the formation's type area, fossils suggested that the boundary between his middle and upper divisions ''more closely approximates a time plane'' than in the Mitchell area studied by Hay (1963).

Working with the classic John Day sequence between Middle Mountain and Kimberly, Fisher and Rensberger opted to retain Merriam's lower and middle ''divisions''. Named the Big Basin and Turtle Cove Members, respectively, these units are lithologically similar but readily distinguishable—in this area—in terms of color and surface expression (fig. 3).

The zeolitization boundary defined the base of Fisher and Rensberger's next youngest unit, the Kimberly Member. Hence, there is a transitional and ''stratigraphically variable'' contact between it and the Turtle Cove Member below. The Kimberly Member is a thick sequence (in aggregate, reported as 900 ft by Fisher but locally, south of Kimberly, 200–300 ft) of unzeolitized, gray volcaniclastic sediments conformably overlying the green or gray-green, zeolitized tuffs of the Turtle Cove Member. This unit is recognizable in outcrops distributed along the John Day River from approximately 4 mi south of Middle Mountain northward to Kimberly, then northwest to the Richmond Fault south of Balm Creek; it is also well-exposed along the North Fork of the John Day River east of Kimberly, and in the valley of Rudio Creek. The Kimberly Member is, in some places, unconformably overlain by younger John Day sediments, and elsewhere by basalts of the Columbia River Group.

The youngest unit formally named by Fisher and Rensberger (1972) is the Haystack Valley Member. In most areas (excepting the basin margin, for example) the member included all sediments sandwiched between the Kimberly Member (where present) and the capping Columbia River Group basalts. The Balm Creek drainage southeast of Haystack Valley is the implied type locality (Fisher and Rensberger, 1972: 17). Here the contact of the Haystack Valley Member with underlying rocks was not clearly indicated; the member—as defined by Fisher and Rensberger—begins with zeolitized well-indurated pale green to buff tuffs that include numerous local channel fills with lenses of fluvial sandstones and welded tuff conglomerate, and continues upward with a sequence of light gray or buff, nonzeolitized, massive air-fall tuffs and fluvial tuffaceous gray to greenish and pale yellow-gray sandstones and siltstones with some lacustrine units.

The Haystack Valley Member was also recognized along the east wall of the John Day valley south of Kimberly, where ''the distinctive welded-tuff-bearing conglomerate clearly overlaps all earlier members'', and is accompanied by fluvial tuffaceous sediments, air-fall tuffs, and paleosols similar to those in Haystack Valley (Fisher and Rensberger, 1972: 18). Significantly, Fisher and Rensberger noted that the conglomerates were found ''almost exclusively in the lower third of the member'', and concluded that the welded tuff conglomerate in the lower part of the Balm Creek section and the conglomerate at the base of the member south of Kimberly along the east wall of the John Day valley were correlatives, and approximately synchronous. We have learned in our investigation that such an assumption was mistaken; a clue hinting at this was Fisher and Rensberger's observation that the lower ~200 ft of the member in the Balm Creek drainage was zeolitized, but that the member south of Kimberly was not. In fact, we shall show that the zeolitized and nonzeolitized parts of the ''Haystack Valley Member'' prove to be of markedly different chronologic ages.

Fisher and Rensberger (1972: 21) also reported the existence in the Kimberly Quadrangle of rare outcrops (≤20 ft thick) of a post-John Day rock unit beneath the Columbia basalts. The unit was more common in the adjacent Monument Quadrangle outside their map area, where it comprised fluvial sandstones, pebble gravel, and lacustrine beds. The sandstone is made up of basaltic grains and lapilli and overlies the gray tuffs of the Kimberly Member. These sediments were interpreted as epiclastic debris derived from the earliest basalt flows entering the region, admixed with tuffaceous sediments eroded from subjacent upper John Day units. Organic material was noted in lacustrine beds, and a flora of Miocene age (J.A. Wolfe in Fisher and Rensberger, 1972: 21–22) included oak, maple, birch, elm, *Zelkova*, and *Sophora* (pagoda tree). The chronologic relationship of this ''post-John Day'' unit to the Haystack Valley Member was not investigated during our field study.

THE ''UPPER'' JOHN DAY BEDS: EARLIER CONCEPTS— SHIFTING PERCEPTIONS

Recognition of an upper part or ''division'' of the John Day ''Series'' first appears in Merriam's (1900, 1901) pioneering work. These upper beds included, in Merriam's words, ''typical products of erosion'' relative to the predominantly airfall origin of the tuffaceous lower units, and his remarks document his awareness of fluvially reworked pyroclastics together with conglomerate lenses in the upper beds. According to Merriam (1901: 291), in Haystack Valley, and in the vicinity of Spray, and south of Kimberly (i.e., ''the lower end of Turtle Cove''), ''good exposures show the highest portion of the series to be composed of one or two hundred feet of hard, blocky tuff, below which is about the same thickness of sand and gravel. The gravels are in some places quite coarse, containing pebbles four or five inches in diameter. The sands sometimes show cross-bedding. Included in these deposits are worn fragments of bones and teeth . . . .'' In fact he stated that the upper division contained the ''only typical sands and gravels in the John Day'' and produced many fossils (Merriam, 1900). His only photograph of beds assigned to the upper division shows conglomerate lenses and sandstones in Haystack Valley (Merriam, 1901: pl. 8, fig.1); these conglomerate bodies are made up of the welded tuff clasts employed by Fisher and Rensberger (1972) in defining their Haystack Valley Member.

Exposures of the upper John Day ''division'' were reported by Merriam (1901) along the John Day River from Haystack Valley eastward to Kimberly and the town of Monument, as well as south of Kimberly (Turtle Cove of Merriam, 1901: pl. 6) where important outcrops occur along the valley margins beneath the thick series of Columbia basalt flows. These exposures in most cases are visible and accessible from highways paralleling the river and have figured significantly in a number of later studies (Fisher and Wilcox, 1960; Wilcox and Fisher, 1966; Fisher and Rensberger, 1972). Additional outcrops attributed to the upper division by Merriam were found to the north at Fossil and Lone Rock, to the east along the Middle Fork of the John Day River, and along Bridge Creek at Sutton Mountain (Merriam, 1901: 298).

The upper beds of the John Day Formation are difficult to study for reasons explicitly mentioned by Merriam (1901): (1) the John Day Formation in the eastern subregion was structurally disturbed, folded, and faulted prior to deposition of the Columbia flood basalts; (2) following tectonic deformation, the John Day beds were subjected to extensive erosion. These erosional episodes, superimposed on the previously folded and faulted strata, produced broad topographic lows that later filled with the Columbia basaltic lavas. Consequently, (3) beds of the upper division may be separated by considerable distances from adjacent correlative strata by the intervening basalts, complicating the lateral tracing and lithostratigraphic correlation of outcrops. To determine age equivalence of geographically disjunct outcrops of the upper John Day beds, biocorrelation using fossil mammals has been and remains an important tool, and it offers considerable potential for the development of a refined regional biochronology.

Whereas Hay's (1963) investigation of low-temperature diagenesis of the John Day tuffs identified zeolitization as a key element in the early postdepositional history of these rocks, it left open the question of the lithostratigraphic succession in the upper part of the formation which, in the Sutton Mountain area, included 1300–1700 ft of tuffaceous sediments above the Picture Gorge marker ignimbrite. A significant amount of time is represented by John Day rocks above the ignimbrite, demonstrated by the great thickness of fine-grained tuffaceous sediments, by fossil mammals, and by an impressive paleosol succession found throughout the upper part of the formation at Sutton Mountain. In addition, Hay's (1963) study, focused in the Mitchell-Sutton Mountain area, did not discuss the lithostratigraphy of Merriam's ''upper John Day division'' in the type area south of Kimberly, or in Haystack Valley.

In contrast to Hay's concept, Merriam's (1901) descriptions of upper John Day rocks in the type area did not include all sediments above the Picture Gorge ignimbrite in his ''upper division''. Merriam emphasized that the upper part of the formation was characterized by sands, gravels, and by buff tuffaceous fine-grained beds several hundred feet thick, but he did not recognize a precise lower boundary. Merriam and Sinclair (1907) later provided a more explicit statement: ''No sharp stratigraphic line can be drawn between the Middle and Upper John Day, the color of the beds usually serving for their discrimination in the field. Faunally, the dividing line between them may be fixed by the downward range of *Promerycochoerus* which is not known to occur in the Middle John Day. This limit is for the present regarded as lying about 100 feet above a prominent stratum of coarse gray tuff [Deep Creek Tuff of Fisher, 1962] exposed quite generally near the top of the Middle John Day in Turtle Cove, where, by differential weathering, it usually forms a terrace.'' Fisher and Rensberger (1972: fig. 6) later reported that the range of the oreodont *Promerycochoerus* extended downward to the Deep Creek Tuff.

Merriam (1901) did not identify lithostratigraphic subdivisions within his ''upper John Day series''. However, he recognized its composite nature and was aware that the uppermost rocks of the ''upper division'' might contain a unique and distinctive mammal assemblage. The discovery of a tapir (Sinclair, 1901), the rodent *Mylagaulodon* (Sinclair, 1903), and small camels in the ''uppermost beds of the Upper John Day'' in the Johnson Canyon area prompted Merriam and Sinclair (1907: 184) to suggest that ''the sands, gravels and tuffs at the top of the Upper John Day may represent a third faunal subdivision.'' These rocks were ''typically exposed on Johnson and Bologna Creeks, on Bridge Creek, and in the upper end of Haystack Valley, and are characterized by numerous remains of [the camel] . . . *Paratylopus*.''

The lithostratigraphy for the upper John Day beds developed by R.V. Fisher (Fisher, 1967; Fisher and Rensberger, 1972), in conjunction with Rensberger's biostratigraphy, identified two members in the type area of Merriam, cropping out from Haystack Valley eastward to Kimberly and Rudio Creek, and south along the John Day River to Picture Gorge. The Kimberly and Haystack Valley Members of Fisher and Rensberger (1972) were mapped together as a single unit in the Kimberly and Picture Gorge quadrangles where they focused their study, but were defined and described separately in their text (Fisher and Rensberger, 1972: 15–19). The two units did not exactly correspond to Merriam's concept of the ''upper division''. Merriam and Sinclair (1907), who placed the upper boundary of the ''middle division'' at ~100 ft above the Deep Creek Tuff, included in their ''upper division'' the uppermost part of the Turtle Cove Member of Fisher and Rensberger.

In our assessment of the rocks and faunas of the upper John Day, we focused our study on the classic exposures of Merriam in Haystack Valley and in the vicinity of Kimberly (fig. 2) that also served as the lithologic basis for the members of Fisher and Rensberger. The detailed geologic and faunal relationships within this geographic area have an important bearing on the concept of ''upper John Day'' in the region. We have examined these rocks in somewhat greater detail than evidenced in previous investigations, and provide measured sections of the key exposures that define the members.

In our study of the upper John Day beds we first discuss the lithostratigraphic succession at specific localities in the ''type area'' where Merriam, Fisher, and Rensberger established a local lithostratigraphy. We next review the earlier fossil collections from these units, and supplement them with newly discovered specimens from our fieldwork in 1992–2001. This enabled us to establish biochronologic relationships between isolated sections. Mammalian fossils from the upper John Day units recognized in this report provide the first reliable biochronological framework for the upper part of the formation.

LITHOSTRATIGRAPHY OF THE UPPER JOHN DAY FORMATION

The work of Fisher and Rensberger (1972) provides the most thorough assessment of the upper beds and their mammalian faunas (Rensberger, 1971, 1973, 1983). Fisher's work (1967) on regional structure, together with the 1972 study, formed a basis for our initial geologic work in the Haystack Valley and Kimberly areas. Fisher and Rensberger clarified and refined Merriam's (1901) earlier observations, recognizing two lithostratigraphic units in the upper part of the formation, the Kimberly and Haystack Valley Members.

Kimberly and Haystack Valley Members

Kimberly Member: The Kimberly Member was defined by Fisher and Rensberger (1972: 15) as gray, yellow-gray, pale greenish-gray, and buff tuffs well exposed near the Kimberly post office. Reported to be ~900 ft in composite maximum thickness, its lower boundary was determined by zeolitization and hence was considered by them to be diachronous on a regional scale. However, in the type area of the member, they noted that the zeolitization boundary and the regional dip of the contact between the Kimberly and Turtle Cove members is nearly coincident so that locally the boundary may be approximately synchronous. Our examination of the contact in the type area of the member south of Kimberly demonstrated that the lithology of the tuffaceous claystones above and below the boundary is identical with the exception of zeolitic alteration. Nor is there any evidence of unconformity or other pause in deposition at this horizon. On the basis of these lithologic observations it would be reasonable to predict faunal continuity across the boundary: Rensberger's (1971, 1973, 1983) rodent zonation for these sediments suggests this is in fact the case.

The upper boundary of the Kimberly Member is an erosional surface at many localities. The upper part of the formation was removed by downcutting accompanying tectonic deformation during late John Day time. Along the west wall of the John Day valley south of Kimberly (secs. 14, 23, 26, T10S, R25E) the eroded surface of the Kimberly Member is overlain by the Columbia basalts. However, if the member is traced northward along the west wall of the valley, a prominent calcareous paleosol appears at the top of the unit (well exposed in SE¼, NW¼, SW¼, NE¼, sec. 12, T10S, R25E) that probably represents an uneroded remnant of the terminal Kimberly Member surface.

At other locations south of Kimberly, higher stratigraphic units fill an irregular topography developed on the surface of the Kimberly Member (Fisher, 1967). These are the sands, gravels, and tuffs of Merriam. Fisher mapped these higher beds together with the rocks of the Kimberly Member as a single map unit (Fisher and Rensberger, 1972: Maps 2, 3, *Tjkh*), but in his text he recognized the higher beds as a distinct stratigraphic unit, the Haystack Valley Member (Fisher and Rensberger, 1972: 17). This reflected Fisher's assumption that these sands and gravels correlated with coarse fluvial sediments in the Balm Creek area of Haystack Valley, as described below.

Our examination of rocks referred by Fisher to the Kimberly Member was centered on the principal exposures of the unit: the type area near Kimberly, the northern Rudio Creek drainage, and along the John Day river from Haystack Valley to Kimberly. Rocks of the Kimberly Member in the type area are uniformly gray tuffaceous sediments, predominantly siltstones, sandstones, and less frequent intraformational conglomerate, with a distinctive obsidian-shard tuff near the base of the Rudio Creek section, considered by Fisher and Rensberger (1972: 14–15) as a possible equivalent of the Deep Creek Tuff. These tuffaceous sediments display primary sedimentary structures and incised channel fills indicating local fluvial reworking together with interbedded airfall units. Burrows and rhizoliths are common at many levels, demonstrating a succession of paleosols suggestive of a gradual, episodic pattern of sediment accumulation through periodic ashfall events. The sediments within channels suggest both rapid deposition of volcaniclastic debris in intense flood events as well as more prolonged periods of channel filling and winnowing that yielded uniformly well-sorted sediments. In the Rudio Creek area, a fluvial channel within the Kimberly Member (NW¼, NE¼, NE¼, sec. 27, T9S, R26E) is incised into tuffaceous gray siltstones and is filled with poorly sorted, locally derived, tuff-pebble conglomerate interbedded with fluvial tuffaceous sandstones and diatomite. These sediments were rapidly deposited with little winnowing. Fossils in these channels include larger unabraded skeletal elements of mammals, indicating minimal transport and rapid burial. On the other hand, incised channel fills situated within the member in its type area south of Kimberly contain well-sorted, clast-supported, tuff-pebble conglomerates filling the base of channel scours. The good clast sorting and rounding and the presence of only well-abraded fragments of mammal bone within these conglomerates demonstrate more prolonged fluvial processing of the channel sediments.

We did not find the Kimberly Member to be particularly fossiliferous, although occasional specimens occur in many outcrops. Much of the bone from coarse sandstones and conglomerate bodies is fragmented and strongly abraded, indicating fluvial processing. Mammal remains in the siltstones and sandstones tend to range from partially articulated limb segments to isolated teeth, mandibles, and limb elements. Complete skeletons are uncommon and we encountered none during our work. The condition of the skeletal material indicates that carcasses decayed, were scavenged, and in some instances the remnants were buried by ashfalls or by fluvial reworking of tuffaceous sediments, possibly during rainfall events following volcanic eruptions.

Gray unzeolitized tuffaceous sediments of the Kimberly Member cropping out in the type area south of Kimberly can be traced eastward into the Rudio Creek drainage and northwestward along the John Day valley from Kimberly nearly to Haystack Valley. Typical gray Kimberly Member tuffs when traced northwest from Kimberly terminate at the projected trace of the Richmond Fault along the east margin of the Balm Creek valley (Fisher and Rensberger, 1972: Map 3, E½, sec. 34, T8S, R25E). Kimberly Member gray tuffs occur in the upper part of outcrops southeast of the fault on the upthrown block in sec. 34; sections on the downthrown block north of the fault in Balm Creek valley contain unzeolitized gray cliff-forming tuffs that we regard as much younger in age. In apparent agreement with Rensberger (1983: 29), we recognize these gray tuffs in the Haystack Valley-Balm Creek area as part of the Haystack Valley Member, as revised in this study.

Fisher and Rensberger (1972: 17) did suggest that rocks *age-equivalent* to the Kimberly Member (along Rudio Creek) are represented by a zeolitized section of green beds in Haystack Valley at UCMP locality Haystack 1. This age-equivalence was said to be demonstrated by the common occurrence of similar species of entoptychine rodents (Rensberger, 1983: 29).[1]

HAYSTACK VALLEY MEMBER: This member was named by Fisher and Rensberger (1972: 17) for mostly unzeolitized fluvial and lacustrine tuffaceous sediments, including airfall tuffs, interbedded with coarse sandstone and conglomerate in the Haystack and Balm Creek valleys, and along the east wall of the John Day valley south of Kimberly. In actual practice, Fisher's concept placed all John Day rocks that incorporated welded tuff-bearing conglomerates in the Haystack Valley Member. Such rocks are typically separated from

[1] The exact geographic location of outcrops of gray Kimberly Member tuffs in the Haystack Valley was not specified by Fisher and Rensberger (1972), resulting in some confusion as to their situation. Rensberger (1973: 91) reported gray unzeolitized rocks of the Kimberly Member overlying greenish zeolitized claystones of the Turtle Cove Member at UCMP locality Haystack 1, but the thickness of the Kimberly Member was not given: however, the thickness (~140 ft) can be determined from their section 11, which we believe includes the exposures at Haystack 1. Later, Rensberger (1983: 29) reconsidered the assignment of these gray tuffs to the Kimberly Member, regarding them as part of their Haystack Valley Member. We agree and include them in our revised Haystack Valley Member.

Fisher and Rensberger (1972: fig. 3), however, show ~200 ft of Kimberly Member in their section 10 at Balm Creek (NE¼, sec. 33, T8S, R25E). Their placement of this thick 200-ft interval in the Kimberly Member in section 10 seemingly conflicts with an earlier remark that the member was quite thin in the Haystack Valley area in secs. 33–34, T8S, R25E where section 10 is located (Fisher and Rensberger, 1972: 17). The 200 ft of Kimberly beds shown in section 10 apparently refer to green zeolitized beds along Balm Creek (E½, sec. 33, T8S, R25E) that correspond to the lowest ~160 ft of our Asher Section (fig. 4), and which elsewhere in this same paper are considered to be the lower part of the Haystack Valley Member by Fisher and Rensberger (1972: 17). Thus, the 200 ft of Kimberly Member shown in section 10 appears to be a *lapsus calami*, and in fact belong to their Haystack Valley Member, an assignment with which we concur.

the Kimberly Member by erosional unconformity south of Kimberly along the east wall of the John Day valley and include fluvially reworked tuffaceous sediments of all textural grades from clay to gravel.

Fisher and Rensberger (1972: 17) frequently refer to ''welded-tuff-bearing conglomerate at the base of the Haystack Valley Member . . . ''. Their generalized regional stratigraphic section depicts the conglomerate as the basal unit within the member (Fisher and Rensberger, 1972: fig.1), separated by erosional unconformity from the Kimberly Member below. Indeed, two of their measured sections (Fisher and Rensberger, 1972: fig. 3, nos. 5 and 8) south of Kimberly show a welded tuff conglomerate as the basal unit of the Haystack Valley Member. However, their principal measured section for Haystack Valley (Fisher and Rensberger, 1972: fig. 3, no. 10), sited at Balm Creek, shows the welded tuff conglomerate as a single horizon ~100 ft above the base of the unit. This placement also appears in the composite lithostratigraphic column for the Kimberly and Picture Gorge quadrangles (Fisher and Rensberger, 1972: fig. 3). We became interested in the stratigraphic occurrence of welded tuff conglomerates when we encountered them at multiple levels at Balm Creek, including one prominent bed quite high in the local section. This contrasted with the member south of Kimberly along the east wall of the John Day valley where, as indicated by Fisher and Rensberger, the welded tuff conglomerate nearly always occurs at a single stratigraphic horizon at the base of the unit.

Comparing the mammalian faunas from the two areas (Balm Creek and the east wall of the John Day valley south of Kimberly) clarified the situation. The Haystack Valley Member rocks at Balm Creek carried a different and much older fauna (appendices 1-1 to 1-7) than that found in the conglomerate unit south of Kimberly (appendices 1-12 to 1-15). Although both stratigraphic units had been included in the Haystack Valley Member, they proved to be of significantly different ages. We thus became aware that welded tuff conglomerates occurred over a considerable time interval in the upper John Day beds.

These observations led us to study the lithostratigraphy, the distribution of fossil mammals, and the clast composition of the conglomerates in more detail in the two principal geographic areas mapped by Fisher and Rensberger (1972): (1) Haystack Valley, and (2) south of Kimberly along the John Day valley. We discovered that, based on the contained mammal faunas and lithostratigraphic relations, several stratigraphic units of different ages were included within the Haystack Valley Member, and could be discriminated on superpositional relations, bounding unconformities, lithofacies, and faunal content. In addition, the conglomerates in these units differed in both clast composition and size in a predictable manner (table 1). Three regionally significant unconformities of early Miocene age (EMU) are recognized in the study, and are indicated in our measured sections, from older to younger, as EMU_1, EMU_2, and EMU_3.

We describe these units first in the Haystack Valley-Balm Creek area, then from exposures along the east and west walls of the John Day valley south of Kimberly.

Balm Creek Syncline

The thickest section of Fisher and Rensberger's Haystack Valley Member occurs along Balm Creek (fig. 2), a small drainage that enters the John Day River about 1.5 mi (2.4 km) southeast of Haystack Creek. This is the locale for their section 10, ~730 ft thick, which was measured in the NE¼, sec. 33 and SE¼, sec. 28, T8S, R25E, Kimberly 7.5-min. quadrangle.[2] The Balm Creek section is represented by badland and cliff exposures along the southern limb of a syncline that forms a topographic high between Haystack Creek and Balm Creek. We have designated this the Balm Creek syncline, noting that it was recognized and mapped by Fisher as a northeast-to-east-trending fold (Fisher and Rensberger, 1972: Map 3, secs. 26–28, T8S, R25E).

[2] Stratigraphic sections in this report show thickness of rock units in both English and metric systems. Elevations are expressed in feet so that future investigators can more easily and accurately locate particular stratigraphic levels on 1:24,000 7.5-minute topographic quadrangle maps of the U. S. Geological Survey. Earlier geologic and faunal studies of the John Day Formation are severely limited in their usefulness by the lack of detailed measured sections tied to geographic locations and topographic elevations, hence the inability of later workers to relocate faunal sites and marker beds in local stratigraphic sections.

TABLE 1

Intermediate Diameter (I.D., in centimeters), 10 Largest Clasts, from Conglomerates of the Upper John Day Formation, Wheeler and Grant Counties, Oregon

	Clast Type								
Locality	Welded Tuff[a]	Rhyolitic/ Dacitic Volc[b]	Obsidian Shard Tuff[c]	Gray Lapilli Tuff[d]	Deep Creek Tuff	Clarno Andesite/ Basalt	Mean I.D.	1SD	SEM
ROSE CREEK MEMBER									
East Wall, John Day Valley South of Kimberly									
Foree South	8	2	0	0	p[f]	0	18.2	4.52	1.43
Ancient Juniper[e]	6	4	p	0	0	0	14.5	3.38	1.07
Branson Creek	8	1	p	?	1	0	14.8	4.99	1.58
Breck North[e]	7	p	1	p	2	0	9.9	2.36	0.75
Caesar's Tomb	10	p	p	p	p	0	13.1	2.40	0.76
Picture Gorge 36	10	0	p	p	0	0	10.9	2.30	0.77
Picture Gorge 36 ND	10	0	p	p	p	0	13.7	4.52	1.43
Rose Creek South	10	p	p	p	p	0	14.9	2.52	0.80
Rose Creek N 2595 ft	7	1	1	1	0	0	12.3	1.91	0.60
Rose Creek N 2560 ft[g]	6	1	1	p	2	0	15.4	6.62	2.09
Fossil Wood Spring	7	p	3	p	p	0	7.1	1.19	0.38
Spring Creek	5	4	1	p	0	0	10.0	4.13	1.31
North Fork, John Day Valley East of Kimberly									
Lone Pine	10	p	0	0	?	0	11.4	1.86	0.59
Balm Creek Syncline									
Beardog 520 ft	p	10	0	p	?	0	7.5	1.57	0.50
Beardog 470 ft	10	p	0	p	0	0	10.0	2.01	0.64
Upper Balm Creek	5	5	0	p	0	0	10.0	1.12	0.36
HS-1 2770–2780 ft	10	?	0	?	0	0	9.3	2.10	0.66
Sutton Mountain									
Hay Loc. 7	6	p	0	p	0	4	12.4	2.04	0.65
NW Hay Loc. 7									
2995–2997 ft	2	0	0	2	0	6	10.7	3.51	1.11
2951–2953 ft	2	1	0	0	0	7	8.7	1.51	0.48
2921–2925 ft	1	0	0	0	0	9	14.3	3.55	1.12
2881–2882 ft	p	1	1	3	0	6	5.8	1.48	0.47
Boulder Cgl	2	0	0	0	0	8	18.9	3.88	1.23
JOHNSON CANYON MEMBER									
Johnson Canyon	All clasts are intraformational vitric tuff pebbles						6.2[h]	1.20[h]	0.38[h]
HAYSTACK VALLEY MEMBER (REVISED)									
Crazy Woman Knob	10	0	0	0	0	0	4.5	0.64	0.20
Asher	10	0	0	0	0	0	4.7	0.69	0.22

[a] Olive-brown devitrified densely welded tuff with dark pumice fiamme.

[b] Greenish-gray, pale yellow or red rhyolitic/dacitic welded tuff with small euhedral or broken quartz and feldspar phenocrysts and without dark pumice fiamme.

[c] Gray to dark gray coarse obsidian-shard tuff (vitreous or microcrystalline) with buff to white pumice lapilli.

[d] Gray devitrified lapilli tuff with brown vitric welded tuff inclusions.

[e] Clast sample taken from debris flow.

[f] Present but not included in 10 largest clasts.

[g] Sample contains both dark gray welded obsidian shard tuff pebbles from the Picture Gorge ignimbrite and the uncompacted buff air-fall obsidian shard tuff pebbles derived from the Johnson Canyon Member. Some pebbles from the Rose Creek North conglomerate show the transition from densely welded brown tuff to black obsidian-like glass described by Fisher (1966: 13) and Ross and Smith (1960: 24).

[h] Data from coarsest conglomerate body in Johnson Canyon Member - all other conglomerate lenses in the member have lower mean values (maximum observed I. D. of an individual clast, 9–10 cm).

NOTES: **(1)** SD = standard deviation, SEM = standard error of the mean. **(2)** The Picture Gorge ignimbrite is represented by four clast types listed above (welded tuff, rhyolitic/dacitic volcanics, obsidian-shard tuff, gray lapilli tuff) that can be recognized in the polymictic conglomerates of the Rose Creek Member. **(3)** Rhyolite clasts in the NW Hay Loc. 7 conglomerates may have been derived from Clarno Formation rhyolites (Hay, 1963: 202). **(4)** Olivine basalts occurring in the lower John Day Formation (Hay, 1963: 205) are not found in the Rose Creek Member conglomerates in Haystack Valley or south of Kimberly.

We measured five sections to demonstrate the lithostratigraphic succession of the south limb of the syncline (figs. 4, 5, also Map A: measured sections 1–5); these are correlated by a marker bed that can be traced throughout the southern limb, a prominently exposed gray massive airfall tuff (GMAT).

Particularly important to our interpretation of the Haystack Valley Member is a measured section situated 0.4 mi (0.64 km) northeast of Fisher and Rensberger's section 10 in the W½, SW¼, sec. 27, T8S, R25E. Named the Beardog Section (figs. 5–7, also Map A: measured sections 5A, 5B)[3], it preserves higher units missing from section 10. The upper 150 ft of the Beardog Section (lost to erosion at section 10) includes a prominent, coarse welded tuff conglomerate, pivotal in assessing the distribution and significance of conglomerates within the upper John Day. We ultimately determined that this stratigraphically high conglomerate of the Beardog Section correlated with coarse welded tuff conglomerate along the east wall of the John Day valley south of Kimberly, and that these polymictic coarse conglomerates and associated lithofacies defined a terminal rock unit (Rose Creek Member of this report, see below) in angular unconformity with all subjacent John Day members. By contrast, the welded tuff conglomerates in the lower part of the Haystack Valley Member along Balm Creek are local in occurrence and have no apparent correlative elsewhere in the study area. Thus, the Beardog Section and Fisher and Rensberger's section 10 (the Asher Section of this study) are central to a reappraisal of the Haystack Valley Member and are described here:

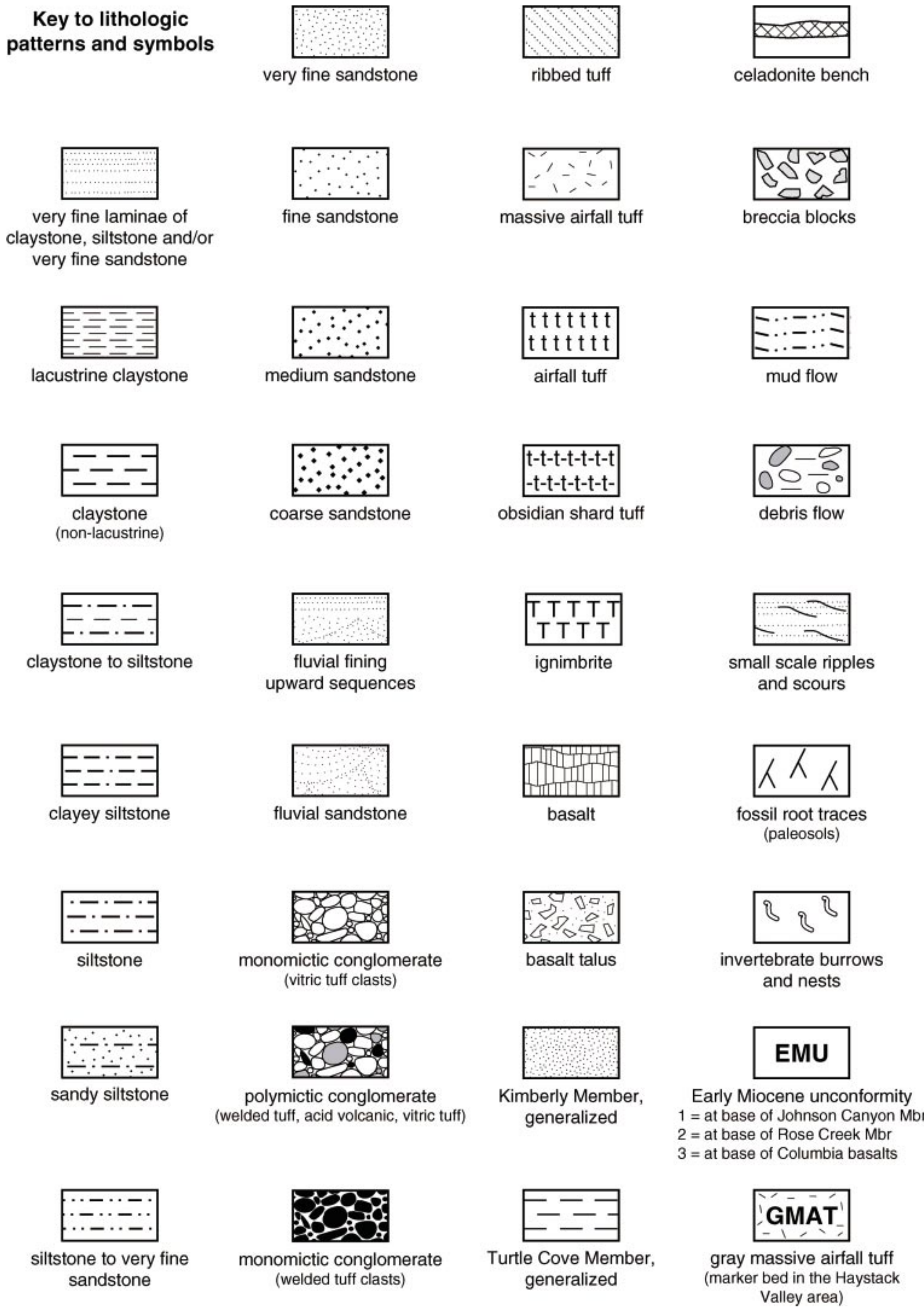
UNIT 1 (fig. 4, Asher Section, lower part, 0 to ~160 ft; appendix 1–4): Greenish-gray to olive-gray tuffaceous zeolitized claystones and siltstones with interbedded channel sandstone lenses comprise the lowest ~160 ft of our measured section. This interval lacks welded tuff conglomerate, with the exception of a few weathered welded tuff pebbles found in a single lens of cross-stratified fluvial sandstone. The lowest 40–50 feet of the 160-ft section contain the only occurrences of entoptychine rodents in the Asher Section, here represented by the most advanced species, *Entoptychus individens* (Rensberger, 1971). The stratigraphically highest entoptychine that we encountered was found 5 feet above a prominent green siltstone (''celadonite bench'', Asher Section, fig. 4). Fisher and Rensberger (1972: 17–18, 25, fig. 6) regarded the greenish zeolitized rocks of Unit 1 as the lower part of their Haystack Valley Member, and also noted that the beds included the terminal John Day entoptychine, *E. individens*. Associated with *E. individens* at UCMP locality Haystack 19 is the rare aplodontid rodent *Allomys tessellatus*; thus, the lowest part of the Haystack Valley Member along Balm Creek includes an *E. individens*-*A. tessellatus* biozone (Rensberger, 1983: 90, table 16).[4]

Figure 4 shows that no basal contact of Unit 1 with a subjacent stratigraphic unit is evident in the Balm Creek drainage. However, older John Day rocks are prominently exposed to the west within Haystack Valley itself along Haystack Creek, but their stratigraphic relationship to Unit 1 is difficult to discern because of faulting and vegetative cover along both the east and west walls of Haystack Valley (see addendum).

In addition to geomyoid rodents, a representative mammal fauna occurs in Unit 1

[3] The name given the measured section refers to a temnocyonine amphicyonid cranium excavated at this locality. The skull and associated mandibles (Northwest Museum NM 280/61, Portland State University, Portland, OR) are the most complete and best preserved amphicyonid cranial remains found in the upper John Day Formation. The fossil carnivore was discovered by M. Fingerhut and G. Pierson on April 2, 1986, during exploration of the John Day beds along Balm Creek, and was donated to Portland State University, where it is conserved by Dr. David Taylor. Taylor and Fingerhut generously permitted our study of the skull.

[4] Rensberger (1971: 155) at first did not apply the term Haystack Valley Member to the greenish zeolitized rocks containing *E. individens* since the member had not been named at that time; he described the stratigraphic occurrence of *E. individens* as follows: ''The highest observed stratigraphic position for *Entoptychus* is slightly above the lowest beds of coarse-grained, water-laid clastics in Haystack Valley . . . ''. Once the member had been named and defined, Rensberger (1973: 86, fig. 2) indicated that the range of entoptychines extended into the base of the Haystack Valley Member (also Fisher and Rensberger, 1972: figs. 6, 8). Thereafter, Rensberger (1983: 29) explicitly noted that *E. individens* occurs in ''greenish, zeolitized deposits at the base of the [Haystack Valley] member (interval G).''


Key to lithologic patterns and symbols
very fine sandstone
ribbed tuff
celadonite bench
very fine laminae of claystone, siltstone and/or very fine sandstone
fine sandstone
massive airfall tuff
breccia blocks
lacustrine claystone
medium sandstone
tttttt tttttt
airfall tuff
mud flow
claystone (non-lacustrine)
coarse sandstone
t-t-t-t-t-t-t -t-t-t-t-t-t-
obsidian shard tuff
debris flow
claystone to siltstone
fluvial fining upward sequences
TTTTT TTTT
ignimbrite
small scale ripples and scours
clayey siltstone
fluvial sandstone
basalt
fossil root traces (paleosols)
siltstone
monomictic conglomerate (vitric tuff clasts)
basalt talus
invertebrate burrows and nests
sandy siltstone
polymictic conglomerate (welded tuff, acid volcanic, vitric tuff)
Kimberly Member, generalized
EMU
Early Miocene unconformity
1 = at base of Johnson Canyon Mbr
2 = at base of Rose Creek Mbr
3 = at base of Columbia basalts
siltstone to very fine sandstone
monomictic conglomerate (welded tuff clasts)
Turtle Cove Member, generalized
GMAT
gray massive airfall tuff (marker bed in the Haystack Valley area)

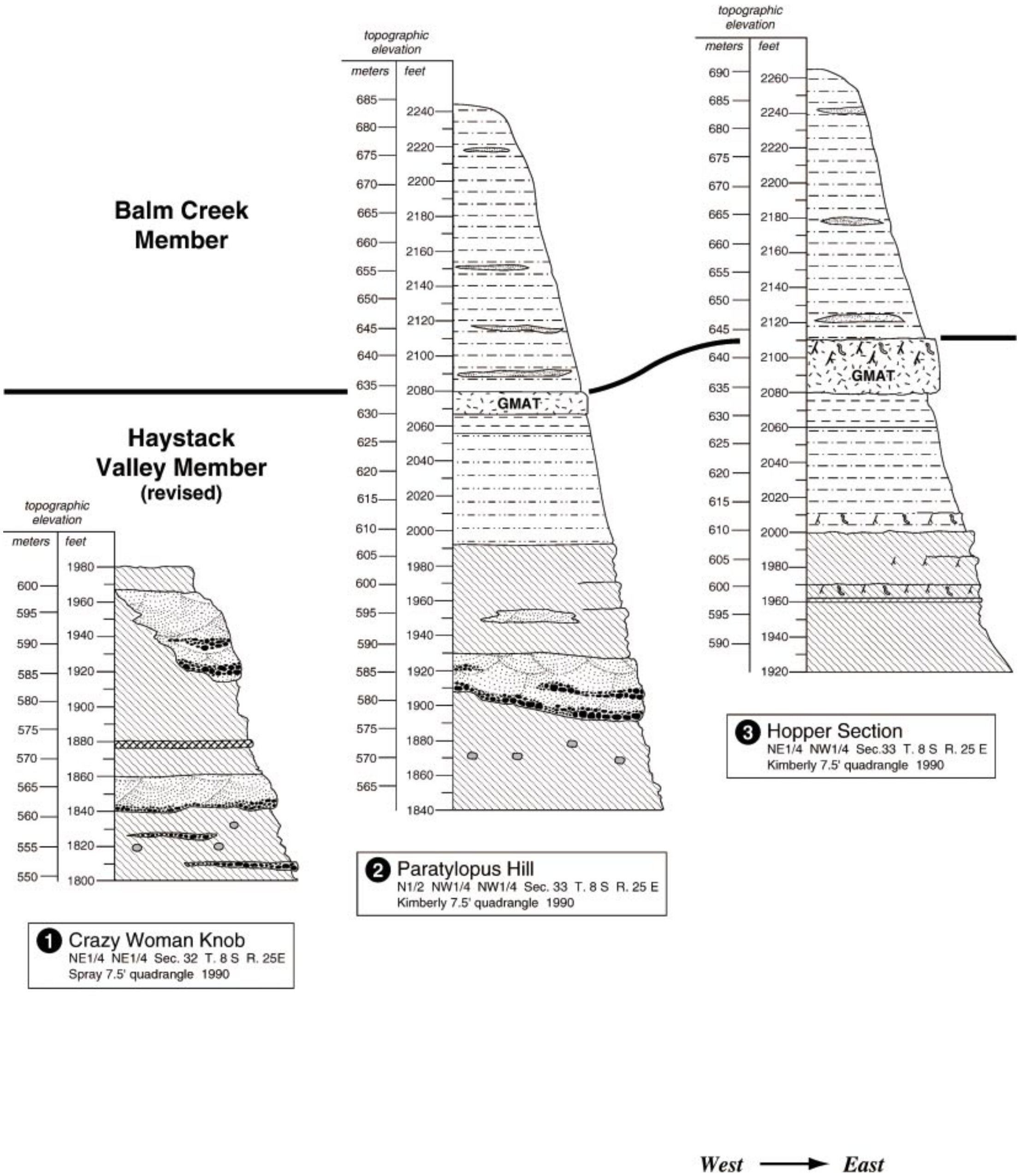


Fig. 4. Stratigraphic profile of the upper John Day Formation from the mouth of Haystack Creek 1 mi (1.65 km) eastward to the Balm Creek drainage. Four measured sections are correlated using a gray massive airfall tuff (GMAT) and local monomictic welded-tuff conglomerate bodies (see p. 17 for lithologic key). Rocks below the GMAT marker bed are particularly fossiliferous and are the source of the mammal fauna from the Haystack Valley Member (revised). Entoptychine rodents occur no higher in the revised member than the 40–50-ft level of the Asher Section (lower part). Unit thicknesses in lowermost 160 ft are estimated within ±5%.

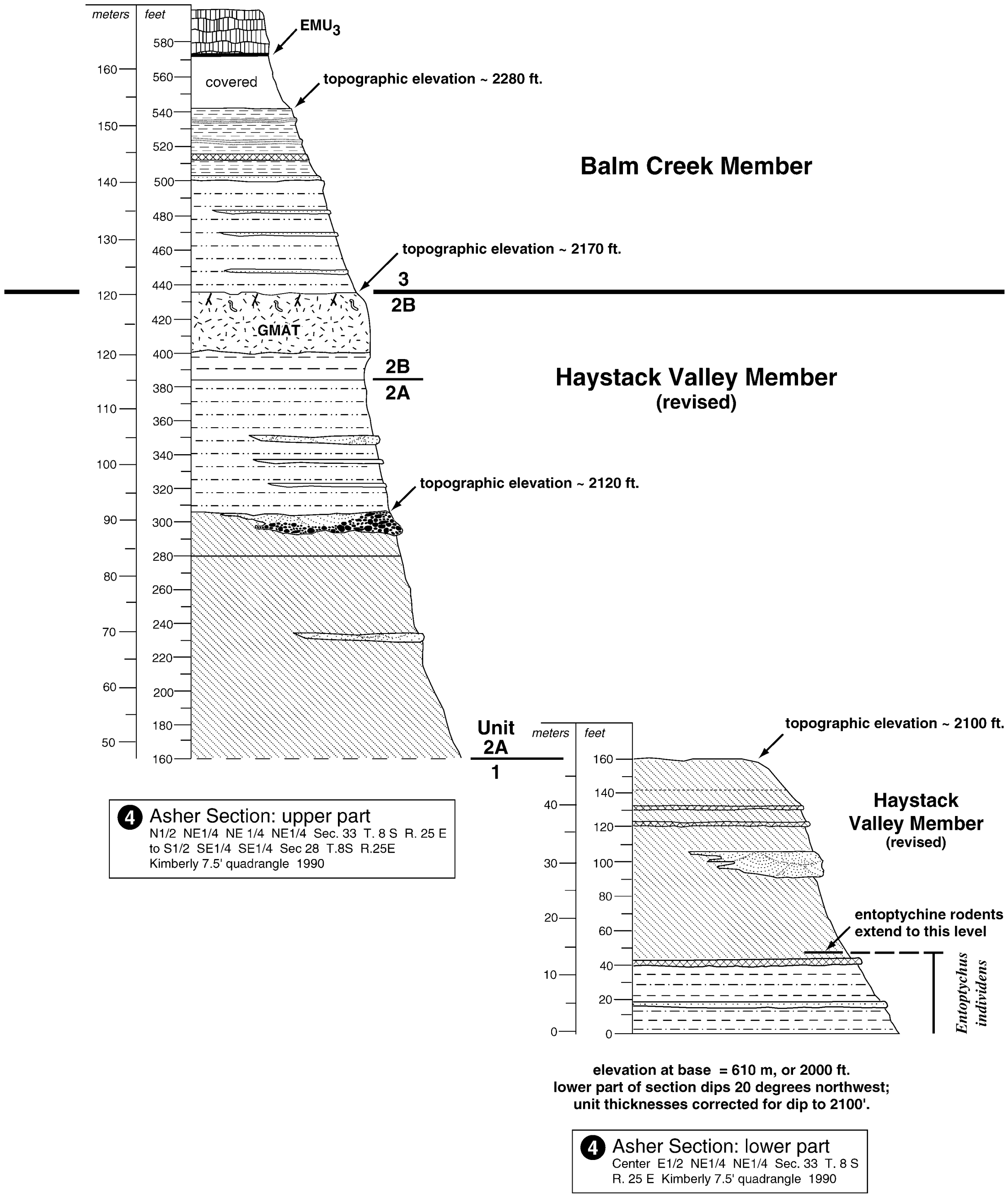
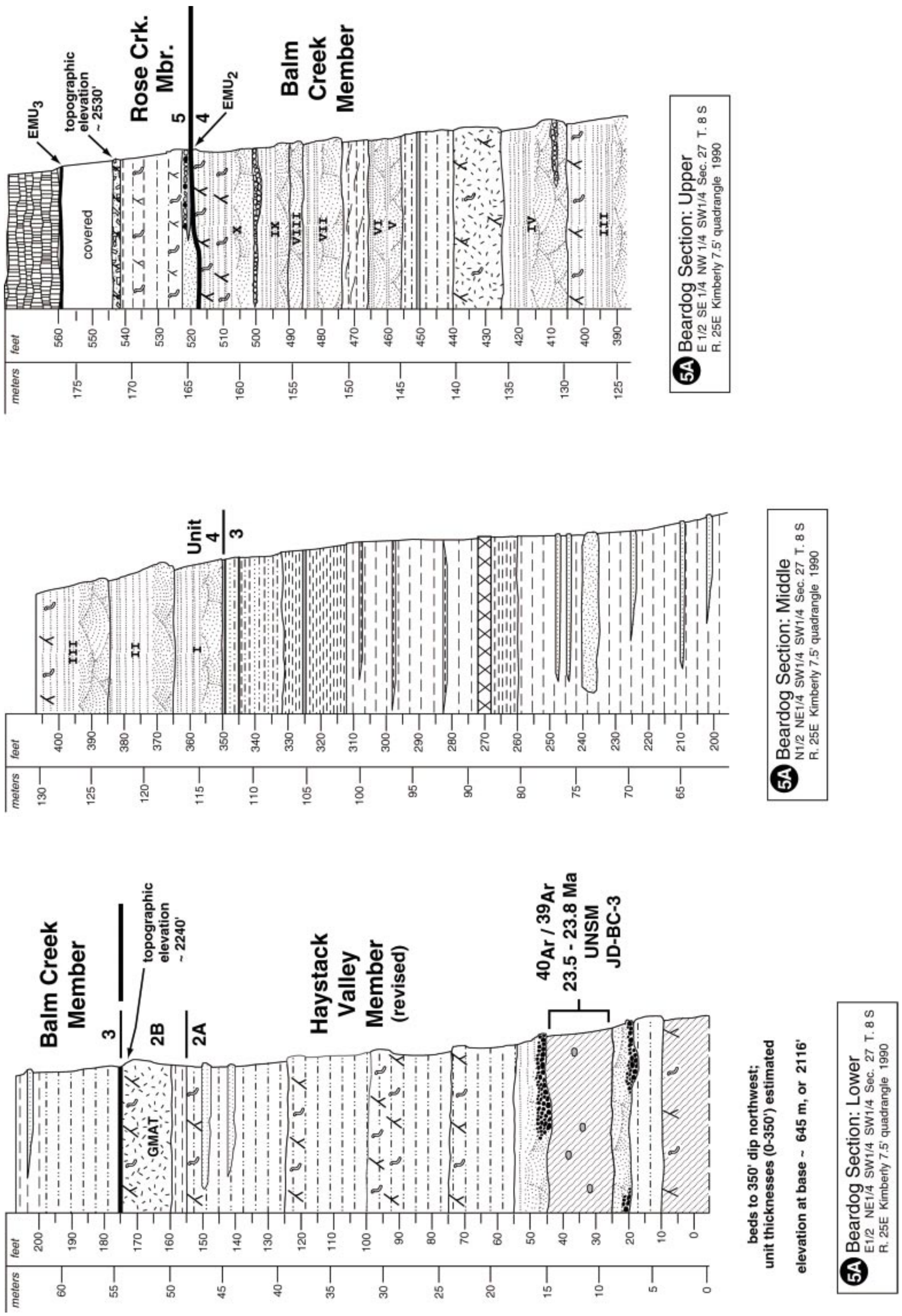


Fig. 4. Continued.

(appendices 1-4, 1-7). These taxa are combined here with those from Unit 2A to form a composite assemblage (table 4; appendices 1-1 to 1-7, from the Haystack Valley Member, revised).

UNIT 2A (fig. 4, Asher Section, upper part, ~160 to 382 ft): From ~160 to 382 ft in the Asher Section, yellow-gray to olive-gray tuffaceous sediments continue to resemble the rocks in the lower 160 ft of the sec-


Beardog Section: Upper
E 1/2 SE 1/4 NW 1/4 SW1/4 Sec. 27 T. 8 S
R. 25E Kimberly 7.5' quadrangle 1990
Rose Crk. Mbr.
Balm Creek Member
EMU_3
EMU_2
topographic elevation ~ 2530'
covered
Beardog Section: Middle
N1/2 NE1/4 SW1/4 Sec. 27 T. 8 S
R. 25E Kimberly 7.5' quadrangle 1990
Unit
Beardog Section: Lower
E1/2 NE1/4 SW1/4 Sec. 27 T. 8 S
R. 25E Kimberly 7.5' quadrangle 1990
Balm Creek Member
topographic elevation ~ 2240'
Haystack Valley Member (revised)
GMAT
$^{40}Ar/^{39}Ar$ 23.5 - 23.8 Ma
UNSM JD-BC-3
beds to 350' dip northwest; unit thicknesses (0-350') estimated
elevation at base ~ 645 m, or 2116'
meters
feet

tion but appear not as strongly zeolitized. The field term ''ribbed tuff'' was applied to these sediments because weathered outcrops are typified by alternating, close-spaced, more and less resistant tuff levels, giving the outcrop a horizontally ribbed appearance. Multiple lenses of welded tuff conglomerate characterize the middle part of the interval, occurring at three or more stratigraphic levels over an interval of at least 130 vertical ft in sections at the mouth of Haystack Creek and along Balm Creek. These are monomictic conglomerates comprising only welded tuff pebbles with mean intermediate diameter (I.D.) less than 5 cm (table 1, Haystack Valley Member, revised). These are the conglomerates recognized in Haystack Valley within the Haystack Valley Member by Fisher and Rensberger (1972: 17–18, fig. 1). Their measured section 10 shows conglomerate present in the lower part of the member, appearing ~100 ft above the base (Fisher and Rensberger, 1972: fig. 3). However, the designation of a particular conglomerate level in their plate 7 as ''*the* [authors' italic] marker bed at the base of Haystack Valley Member'' contradicts section 10. In fact, section 10 correctly represents the stratigraphy. Although multiple levels of these welded tuff conglomerates are present in the 160 to 382-ft interval in the Balm Creek measured sections (fig. 4: sections 1, 2, 4), no marker conglomerate bed identifies the base of the unit.

Fossil mammals are present as scattered occurrences throughout Unit 2A, and are combined with those of Unit 1 to form a composite assemblage (table 4; appendices 1-1 to 1-7).

UNIT 2B (fig. 4, Asher Section, upper part, ~382 to 435 ft): Unit 2A is succeeded in the Balm Creek drainage and throughout Haystack Valley by a gray massive airfall tuff (GMAT), a marker bed that ranges from ~5 to 35 ft in thickness. It forms a vertical cliff in the Balm Creek area and can be traced from the S½, sec. 27, to SE¼, sec. 28, and into N½, sec. 33, T8S, R25E. The rock matrix includes predominantly glass shards with scattered volcanogenic euhedral crystals and abundant pumice fragments. The upper 10–15 ft of this unit are overprinted by a well-developed paleosol with siliceous rhizoliths, small burrows, petrosilicic laminae, and soil breccia. Directly beneath this airfall tuff at one locality (fig. 8, HS-1 section; Map A: measured section 6, SE¼, SE¼, sec. 27, T8S, R25E) are 10–30 ft of dark gray, cross-stratified fluvial sandstones, incorporating polymictic (made up of welded tuff, other rhyolitic/dacitic volcanic, and intraformational tuff clasts) pebble conglomerate, that incise the uppermost beds of Unit 2A. These fluvial sediments appear to grade upward into the GMAT, hence these sediments and the GMAT are considered a single depositional unit postdating Unit 2A by an unknown amount of time (no fossil mammals have been found as yet in Unit 2B to gauge this). However, the GMAT unit is most often underlain not by coarse fluvial sediments but by silty tuffaceous buff claystones that appear to be a lateral facies of the dark gray channel sands and pebble conglomerate seen in HS-1. It may be advisable at a later date to segregate Unit 2B as a distinct lithostratigraphic unit should an erosional unconformity identified by incision of fluvial Unit 2B channels into Unit 2A (fig. 8) prove to be recognizable throughout the Haystack Valley-Balm Creek area.

Although description of the Balm Creek stratigraphy could be continued here using

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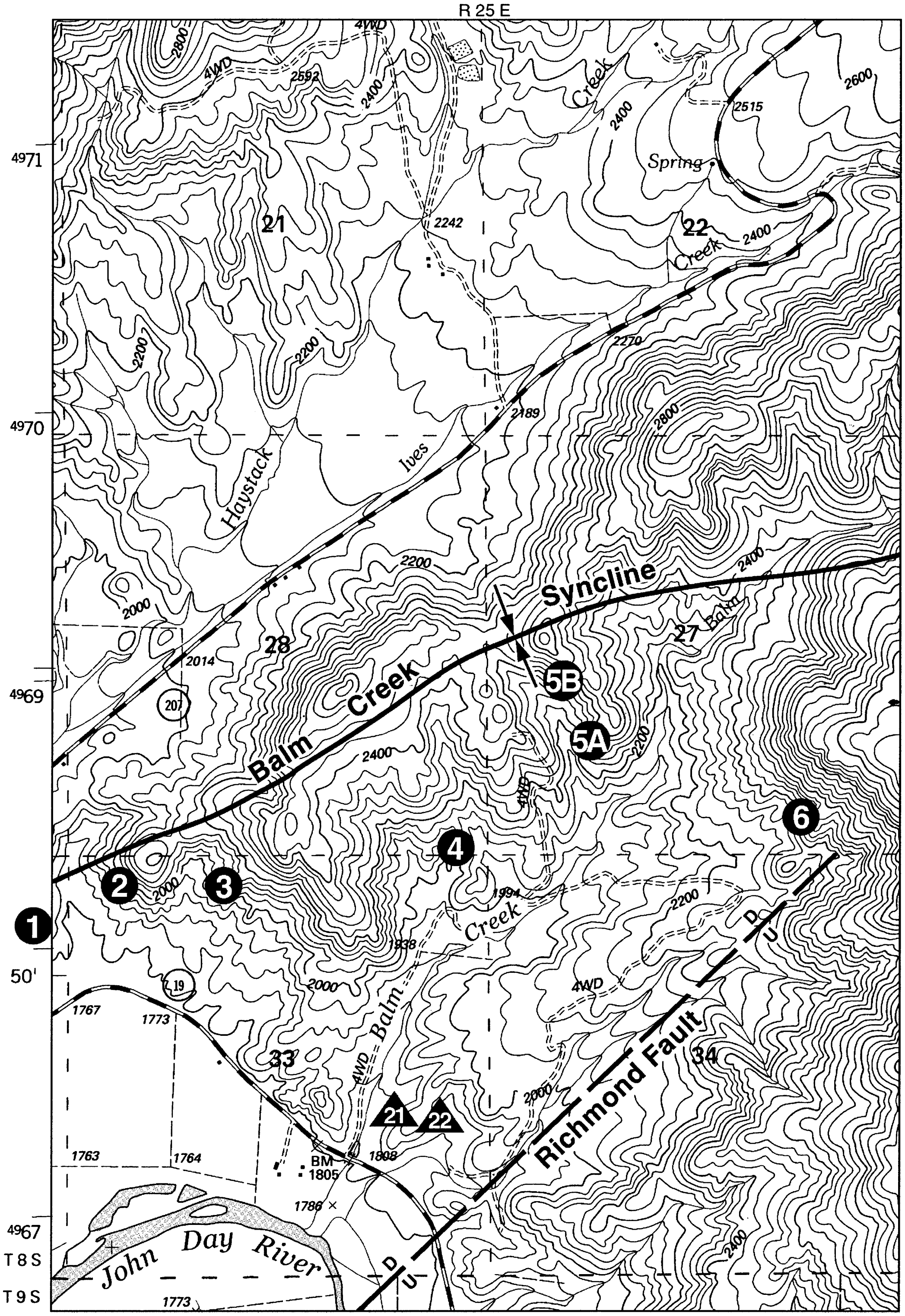
Fig. 5. Beardog Section: situated 0.3 mi (0.5 km) northeast of the Asher Section in the Balm Creek drainage in SW¼, sec. 27, T8S, R25E. This measured section transects the south limb and core of the Balm Creek syncline. Unit thicknesses (in feet and meters) include reference topographic elevations because the attitude of strata varies markedly upward in the section as the core of the syncline is approached; the lowermost 350 ft of section dip steeply northwest, with progressively decreasing apparent dip in the upper cliff outcrops. Unit thicknesses in the lowermost 350 ft are estimated within ±5%. Roman numerals (I–X) indicate fluvial fining-upward sequences within the Balm Creek Member. The GMAT unit in the Beardog Section (Lower) also occurs in figure 4, correlating the Asher and Beardog Sections.


R 25 E
4971
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21
22
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33
34
Spring
Creek
Haystack
Ives
Balm Creek Syncline
Balm
Creek
Richmond Fault
John Day River
4WD
2800
2592
2400
2515
2600
2242
2200
2270
2189
2000
2014
207
19
1994
1938
1767
1773
1763
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BM 1805
1786
D
U
1
2
3
4
5A
5B
6
21
22

the less complete Asher Section, we employed the GMAT as a marker bed that allowed us to trace the local stratigraphic section 0.4 mi (0.64 km) to the northeast in order to describe the more complete upper part of the Balm Creek sequence at the Beardog Section.

UNIT 3 (fig. 5, Beardog Section: Lower and Middle, ~175 to 350 ft): Above the GMAT marker bed we measured ~175 ft of fluvial tuffaceous siltstones and fine sandstones overlain by and interbedded with finely laminated lacustrine claystones and thin airfall tuffs. Unit 3 can be divided into a lower 65–85 ft-thick interval of yellow tuffaceous claystones, with occasional lenses of fluvially reworked siltstone and fine sandstone, that weathers to a smooth slope marked by infrequent thin resistant beds. Above this are ~90 ft of white to light gray lacustrine tuff and a few thin interbedded dark gray airfall tuffs. These finely laminated lacustrine sediments and airfall tuffs were deposited in a shallow confined body of water. From 272 to 312 ft in the Beardog Section, the yellow tuffaceous claystones are interbedded with the lacustrine tuffs, demonstrating that the lower and upper parts of Unit 3 represent a single depositional sequence.

Only a single fossil mammal, a partial skull of a peccary (cf. *Hesperhys*) in a private collection, has been found in Unit 3. It occurred a few feet above the base of Unit 3 in the Beardog Section (appendix 1-6). The lacustrine beds in the upper part of the unit have not produced fossil mammals.

UNIT 4 (fig. 5, Beardog Section: Middle and Upper, ~350 to 520 ft): Above Unit 3 are ~170 ft of stacked fining-upward sequences composed of fluvial tuffaceous sandstone, siltstone, and rare lenses of intraformational pebble conglomerate (I.D. <2cm) lacking welded tuff pebbles. Coarse obsidian shards are evident in some fluvial sandstones. Two major paleosols are present, a lower one developed on a gray airfall tuff (425–440 ft), and a terminal paleosol 12 ft thick at the top of the sequence (508–520 ft).

No fossil mammals have been found in this unit.

UNIT 5 (fig. 5, Beardog Section: Upper, ~517–544 ft, measured section 5A; however, Unit 5 is incised to the 469 ft level 0.2 mi (0.3 km) to the northwest in fig. 6, measured section 5B): Here the terminal Unit 4 paleosol is deeply incised by a Unit 5 channel to a depth of ~50 feet (fig. 6, Beardog Section: Upper, 0.2 mi northwest, channel incision from 518 ft to ~469 ft level). The base of this channel is filled with clast-supported polymictic welded tuff-bearing conglomerate that includes cobbles as large as 14 cm I.D. This is a much coarser conglomerate than the conglomerate lenses of Unit 2A; mean I.D. for the various conglomerate bodies in Unit 5 range from 7.5 to 10.0 cm (table 1, Balm Creek syncline). Unit 5 conglomerates are found only at the highest elevations beneath the capping basalts of the Balm Creek drainage and are polymictic (varied clasts types, most commonly, welded tuff derived from the Picture Gorge ignimbrite, and indurated intraformational vitric tuff) in contrast to the monomictic (a single clast type of welded tuff) conglomerates of Unit 2A. The coarsest conglomerate forms the basal lithofacies of Unit 5 in the Beardog Section but polymictic welded tuff-bearing conglomerate lenses with slightly smaller average clast diameter occur at higher levels within the unit (figs. 5, 6, Beardog Section: Upper, at ~520 ft). Unit 5 appears to be angularly unconformable on lower units in the Balm Creek valley, and hence it postdates the compressive folding and associated faulting that created the Balm Creek syncline. The tuffaceous sediments and polymictic conglomerates of Unit 5 are not mentioned by Fisher and Rensberger (1972) because the unit was removed by

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Map A: Topographic map of the Haystack Creek-Balm Creek area, John Day valley, Oregon, Kimberly 7.5-minute quadrangle, indicating the Balm Creek syncline and Richmond fault in relation to measured sections of this report: **1,** Crazy Woman; **2,** *Paratylopus* Hill; **3,** Hopper; **4,** Asher; **5,** Beardog; **6,** HS-1. Triangles indicate approximate locations of UCMP Haystack 21 and 22 where *Entoptychus individens* occurs in the lower part of the Haystack Valley Member (revised).

erosion from their section 10, prior to the outpouring of the Columbia basalts. The principal outcrop of Unit 5 in the Beardog Section is exposed (fig. 7) over a very small area within the axis of the Balm Creek syncline (NW¼, NE¼, SE¼, NW¼, SW¼, sec. 27, T8S, R25E) and could be easily missed in a regional reconnaissance study.

Despite diligent searching, no fossil mammals have been found in Unit 5.

REVISION OF THE HAYSTACK VALLEY MEMBER[5]: Fisher and Rensberger did not describe the rocks of the Haystack Valley Member in the Balm Creek valley in detail; however, their principal stratigraphic section (Fisher and Rensberger, 1972: fig. 3, section 10) was measured in the Balm Creek drainage at the same location as our Asher Section. Because section 10 had lost Unit 5 and the upper part of Unit 4 to erosion, Fisher and Rensberger's concept of the Haystack Valley Member did not include these uppermost John Day rocks.

Fisher and Rensberger (1972: pls. 7, 8) selected the welded tuff-bearing conglomerate at the 300 ft level in our Asher section as the base of the Haystack Valley Member. The totality of exposures in the Balm Creek drainage (figs. 4–8) demonstrates the difficulty in using the appearance of a particular welded tuff-bearing conglomerate to identify the base of the Haystack Valley Member since there are multiple levels with conglomerate of this type in the Haystack Valley-Balm Creek area, and the conglomerate body of their plate 7 is not the stratigraphically lowest such lens. In fact, lithologies above and below this bed are similar and do not warrant stratigraphic separation. The location of the lower boundary of the member is further placed in doubt when, in section 10, an additional ~100 feet of the member is shown below the welded tuff conglomerate level.

Fisher and Rensberger considered all rocks of their section 10 from the welded tuff conglomerates up to the capping basalts as the Haystack Valley Member. We suggest a more circumscribed stratigraphic definition of the Haystack Valley Member (revised) incorporating only our Units 1 and 2, thus limiting the member to the lower 435 feet of the Asher Section along Balm Creek (fig. 4). The upper boundary of the unit is demarcated by the prominent siliceous paleosol developed on the gray marker tuff (GMAT, fig. 4) of Unit 2B. Rocks below this marker bed in Units 1 and 2 are of uniform lithology and surface-weathering characteristics; the alternating resistant ledges and softer interbeds give a horizontally ribbed appearance to these outcrops along Balm Creek and were termed ''ribbed tuffs'' during our field study. Units 1 and 2A are zeolitized, more strongly toward the base. Importantly, monomictic welded tuff conglomerates are present at multiple levels in Unit 2A, although more concentrated from 100 to 170 feet below the gray marker tuff (GMAT) in the middle part of the section. In Unit 2B, only a single lens of polymictic conglomerate with welded tuff pebbles was observed, occurring at the base of the unit in a channel cut into Unit 2A (fig. 8, ~2632 ft). Above Unit 2, only rare, minor welded tuff conglomerate lenses occur in the section below the coarse basal polymictic conglomerate of Unit 5 (at Section HS-1, thin granule to pebble conglomerate lenses at two levels within the lower part of Unit 3 contained welded tuff clasts). Fossil mammals in the Balm Creek drainage are entirely restricted to the revised member and do not occur above it, except for one specimen, a peccary skull, found at the base of Unit 3 (appendix 1-6).

The revised member is principally exposed along Balm Creek in sections 33–34, T8S, R25E, but does not occur south of the Richmond Fault in section 34 (Map A). It also crops out in cliffs along the west and east walls of Haystack Valley where the member is in fault contact with the Turtle Cove Member which occupies the central part of the valley.

[5] The North American Stratigraphic Code (1983: 855) defines revision of a geologic unit as ''either minor changes in the definition of one or both boundaries of a unit, or in the unit's rank.'' Our revised Haystack Valley Member alters only the upper boundary of the unit, retaining in the unit the lower 435 ft of section that includes the primary lithologic content attributed to the member by Fisher and Rensberger (1972). We remove the uppermost ~100 ft of their measured section 10 and assign it to the Balm Creek Member (new). This action on our part conforms to the recommendation of the Code (1983: article 19a) which states that ''Revision is justifiable if a minor change in boundary or content will make a unit more natural and useful. If revision modifies only a minor part of the content of a previously established unit, the original name may be retained.''

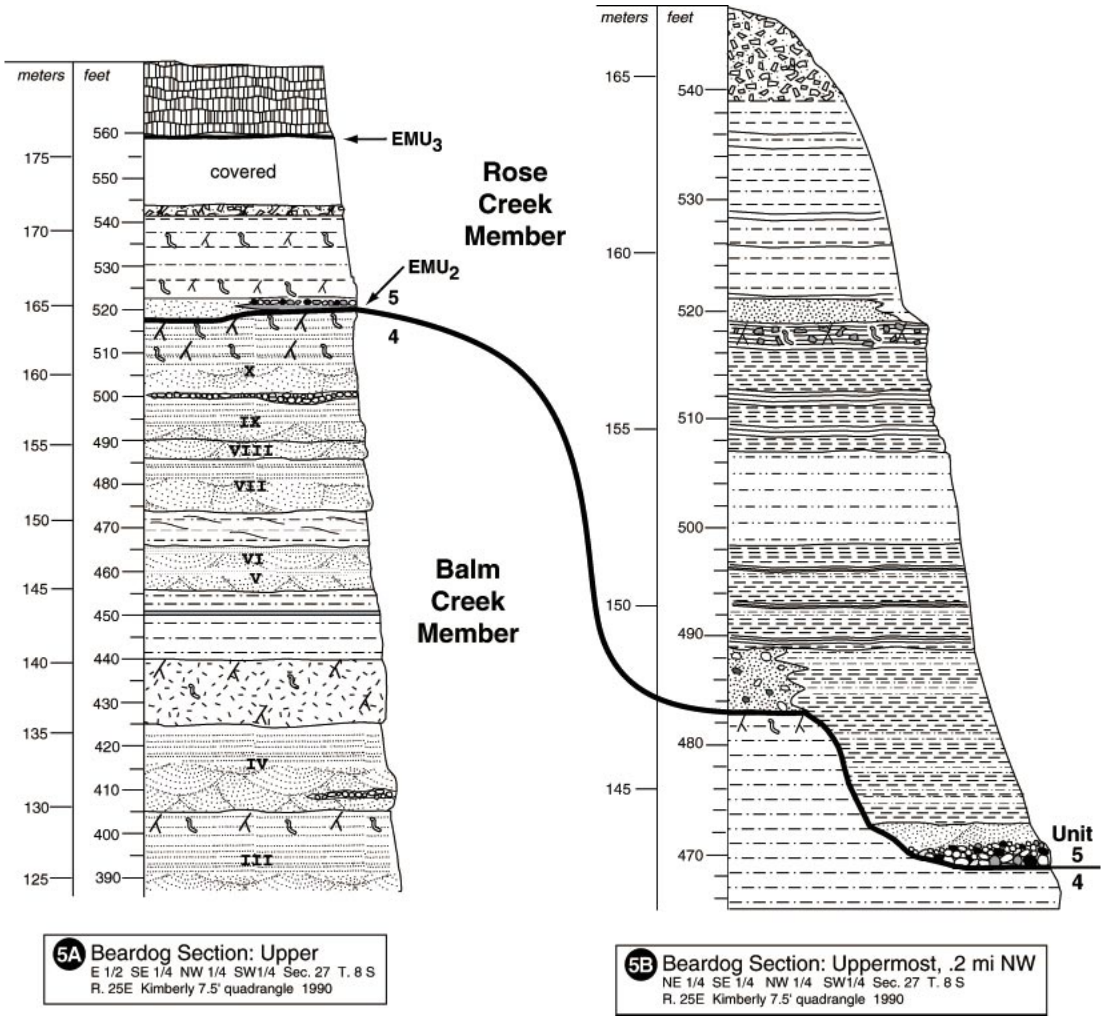


Fig. 6. Uppermost part of the Beardog Section: a basal fluvial channel of the Rose Creek Member is incised ~50 ft into the Balm Creek Member. Debris flow and finely laminated lacustrine tuffs comprise much of the channel fill overprinted by numerous siliceous paleosols. The Rose Creek Member was not identified by Fisher and Rensberger (1972: section 10) whose measured section terminated below this stratigraphic level.

It may prove advisable after future field study to emphasize a lithologic and biochronologic distinction between Units 1 and 2A. At this level in the Asher section there is an apparent division between green zeolitized soft-weathering claystones and siltstones of Unit 1 carrying the *Entoptychus individens–Allomys tessellatus* rodent assemblage, and overlying pale gray-green to yellow-gray well-indurated tuffaceous siltstones of Unit 2A lacking this assemblage.

The rocks of Unit 1 with *E. individens–A. tessellatus* were considered part of the Haystack Valley Member by Rensberger (1983: 90, table 16). We concur, thinking it appropriate at present to include these beds in the member because (1) the zeolitized coarse sandstones of Unit 1 at one of the localities yielding *E. individens* (SW¼, NE¼, NE¼, SE¼, sec. 33, T8S, R25E: probably UCMP locality Haystack 22) included a few highly weathered welded tuff pebbles, suggesting that these coarse fluvial lenses mark the first access of local streams to exposures of the

Fig. 7. The valley of Balm Creek (in foreground), looking north, with the Beardog Section (center of photograph) exposed along the east valley wall of a small tributary trending northwest from Balm Creek. This locality is in the W½, SW¼, T8S, R25E, Kimberly 7.5-minute quadrangle. **a,** Picture Gorge Group Basalt; **b,** Rose Creek Member; **c,** Balm Creek Member; **d,** GMAT marker tuff; **e,** Haystack Valley Member (revised).

Picture Gorge ignimbrite, the source of the welded tuff pebbles in these beds; and (2) a general similarity in the ''ribbed tuff'' lithologies of Units 1 and 2A.

BALM CREEK MEMBER: Fisher and Rensberger included all rocks of section 10 from the welded tuff conglomerates up to the capping basalts in their Haystack Valley Member. We think it useful to recognize a marked change in the style of sedimentation within this stratigraphic sequence that occurs at the boundary between Units 2 and 3. Unit 3 in its lower part is comprised of yellow-gray tuffaceous siltstones, claystones, and very fine sandstones with thin interbeds of low-angle, cross-stratified gray fine-to-medium sandstones. The yellow-gray beds appear to be airfall tuffs occasionally reworked by lower-flow regime fluvial processes, punctuated by slightly coarser detrital gray sands and gravel representing intermittent sheetflooding. The upper part of Unit 3 is made up of thinly laminated lacustrine tuff and claystone that in its lower part intertongues with the yellow-gray tuffs of the lower part of Unit 3. Occasional thin detrital volcaniclastic sands and airfall tuffs occur within the upper 25 feet of the lacustrine beds. The presence of quiet-water lacustrine sediments probably reflects the damming of local drainages in response to syntectonic compression that modified local topography during the development of the Balm Creek syncline.

Units 3 and 4 are lithically distinguished from the units below by their lack of zeolitization. Unit 3 weathers to smooth slopes with a soft powdery surface suggestive of montmorillonitic clay; Unit 4 is distinguished by fresh glass, including in some beds black obsidian shards.

Unit 4 is characterized by lower (beds I–IV) and upper (beds V–X) sets of stacked fining upward sequences (fig. 5, Beardog Section: Middle and Upper) of tuffaceous fluvial sandstones (some with coarse obsidian shards), separated by a massive 15-ft thick

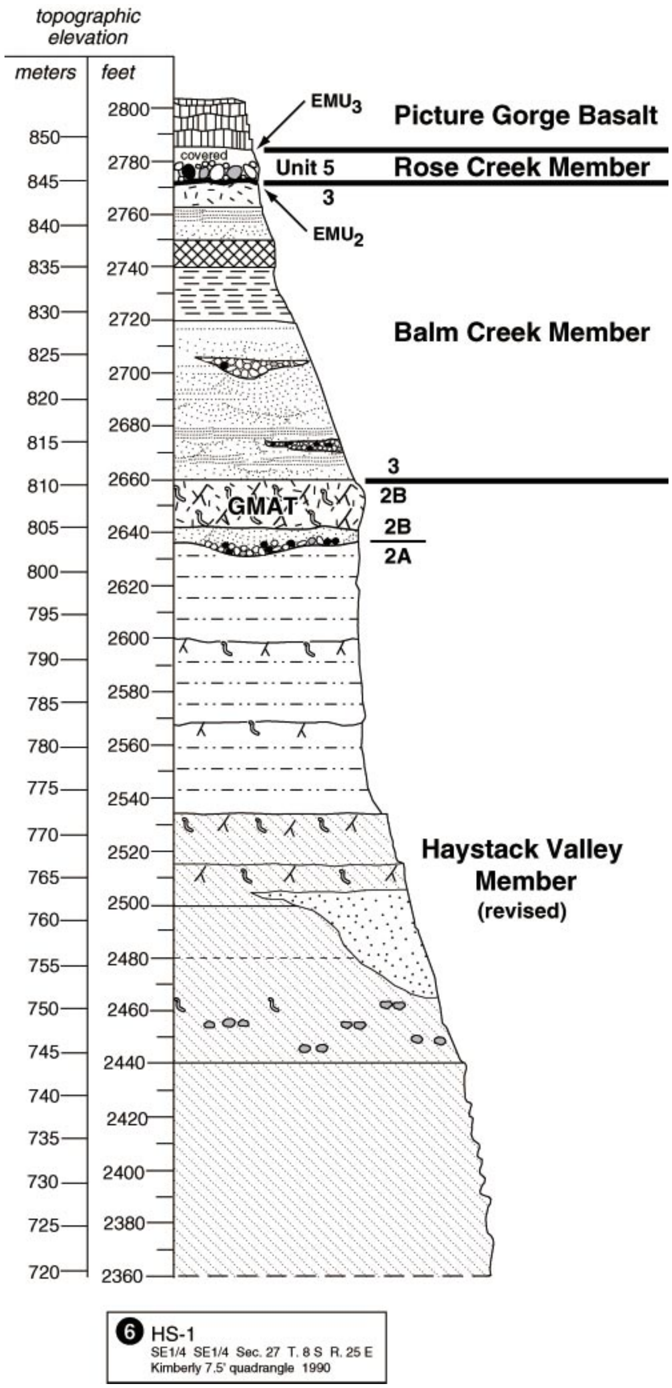


Fig. 8. Section HS-1, situated 0.5 mi (0.8 km) east of the Beardog Section, occupies the southern margin of the south limb of the Balm Creek syncline. Here steeply dipping strata of the south limb become horizontal and abut directly against the Richmond Fault of Fisher. The section from 2360 to 2660 ft (Units 2A, 2B) represents the Haystack Valley Member (revised), which is fossilferous except for Unit 2B. Unit 2B (2630–2660 ft) includes a fluvial channel complex at the base overlain by the GMAT marker bed; GMAT correlates Section HS-1 with measured sections of figures 4 and 5. The Rose Creek Member is unconformable on older John Day rocks (EMU$_2$), indicating removal of the upper part of the Balm Creek Member.

gray airfall tuff. This tuff is overprinted by a prominent paleosol (fig. 5, 425–440 ft).

The upper limit of Unit 4 is marked by a 12-ft thick terminal paleosol (fig. 5, 508–520 ft) developed on the uppermost fining-upward sequence (fig. 5, bed X). This paleosol is removed where incised by the fluvial channels of Unit 5 (fig. 6). Unit 4 lithologies are clearly distinct from the zeolitized ribbed tuffs and conglomerates of our revised Haystack Valley Member.

We designate Units 3 and 4 the *Balm Creek Member*, noting that these units are well exposed along the axis of the Balm Creek syncline (Map A: W½, SW¼, sec. 27, T8S, R25E). Because no fossil mammals have been found in Unit 4 and only a single fossil mammal (a peccary skull) has been found in Unit 3 at its base, age is conjectural. However, the peccary (table 4, cf. *Hesperhys*) suggests a late or latest Arikareean age for Unit 3, which is supported by the stratigraphic placement of Units 3–4 between Units 2A (early late Arikareean) and 5 (early Hemingfordian, see below).

Importance of Unit 5 in Regional Correlation: As mentioned previously, Fisher and Rensberger's section 10 omitted Unit 5 because at that location post-John Day erosion removed the uppermost rocks of the formation, and the resulting topographic low was later filled by basalt flows. Section 10 was measured 0.43 mi (0.7 km) southwest of the more complete Beardog Section where Unit 5 escaped post-John Day erosion. The existence of Unit 5 has important implications for regional lithostratigraphy and tectonics in the Haystack Valley-Kimberly area. Unit 5 includes coarse polymictic welded tuff-bearing conglomerates and stream-deposited sands, debris flows, lacustrine claystones, and yellow-gray tuffaceous fine-grained rocks with siliceous paleosols that correspond to a similar lithofacies association found in the highest stratigraphic unit of the upper John Day Formation along the east wall of the John Day valley south of Kimberly. It became evident that the polymictic welded tuff-bearing cobble conglomerates of Unit 5 correlated to the equally coarse polymictic welded tuff conglomerates of this high unit along the east wall of the valley south of Kimberly (table 1), and that these rocks were much younger than previously believed. Although no fossil mammals were found in Unit 5 at Balm Creek, a representative early Hemingfordian fauna (table 4; appendices 1-12 to 1-14, fauna of the Rose Creek Member, see below) occurred in the unit south of Kimberly. We eventually realized that these particularly coarse polymictic conglomeratic beds had no close temporal relationship with the monomictic welded tuff conglomerates of the revised Haystack Valley Member at Balm Creek and in Haystack Valley where $^{40}Ar/^{39}Ar$ dating of Unit 2A (table 2, and fig. 5, Beardog Section: Lower, 25–45-ft level) revealed that the revised Haystack Valley Member is a much older rock unit.

John Day Valley South of Kimberly

South of Kimberly along the east and west margins of the John Day valley, Fisher identified the Haystack Valley Member but did not map it as a discrete body of rock, having included it with the Kimberly Member in an undifferentiated upper John Day unit (Fisher and Rensberger, 1972: Map 2, map symbol *Tjkh*). We identified the Haystack Valley Member of Fisher and Rensberger south of Kimberly using lithology and stratigraphic position above the Kimberly Member tuffs. On both the east and west walls of the John Day valley these rocks are separated from the subjacent Kimberly tuffs by erosional unconformity. Significantly, only on the east wall does the member include polymictic, welded tuff-bearing, pebble-to-cobble conglomerate, whereas along the west wall only intraformational monomictic vitric tuff-pebble conglomerates occur. It is not possible to walk out rocks of the Haystack Valley Member between Haystack Valley and Kimberly because post-John Day erosion has removed much of the upper part of the formation, resulting in topographic lows filled by Columbia basalts. Along Highway 19 that follows the John Day River between Haystack Valley and Kimberly, one observes only isolated outcrops of the John Day Formation, mostly Kimberly gray tuff, separated by basalt-filled valleys.

Rose Creek Member (East Wall of the John Day Valley from Kimberly to

TABLE 2

$^{40}Ar/^{39}Ar$ analytical data for the Haystack Valley Member (Revised), Balm Creek, Oregon.

Lab No.	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	$^{39}Ar_K$ (x 10^{-15} mol)	K/Ca	$^{40}Ar^*$ (%)	Age (Ma)	±1σ (Ma)
JD-BC-3, sanidine, J=0.0016043±0.10%, D=1.0074±0.0018, NM-59								
7251-03	8.608	0.0424	0.001368	3.873	12.0	95.3	23.60	0.07
7251-01	8.465	0.0566	0.000600	3.269	9.0	98.0	23.84	0.06
7251-04	8.768	0.3391	0.001617	1.061	1.5	94.8	23.91	0.12
7251-02	8.852	0.1810	0.001722	0.963	2.8	94.4	24.03	0.12
Mean age ± 2σ (n=4)			MSWD=4.17		6.3 ±10.0		23.79	0.18

Notes:

Sanidine crystals were removed from a single hand specimen of a tuffaceous siltstone collected from the 25-45 ft interval of Beardog Section (fig. 5), north of Balm Creek; center, S1/2, SW1/4, T8S, R25E, Oregon. $^{40}Ar/^{39}Ar$ dating through the courtesy of Wm. McIntosh and L. Peters, New Mexico Bureau of Mines & Mineral Resources, Socorro.

$^{39}Ar_K$ is moles of K derived ^{39}Ar. K/Ca is calculated from measured $^{37}Ar_{Ca}/^{39}Ar_K$. $^{*40}Ar$ is percent of measured ^{40}Ar that is radiogenic.

Sample preparation and irradiation:

Sanidine crystals were separated with standard heavy liquid, Franz Magnetic and hand-picking techniques.

Samples were loaded into a machined Al disc and irradiated for 14 hours in the D-3 position, Nuclear Science Center, College Station, TX.

Neutron flux monitor Fish Canyon Tuff sanidine (FC-1).

J-factors determined to a precision of ± 0.1% by CO2 laser-fusion of 4 single crystals from each of 4 radial positions around the irradiation tray.

Instrumentation and analytical parameters:

Mass Analyzer Products 215-50 mass spectrometer on line with automated all-metal extraction system.

Aliquots of 3 to 5 sanidine crystals were fused by a 10 watt Synrad CO2 laser.

Reactive gases removed during a 2 minute reaction with 2 SAES GP-50 getters, 1 operated at ~450∞∞C and 1 at 20∞∞C. Gas also exposed to a W filament operated at ~2000∞∞C and a cold finger operated at -140∞∞C.

Electron multiplier sensitivity averaged 1.67 x 10-17 moles/pA.

Total system blank and background averaged 258, 1.5, 0.5, 2.0, 2.1 x 10-18 moles at masses 40, 39, 38, 37 and 36, respectively.

Correction factors for interfering nuclear reactions were determined using K-glass and CaF2 and are as follows:

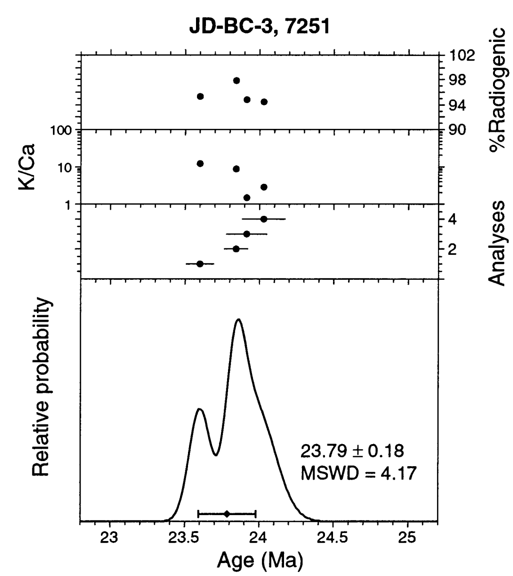
Age calculations:

Isotopic ratios corrected for blank, radioactive decay, and mass discrimination, not corrected for interfering reactions.

Errors quoted for individual analyses include analytical error only, without interfering reaction or J uncertainties.

Mean age is weighted mean age of Taylor (1982). Mean age error is weighted error of the mean (Taylor, 1982), multiplied by the root of the MSWD where MSWD>1, and also incorporates uncertainty in J factors and irradiation correction uncertainties.

Ages calculated relative to FC-1 Fish Canyon Tuff sanidine interlaboratory standard at 28.02 Ma (Renne et al., 1998).



McCarty Creek): The outcrops used by Fisher and Rensberger to identify the Haystack Valley Member south of Kimberly were considered by them to be ''particularly well developed along the eastern margin of the John Day River valley (secs. 7 and 17, T10S, R26E), where [this unit] lies in well-exposed contact with the underlying Kimberly Member.'' At the base of the unit they recognized a distinctive welded tuff-bearing conglomerate (Fisher and Rensberger, 1972: 17–18, fig. 3, measured section 8). The unit appears as a series of topographically high exposures not exceeding 70–100 feet in thickness along the eastern wall of the John Day valley for about 7 miles south of Kimberly post office (fig. 2). It lies with erosional and angular unconformity (EMU_2) across both Kimberly and Turtle Cove Members, as Fisher noted. The polymictic welded tuff-bearing conglomerate, which can be traced at the base of the unit from Spring Creek south to McCarty Creek (figs. 9–11, Maps C, D), is strikingly similar in clast size and composition to the polymictic conglomerate at the base of Unit 5 in the Beardog Section at Balm Creek (fig. 6, Map A).

A distinctive lithofacies association characterizes the unit south of Kimberly: polymictic welded tuff-bearing conglomerate, debris flows, coarse-shard tuffs (commonly with vesicular obsidian shards), and thin beds of dark gray airfall tuff. Interbedded fine-grained tuffaceous claystones, siltstones, and very fine sandstones are commonly olive-gray to pale yellow-gray and weather to smooth slopes with occasional thin resistant interbeds. The debris flows are lithically uniform: welded tuff pebbles derived from the Picture Gorge ignimbrite occur as well-rounded matrix-supported clasts scattered through fine-grained gray structureless tuff (fig. 12). These flows are frequently heavily overprinted by paleosol features: siliceous white rhizoliths, invertebrate burrows, devitrification, and soil brecciation. The unit is not zeolitized and often terminates in sets of stacked siliceous paleosols. This lithofacies association is also present in Unit 5 on Balm Creek (fig. 6).

An important lithologic correlation exists between the high unit south of Kimberly on the east wall of the valley and Unit 5 at Balm Creek (figs. 6, 10). Both units show erosional and angularly unconformable relations with the John Day rocks below; both have basal polymictic conglomerates of similar clast type and mean intermediate diameter for the 10 largest clasts (table 1, −6 to −8ø, cobble gravel of the Wentworth-Udden scale); both include similar lithologies and lithofacies above the basal conglomerate; and both represent the stratigraphically highest unit in their local areas beneath the Columbia basalts. We select the name *Rose Creek Member* for this unit and designate as its type area the narrow belt of nearly continuous exposures along the east wall of the John Day valley south of Kimberly (figs. 9, 10), extending from the NW¼, sec. 8, T10S, R26E on the north, through the west half of sections 17, 20, 29, T10S, R26E, to the SW¼, sec. 32, T8S, R26E, Mt. Misery 7.5-minute quadrangle (Maps C, D, sections 7–14). We also apply this member designation to Unit 5 of the Balm Creek syncline based on similar lithologic, lithofacies, and positional relations.

This interpretation differs from that of Fisher and Rensberger (1972), who suggested that the high unit south of Kimberly along the east wall of the John Day valley correlated with our Unit 2 and higher beds below the Columbia basalts in the Balm Creek section. Their interpretation was based in part on the presence of welded tuff conglomerate in both Unit 2 of the Balm Creek section and in the Rose Creek Member. Here we emphasize that the mean intermediate diameters and clast types of the Unit 2 conglomerates of the revised Haystack Valley Member in the Balm Creek sections differ from the Rose Creek Member conglomerates south of Kimberly as shown in table 1. Unit 2A conglomerates are monomictic, welded tuff-bearing, pebble gravels, whereas Rose Creek Member conglomerates are polymictic (welded tuff and various other clasts) pebble-to-cobble gravels considerably coarser than those of Unit 2. Furthermore, biochronologic and radiometric data discussed below show that Unit 2 at Balm Creek and the Rose Creek Member along the east wall of the John Day valley differ significantly in age by as much as 5–6 million years (table 3).

Welded-Tuff Conglomerates of the

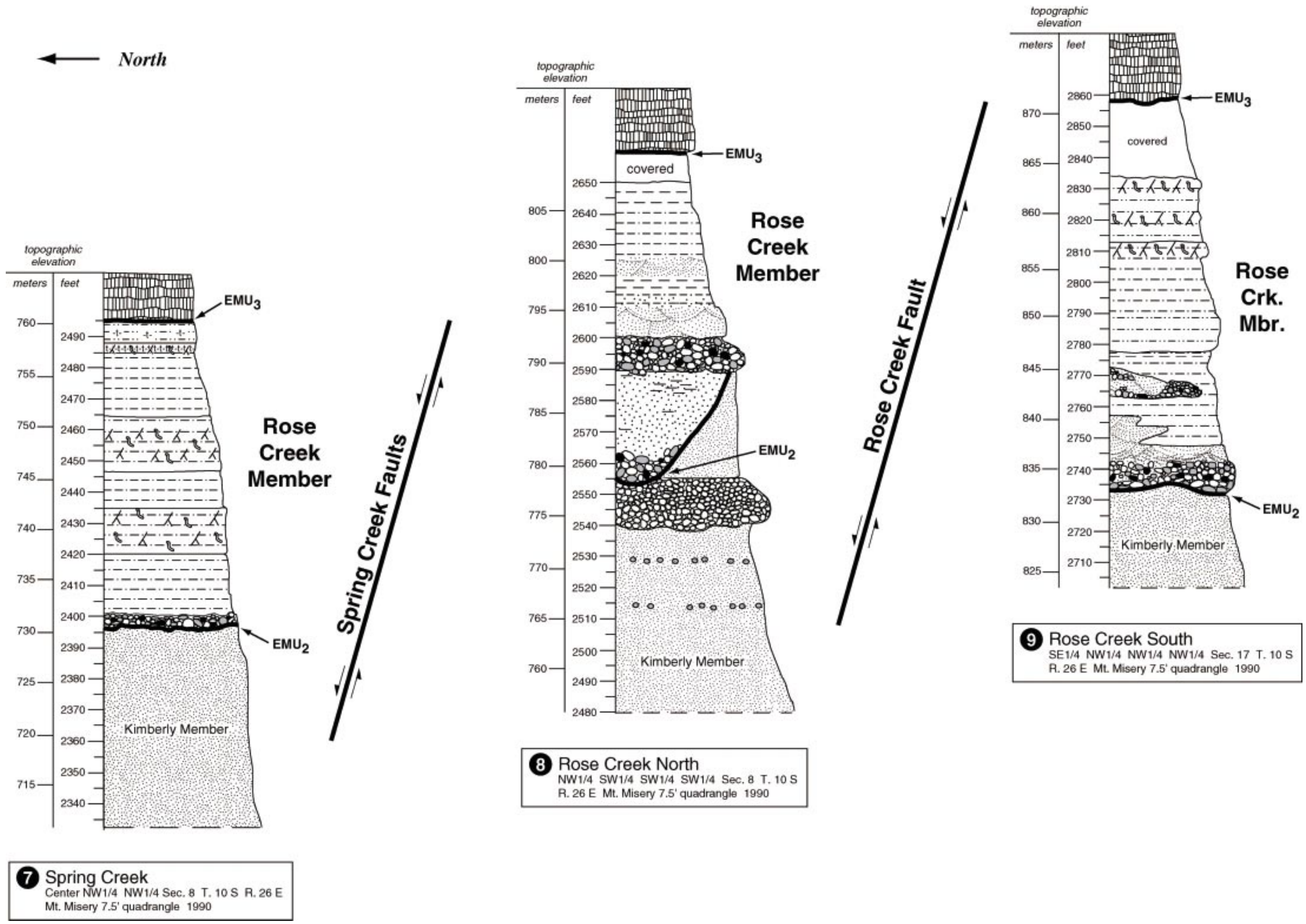


Fig. 9. Stratigraphic profile of the east wall of the John Day valley south of Kimberly from Spring Creek to Rose Creek. Downfaulting of the Rose Creek Member along the Rose Creek fault and at faults in the vicinity of Spring Creek results in offset of >300 ft (from ~2735 to ~2400 ft) over a distance of 1 mi (1.6 km). The profile continues to the south in figure 10.

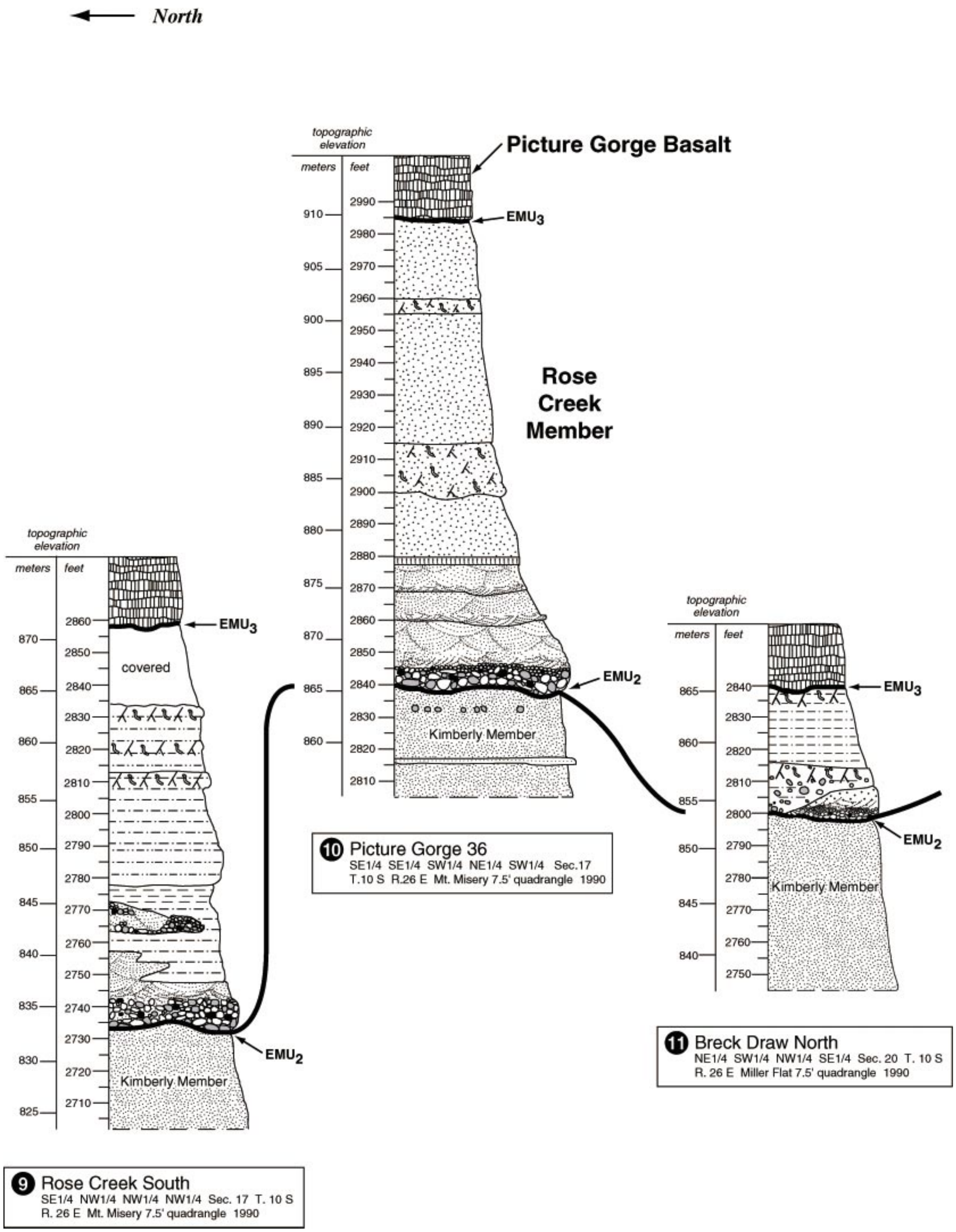


Fig. 10. Stratigraphic profile of the east wall of the John Day valley south of Kimberly from Rose Creek south to McCarty Creek (Foree South). The Rose Creek Member rests with angular unconformity on older John Day rocks (Turtle Cove and Kimberly Members). The early Hemingfordian mammal fauna from the Rose Creek Member comes primarily from Picture Gorge 36 and sites at Rose Creek.

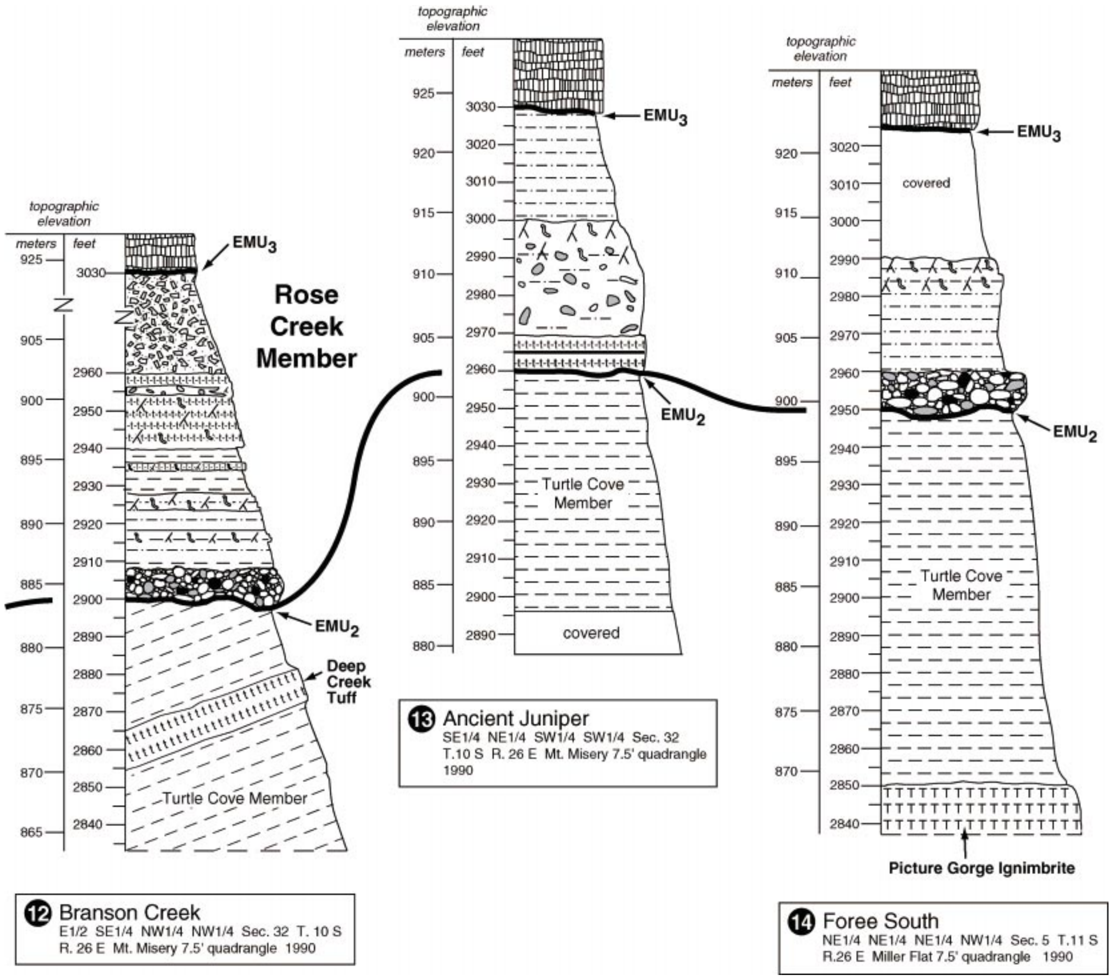


Fig. 10. Continued. The Rose Creek Member is characterized by a lithofacies association comprising polymictic welded tuff-bearing conglomerate fining upward to gray-black coarse detrital fluvial sandstone, debris flows, coarse obsidian-shard tuff, and olive-gray tuffaceous siltstone and claystone, overprinted by siliceous paleosols.

ROSE CREEK MEMBER: Clasts derived from the Picture Gorge ignimbrite, particularly those from partially to strongly welded parts of the flow, make up a significant fraction of the pebbles and cobbles in the conglomerates of the Rose Creek Member. The term ignimbrite is used here in the sense of Fisher (1966b: 6) as a general term for all rock types that are produced by dispersal of fragments from a pyroclastic flow. Fisher observed several lithologies in the two cooling units of the Picture Gorge ignimbrite, including air-fall tuff, unwelded and partially welded lapilli tuff, and densely welded tuff. Some of these types can be recognized in hand specimen in the conglomerates and are summarized in table 1. Hay (1963: 206) recorded that the ''ignimbrite exhibits all gradations between nonporous, highly welded tuff and porous, friable lapilli tuff in which the particles of glass are neither flattened by compaction nor welded.''

According to Fisher (1966b), a basal air-fall tuff and unwelded tuff making up the lowest two units of the ignimbrite are rhyolitic and the higher units are dacitic in composition. The air-fall tuff and the two overlying cooling units are composed mostly of

Fig. 11. The Rose Creek Member at the early Hemingfordian mammal locality Picture Gorge 36. Coarse polymictic gravels, sands, and overlying tuffaceous sediments of the Rose Creek Member (**rc**) incise the Kimberly Member gray tuffs (**k**). Dashed white line marks the contact between the two units.

vitric shards and pumice fragments which can be readily observed in hand specimen under the binocular microscope. Lapilli include pumice and rock fragments of crystalline salic rocks and vitric welded tuff. The unwelded base of Fisher's cooling unit 1 is a friable tuff that grades in places into welded tuff and a black obsidian-like glass.

Many clast types in the Rose Creek Member conglomerates can be attributed to the Picture Gorge ignimbrite. They are derived from the densely welded or partially welded portions of the ignimbrite and can be grouped into discrete classes: (a) olive to dark brown, crystal-poor, densely welded tuff with dark pumice fiamme; (b) greenish-gray, pale yellow or red rhyolitic/dacitic welded tuff, with a few small euhedral or broken quartz and feldspar phenocrysts distributed in an aphanitic microcrystalline groundmass (without dark pumice fiamme); (c) partially to densely welded, gray to dark gray obsidian-shard tuff, often vitreous, exhibiting shard compaction and buff pumice lapilli; (d) welded obsidian-like black glass clasts (not a true obsidian but an end-member densely welded tuff described by Ross and Smith, 1960: 24, fig. 9); (e) gray lapilli tuff, commonly with brown vitric welded tuff lapilli in a gray devitrified aphanitic groundmass. Locally, clasts of the densely welded tuff display an attractive red and gray banding.

Smith (1960) observed that deformation of shards and pumice fragments is the only certain criterion for recognition of welding in tuffs that have crystallized, which is often the case in geologically older ash flows. Only the densely welded and/or crystallized units of the ignimbrite have survived as clasts in the conglomerates of the Rose Creek Member, the unwelded tuff and air-fall tuff units being too soft and friable to survive erosion and transport as cohesive clasts. Smith noted that the transition from unwelded to densely welded is accompanied by loss of pore space and progressive deformation of glass shards and pumice. The Rose Creek conglomerate

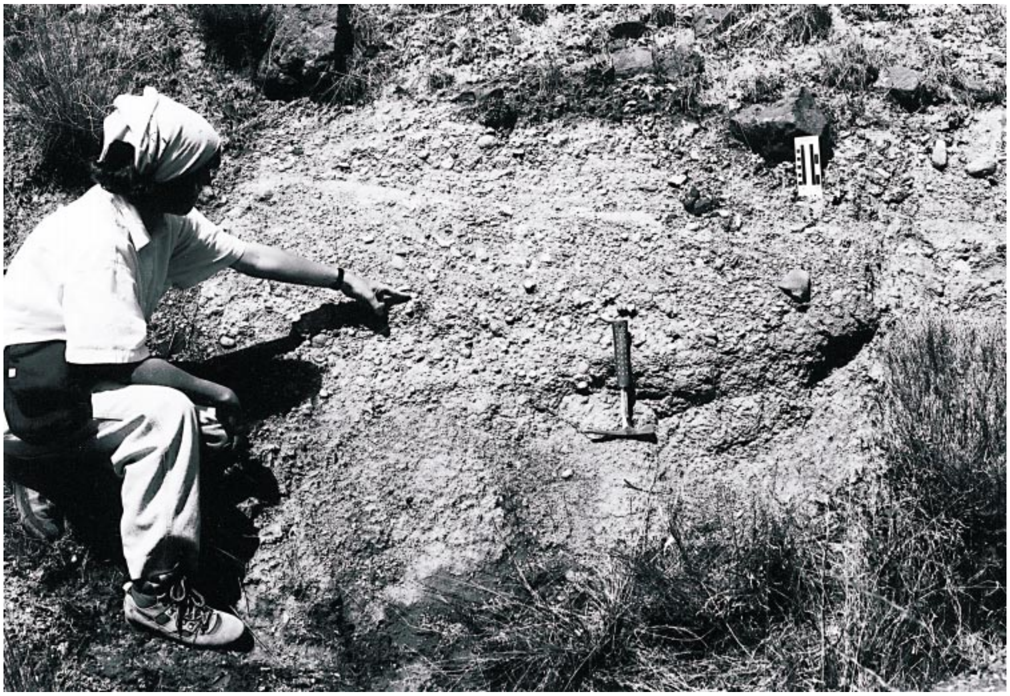


Fig. 12. Debris flows characterize Rose Creek Member outcrops along the east wall of the John Day valley south of Kimberly, at Sutton Mountain, and at Balm Creek. Rounded clasts of welded tuff derived from the Picture Gorge ignimbrite, vitric tuff from subjacent John Day units, and clasts of Deep Creek tuff, are supported in a fine-grained tuffaceous matrix. Masses of water-saturated volcanic ash moved downslope into stream courses where fluvial gravels were incorporated and deposited as local debris lenses.

TABLE 3

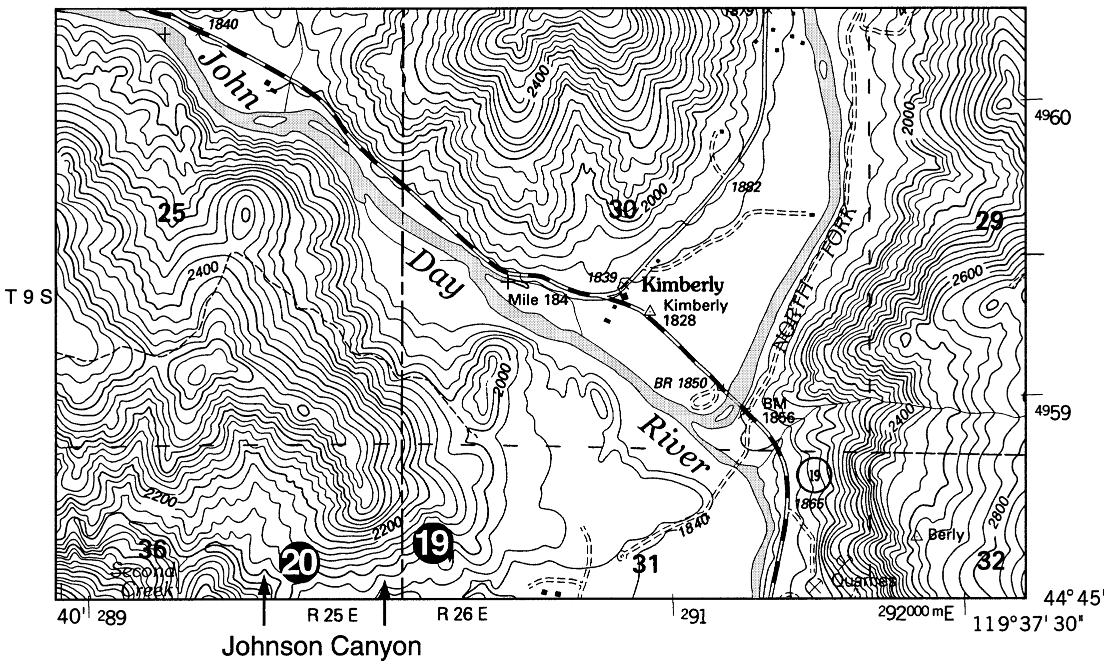
Biochronology and Geochronology of the Upper John Day Formation in the Haystack Valley-Kimberly Areas, John Day River Valley, Oregon

Lithostratigraphic unit	NALMA	Age
Rose Creek Member	Earliest Hemingfordian	~18.2–18.8 Ma[a]
Johnson Canyon Member		
Upper Unit	—	—
Lower Unit	Late or Latest Arikareean	?19.2–22.6 Ma[b]
Balm Creek Member	Late Arikareean	—
Haystack Valley Member (Revised)	Early Late Arikareean	~23.5–23.8 Ma[c]

[a] Paleomagnetic determination of earliest Hemingfordian strata in northwest Nebraska (MacFadden and Hunt, 1998: 162–163) and biochronologic correlation with fauna of the Rose Creek Member.

[b] An Upper Harrison tuff in Sioux County, Nebraska, was fission-track dated (zircon) at 19.2 ± 0.5 Ma (Hunt et al., 1983), and the white tuff in the lower part of the Johnson Canyon Member (ATR tuff, Fremd et al., 1994) was dated at 22.6 ± 0.13 Ma by $^{40}Ar/^{39}Ar$ (single crystal laser fusion method, C.C. Swisher, Rutgers University), defining an age range for the unit.

[c] $^{40}Ar/^{39}Ar$ dating of volcanogenic feldspar crystals in the Haystack Valley Member (revised), from 25–45 ft interval of Bear-dog Section (fig. 5), sampling a buff tuffaceous siltstone (table 2).



Map B: Topographic map of the Kimberly area, John Day valley, Oregon, Kimberly 7.5-minute quadrangle, indicating the location of measured sections in Johnson Canyon: **19,** Johnson Canyon East; **20,** Johnson Canyon West.

clasts derived from the ignimbrite, despite their textural and compositional variety, are nearly all entirely lacking in pore space and many display deformed pumice clasts and compacted shards, indicating their derivation from the welded portions of the ignimbrite cooling units. It is important to consider whether in Miocene and older ash flows such as the Picture Gorge ignimbrite the composition of the various ignimbrite zones may have been affected long after cooling by burial and ground-water diagenesis, further obscuring the initial textural composition of the rocks (Smith, 1960: 153). However, transport of these clasts and subsequent diagenesis in Rose Creek Member drainages has not prevented the identification in hand specimen of the various ignimbrite phases.

In addition to clasts derived from the ignimbrite, the Rose Creek conglomerates also contain clasts derived from the Deep Creek tuff (Fisher, 1962) and from subjacent vitric tuffs of the John Day Formation incised by the Rose Creek Member.

JOHNSON CANYON MEMBER (WEST WALL OF THE JOHN DAY VALLEY SOUTH OF KIMBERLY): Fisher's appraisal of the Kimberly and Haystack Valley Members south of Kimberly mentioned the stratigraphically high unit on the east wall (our Rose Creek Member) but did not discuss or examine in detail the beds thought by him to be of the same age on the west wall. Fisher and Rensberger (1972: fig. 3, measured section 9) presented a stratigraphic section of the west wall at the mouth of Johnson Canyon; a conglomerate near the base in that section was questionably correlated with the basal conglomerate of the Rose Creek Member (their section 8) on the east wall. Haystack Valley and Kimberly Members were mapped together as a single unit both on the west and east walls of the valley without differentiation (Fisher and Rensberger, 1972: Map 2).

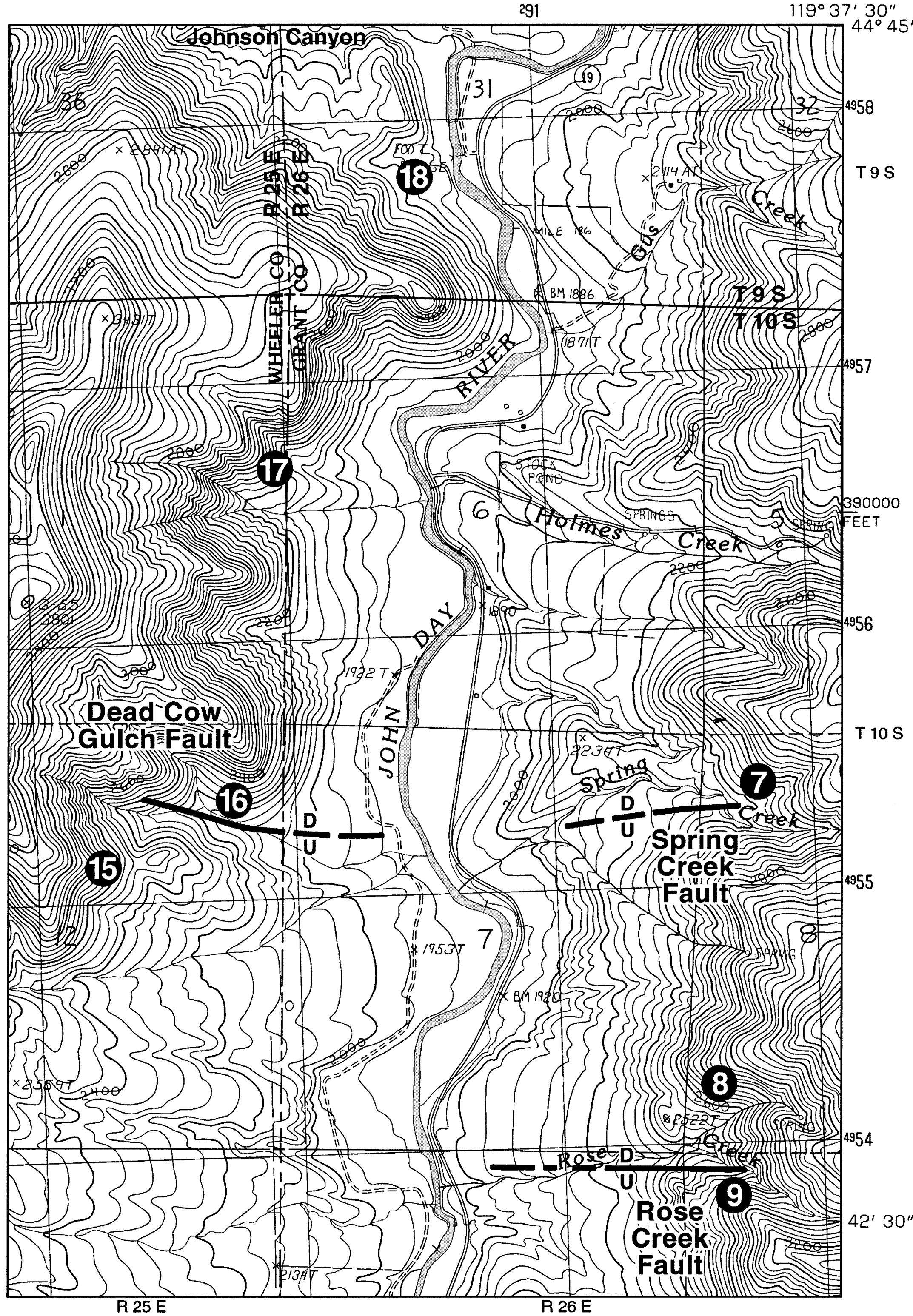
The best exposures of the Kimberly and Haystack Valley Members (*sensu* Fisher and Rensberger) along the west wall occur in Johnson Canyon 0.6 mi (1 km) southwest of Kimberly and along the John Day river for 3 mi south of Kimberly (Maps B, C, sections 16–20). Here Kimberly gray tuffs are disconformable beneath, in fact incised by, yellow-gray tuffaceous siltstones, sandstones, and intraformational monomictic vitric tuff-pebble conglomerate (figs. 13, 14, sections 16–17, EMU_1). These yellow-gray, fluvially worked tuffaceous sediments and the subjacent gray tuffs of the Kimberly Member are evidently the rocks assigned to their *Tjkh* map unit (Kimberly and Haystack Valley Members) by Fisher and Rensberger (1972: Map 2). It is these yellow-gray beds incised into the Kimberly Member that we regard as a lithostratigraphic unit distinct from the Haystack Valley Member (revised) along Balm Creek, and also lithically distinct from the Rose Creek Member along the east wall.

Outcrops at the mouth of Johnson Canyon (Maps B, C, sections 18–20) constitute the thickest measured section of these yellow-gray tuffaceous rocks along the west wall of the John Day valley south of Kimberly (~355 ft, fig. 15, from 1920 to 2278 ft). Here, these Johnson Canyon beds can be divided into an upper unit conformably superposed on a lower unit (fig. 16). The lower unit (fig. 15, ~1920–2130 ft) consists of fluvial sequences of intraformational monomictic vitric tuff-pebble conglomerate, tuffaceous sandstone, and siltstone that fine upward, terminating in a prominent paleosol that is continuous along the north wall of the canyon for 0.25 mi (0.4 km). An enormous tuff-filled vertebrate burrow, probably excavated by a large carnivore, can be seen in the north wall of Johnson Canyon penetrating this well-developed land surface (fig. 15, section 20, 2130 ft). Calcareous cementation predominates in the lower unit. Above the lower unit is an upper unit of three superposed massive gray airfall tuffs overprinted by siliceous paleosols (fig. 15, section 20, 2130–2212 ft). These cliff-forming tuffs are succeeded by coarse obsidian-shard tuffs, each fining upward and ending in a developed paleosol horizon (fig. 15, section 20, 2212–2250 ft). The upper unit concludes with ~25–30 ft of yellow-gray tuffaceous sandy siltstones beneath the capping basalts. The upper unit is characterized by silica cementation, especially in the paleosol horizons rich in siliceous rhizoliths.

A white vitric tuff is present in the lower unit of the Johnson Canyon beds 0.4 mi (0.6 km) south of the mouth of Johnson Canyon at UCMP locality Picture Gorge 1. Named the ATR tuff (Fremd et al., 1994), it has been dated by C.C. Swisher of Rutgers University at 22.6 ± 0.13 Ma ($^{40}Ar/^{39}Ar$). The ATR tuff can be traced from Picture Gorge 1 northward into the principal measured section of the Johnson Canyon beds along the canyon's north wall (fig. 15, Picture Gorge 1 to Johnson Canyon East). The tuff serves as a useful marker bed within Johnson Canyon and occurs at progressively lower elevations in outcrops from south to north, due to local block faulting.

We designate the upper and lower units at Johnson Canyon as the *Johnson Canyon Member*. These rocks can be distinguished from the Kimberly Member by the yellowish-gray color of the fine-grained tuffaceous beds, the more varied lithofacies, more numerous and deeply incised intraformational monomictic conglomerates of locally derived vitric tuff pebbles, the presence of the ATR marker tuff, and superposition on the uniformly gray Kimberly Member. When traced southward along the west wall of the John Day valley, the Johnson Canyon Member rests in erosional disconformity (EMU_1) on the gray tuffs of the Kimberly Member (fig. 13, Big Valley and UCMP V-6668 sections). A measured section at UCMP locality V-6668 shows a basal channel of the Johnson Canyon Member incised to a depth of at least 50 ft (fig. 13, 2310 ft) into the Kimberly Member gray tuffs. Similarly, at our Big Valley section, superposition of the Johnson Canyon Member on Kimberly beds is demonstrated by a sharp erosional contact between the underlying Kimberly gray tuff and a channel fill of intraformational monomictic conglomerate at the base of the Johnson Canyon Member (fig. 13, 2340 ft).

The Johnson Canyon Member is best exposed in Johnson Canyon and in isolated outcrops along the west wall of the John Day valley south of Kimberly above the uniformly gray Kimberly beds that form the base of the cliffs. We have not observed the member south of the N½, NE¼, sec. 12, T10S, R25E. South of this area the unit appears to have been removed by erosion, if it was ever present. The member occurs north of Johnson Canyon in the area of the Kimberly post office and can be traced northwest of Kimberly



Johnson Canyon
291
119° 37′ 30″
44° 45′
4958
T 9 S
4957
390000 FEET
4956
T 10 S
4955
4954
42′ 30″
R 25 E
R 26 E
WHELER CO
GRANT CO
R 25 E
R 26 E
T 9 S
T 10 S
JOHN DAY RIVER
Holmes Creek
Gus Creek
Spring Creek
Rose Creek
Dead Cow Gulch Fault
Spring Creek Fault
Rose Creek Fault
D
U
18
17
16
15
7
8
9

into the SE¼, sec. 24, T9S, R25E, and to the center, sec. 13, T9S, R25E along Bologna Creek.

When we first studied the outcrops in Johnson Canyon and other less exposed sections of upper John Day rocks south of Kimberly along the west wall, we were surprised to discover that there are no welded tuff-bearing conglomerates in these beds. The seven to eight levels of intraformational monomictic conglomerate in Johnson Canyon and nearby outcrops contain only locally derived, well-rounded, indurated vitric tuff clasts from subjacent tuffs incised by the channel scours (table 1, Johnson Canyon). Also, the clast size was much smaller on average (mean I.D. <7 cm) than that for the basal conglomerate of the Rose Creek Member on the east wall (mean I.D., 12 samples, 12.9 cm, table 1). This prompted us to ask whether the outcrops attributed by Fisher to the ''Haystack Valley Member'' on the west and east walls might not represent two different lithostratigraphic units that differed to some degree in age. Alternatively, they might be temporally equivalent sediment prisms distinguished by lithofacies formed in different depositional environments. In the latter case the polymictic welded tuff conglomerates of the east wall and the monomictic intraformational conglomerates of the west wall might simply reflect stream access to geographically disjunct source areas, one deriving welded tuff clasts from the Picture Gorge ignimbrite, the other from a drainage network of local gullies lacking access to the ignimbrite. We looked for other evidence that might provide insight into this problem. It was the unexpected discovery of a topographically high remnant outcrop of the Rose Creek Member on the *west* wall of the valley that initially suggested that the Rose Creek Member and the Johnson Canyon Member might be distinct lithostratigraphic units of different ages. This was eventually confirmed by the mammal faunas from the two members (table 4) and by radiometric dating.

RELATIVE AGES OF THE JOHNSON CANYON AND ROSE CREEK MEMBERS: High on the west wall of the John Day valley in the NE¼, sec. 12, T10S, R25E, opposite the mouth of Spring Creek, is an isolated outcrop overlying several hundred feet of Kimberly gray tuff at an elevation of 2670 feet (figs. 13, 14, Dead Cow Gulch Section). The outcrop begins with 70 feet of gray-brown claystones overlain by 30–40 feet of tuffaceous sediments that include distinctive coarse obsidian-shard tuff and debris flow units heavily overprinted by paleosols. This facies association is similar to Rose Creek Member lithofacies along the east wall of the valley (figs. 9, 10) where welded tuff conglomerates and fluvial sandstones yielded an early Hemingfordian fauna (~18.2–18.8 Ma) and were accompanied by obsidian-shard tuff and debris flow units with strong paleosol overprints. There is an evident correlation between these topographically high obsidian-shard tuff and debris flow units on the east and west walls of the valley, suggesting that the Dead Cow Gulch outcrop is an isolated outlier of the Rose Creek Member, in fact the only vestige of the member remaining along the west wall of the valley south of Kimberly.

The Rose Creek Member outlier rests on a mature calcareous paleosol at the top of the Kimberly Member that probably represents the uneroded, intact terminal surface of Kimberly deposition (fig. 13, Dead Cow Gulch Section, 2670 ft). A short distance (2000 ft) to the northeast at UCMP Locality V-6668 (fig. 13), a basal channel of the Johnson Canyon Member that deeply incises the Kimberly gray tuffs at this location is 360 ft below the high remnant outlier of the Rose Creek Member. Although these outcrops are separated by a normal fault (fig. 13, Dead Cow Gulch fault), the contrast in lithofacies and lithology in such a short distance is so

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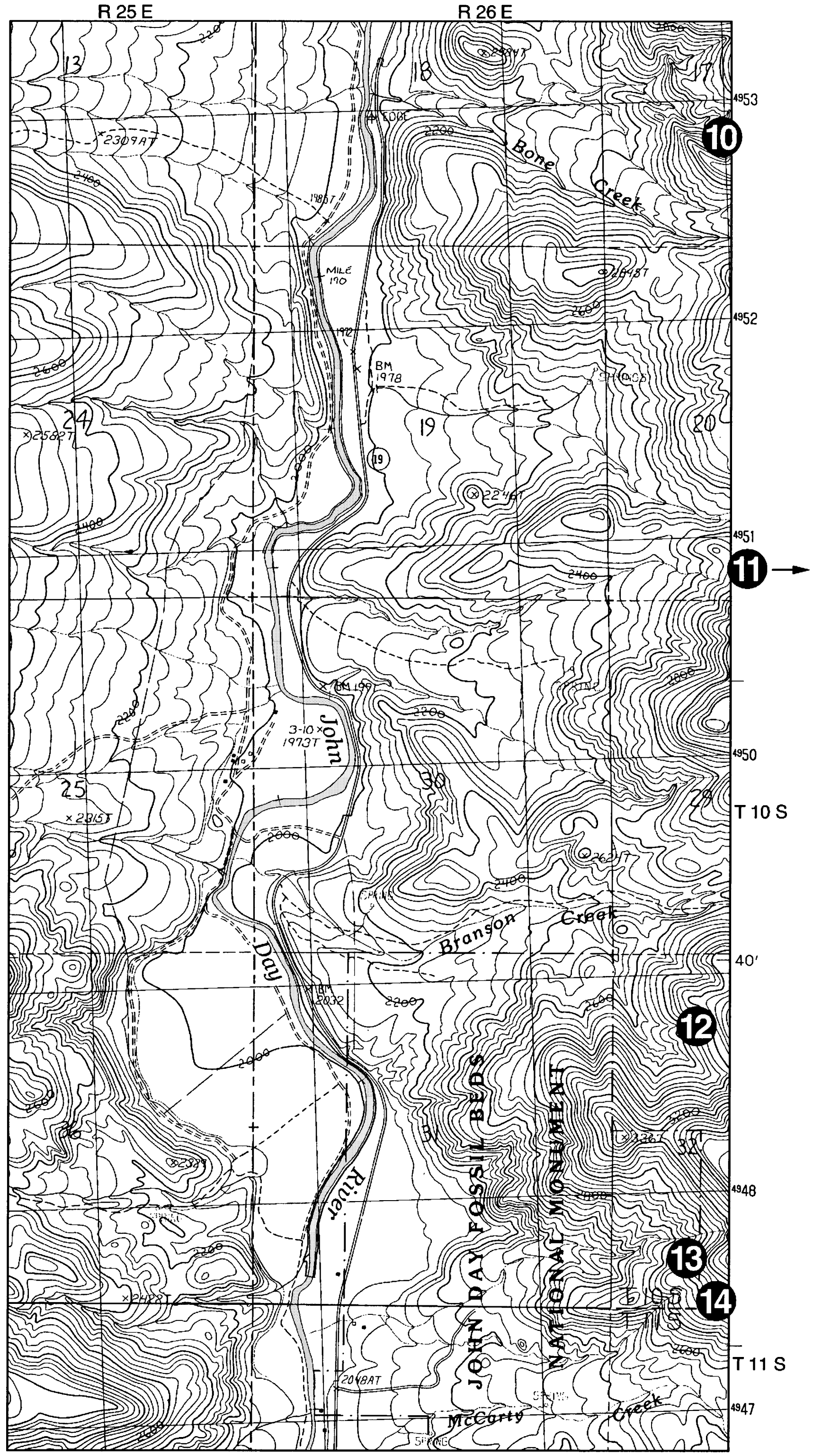
Map C: Topographic map of the John Day valley south of Kimberly, Oregon, Mt. Misery 7.5-minute quadrangle, from Johnson Canyon to Rose Creek, indicating measured sections along the east and west walls of the valley: **7,** Spring Creek; **8,** Rose Creek North; **9,** Rose Creek South; **15,** Dead Cow Gulch; **16,** UCMP locality V-6668; **17,** Big Valley; **18,** Picture Gorge 1.


R 25 E
R 26 E
4953
10
Bone Creek
MILE 190
4952
BM 1978
4951
11
4950
T 10 S
John Day River
Branson Creek
40′
12
JOHN DAY FOSSIL BEDS NATIONAL MONUMENT
4948
13
14
T 11 S
McCarty Creek
4947

marked that lateral equivalence is unlikely. The Johnson Canyon Member to the north of the Rose Creek outlier is capped by basalt flows that abut against the fault; thus, if the Rose Creek Member was superposed on the Johnson Canyon Member at an earlier time, it was removed by erosion before influx of the basalts.

At no locality south of Kimberly have we been able to observe the Rose Creek Member in superposition on the Johnson Canyon Member. However, biochronologic evidence discussed below reveals that the mammalian fauna obtained from the Johnson Canyon Member in Johnson Canyon is older than that from the Rose Creek Member, and at Sutton Mountain the Rose Creek Member overlies rocks that closely resemble the Johnson Canyon Member south of Kimberly (fig. 17).

UPPER JOHN DAY UNITS AT SUTTON MOUNTAIN: Hay (1963: fig. 2, sections 10–11) measured particularly thick sections of the upper John Day beds north of Bridge Creek along the southern face of Sutton Mountain. We studied the same area which occurs in the N½, sec. 33, and S½, sec. 29, T10S, R21E, Sutton Mountain 7.5-minute topographic quadrangle (fig. 17, appendices 1-10, 1-11). Upper John Day rocks fill a large paleovalley incised into earlier John Day beds in the center of section 33; this paleovalley fill is downdropped to the north along a west to east-trending normal fault mapped by Hay (1963: fig. 2, sec. 33, T10S, R21E). A thick, lithically homogeneous series of yellow-gray upper John Day tuffaceous sandstones, siltstones, and occasional lenses of intraformational monomictic vitric tuff-pebble gravel fills the paleovalley north of the fault, continuing upward for ~350 ft (fig. 17, Unit D, lower sequence[6]). This rock unit is overlain along a sharp but conformable contact by a gray cliff-forming tuff containing small obsidian shards, heavily overprinted by multiple stacked siliceous paleosols (fig. 17, Unit D, upper sequence); this upper sequence, 25–30 ft thick, is expressed topographically as a prominent bench along the south face of Sutton Mountain (center and NW¼, sec. 33, T10S, R21E).

Resting on Unit D, and in places incised into it with low relief, are ~100 ft of coarse polymictic welded tuff conglomerates, medium to coarse detrital sandstones, and brown to gray-brown tuffaceous claystones and siltstones interbedded with debris flow, gray lapilli tuff, and coarse obsidian-shard tuff units: these make up a series of fluvial fining-upward volcaniclastic units, most beginning with welded tuff conglomerate, grading upward through detrital sandstones to brown claystones. These lithofacies are typical of the Rose Creek Member south of Kimberly, suggesting correlation of the member over an east-west distance of ~32 mi (51.5 km).

In lithology, lithofacies, color, and style of sedimentation, Unit D resembles the Johnson Canyon Member south of Kimberly. The ~350 ft of section making up the lower sequence of Unit D closely corresponds to the lower unit in Johnson Canyon (fig. 15), and the upper sequence of gray tuff overprinted by siliceous paleosols is much like the upper unit in Johnson Canyon, although not as thick. We also have collected teeth of the small chalicothere *Moropus* cf. *oregonensis* from both the lower sequence of Unit D at Sutton Mountain and from the lower unit of the Johnson Canyon Member in Johnson Canyon. Thus, we consider Unit D at Sutton Mountain the lithologic and temporal correlative of the Johnson Canyon Member.

Superposition of the Rose Creek Member on the Johnson Canyon Member could not be demonstrated in the John Day valley south of Kimberly. However, along the south face

[6] Units A–C of our measured sections north of Bridge Creek are not described in this report.

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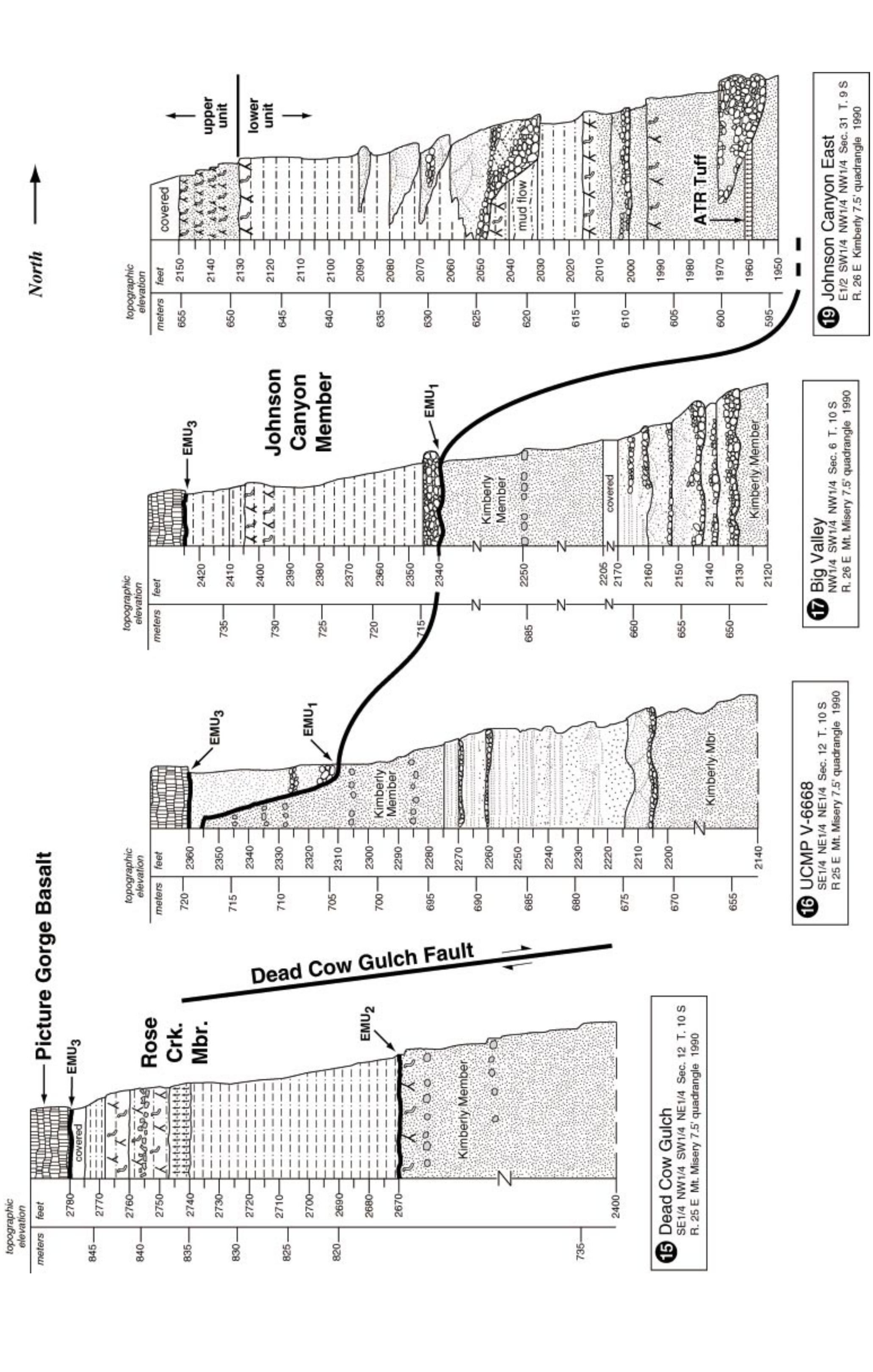
Map D: Topographic map of the John Day valley south of Kimberly, Oregon, Mt. Misery 7.5-minute quadrangle, from Bone Creek south to McCarty Creek, indicating measured sections along the east wall of the valley: **10,** Picture Gorge 36; **11,** Breck Draw North; **12,** Branson Creek; **13,** Ancient Juniper; **14,** Foree South.


North
Picture Gorge Basalt
Rose Crk. Mbr.
Dead Cow Gulch Fault
Johnson Canyon Member
upper unit
lower unit
EMU$_3$
EMU$_2$
EMU$_1$
ATR Tuff
mud flow
covered
Kimberly Member
Kimberly Mbr
topographic elevation
meters
feet
15 Dead Cow Gulch
SE1/4 NW1/4 SW1/4 NE1/4 Sec. 12 T. 10 S
R. 25 E Mt. Misery 7.5' quadrangle 1990
16 UCMP V-6668
SE1/4 NE1/4 NE1/4 Sec. 12 T. 10 S
R 25 E Mt. Misery 7.5' quadrangle 1990
17 Big Valley
NW1/4 SW1/4 NW1/4 Sec. 6 T. 10 S
R. 26 E Mt. Misery 7.5' quadrangle 1990
19 Johnson Canyon East
E1/2 SW1/4 NW1/4 NW1/4 Sec. 31 T. 9 S
R. 26 E Kimberly 7.5' quadrangle 1990

of Sutton Mountain the superposition of the Rose Creek Member on the Johnson Canyon Member (Unit D) supplies this critical stratigraphic relationship. Thus, the Johnson Canyon Member, considered older than the Rose Creek Member based on the mammalian fauna from Johnson Canyon south of Kimberly, can be documented in stratigraphic relation beneath the Rose Creek Member at Sutton Mountain, supporting the age relationship suggested independently by faunal content.

BIOCHRONOLOGY

The richly fossiliferous mid-Cenozoic rocks of the John Day region of central Oregon have attracted attention since the 1860s when Thomas Condon first collected fossil mammals in the John Day basin. Alerted by Condon's discoveries, O.C. Marsh of Yale University visited the region in 1871 and employed Leander Davis and William Day to collect John Day mammals during extensive field explorations from 1871 to 1877. In 1878–1879, Jacob Wortman and Charles Sternberg made important contributions to E.D. Cope's John Day collection, now conserved in the American Museum of Natural History, and in 1889 a party led by W.B. Scott acquired a significant collection for Princeton University. However, more disciplined investigations of the geology of the John Day sequence began with the University of California expeditions under John C. Merriam in 1899–1900. Merriam and his students established the first lithostratigraphic and petrographic characterization of the John Day beds, and at the same time added significantly to knowledge of the fauna, particularly in terms of the biostratigraphic succession.

Fossil mammals proved particularly important in age determination of upper John Day rock units in our study. Representative mammal faunas from the stratigraphically lowest and highest rock units in the Haystack Valley Member (sensu lato) of Fisher and Rensberger suggested that its age spanned about five million years, from ~23.5–23.8 Ma to as young as ~18.2–18.8 Ma (table 3), a much greater interval than previously suspected. The biochronologic data were supplemented by $^{40}Ar/^{39}Ar$ age determination of feldspars from the Haystack Valley Member (revised) at Balm Creek (table 2).

Mammals found by UNSM from 1993 to 2001, or otherwise identified in paleontological collections conserved at the University of California-Berkeley, Yale University, the American Museum of Natural History, and Princeton University, were assigned to the four members identified in our field study (table 4). Only specimens that could be attributed without question to a member are included in table 4. Exact stratigraphic placement of the fossils is documented in the appendices.

FAUNA OF THE HAYSTACK VALLEY MEMBER (REVISED): Fossil mammals occur throughout Units 1 and 2A in the Balm Creek drainage but were not found in Unit 2B. The fauna from Units 1 and 2A includes rodents, several oreodonts, two species of peccaries, a horse, a dicerathere rhinoceros, temnocyonine amphicyonids (beardogs), and rare specimens of small canids, camel, tapir, and hypertragulid (table 4; appendices 1-1 to 1-7). The stage of evolution of the fauna suggests an early late Arikareean age based on correlation with the Great Plains sequence.

Key mammalian taxa indicative of this age assignment are *Miohippus*, Hypertragulidae, temnocyonine beardogs, and advanced species of the rodents *Entoptychus* (*E. individens*) and *Allomys* (*A. tessellatus*), none of

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Fig. 13. Stratigraphic profile of the west wall of the John Day valley south of Kimberly. North of the Dead Cow Gulch fault the Johnson Canyon Member is incised into the Kimberly Member at UCMP V-6668 and Big Valley. The Johnson Canyon Member is downfaulted at least 400 ft between Big Valley, where the base of the member is exposed at 2340 ft, and Johnson Canyon, where the base occurs in the subsurface at unknown depth. South of the Dead Cow Gulch fault a terminal paleosol developed on the Kimberly Member is overlain at high elevation by an isolated outlier of the Rose Creek Member. Conglomerates of the Johnson Canyon Member are intraformational vitric tuff-pebble gravels; welded tuff clasts derived from the Picture Gorge ignimbrite are absent.

Fig. 14. West wall of the John Day valley south of Kimberly at Dead Cow Gulch. The Rose Creek Member (**a**) caps the Dead Cow Gulch measured section (fig. 13) south of the Dead Cow Gulch fault (**c**); the V-6668 section (**b**) occurs north of the fault. The fault follows a west-to-east trend along the gulch; flows of the Picture Gorge Basalt (**d**) abut the fault plane.

which has been found stratigraphically higher than the redefined member in the study area. Also useful in this regard are primitive forms of the camel *Paratylopus*, the oreodont *Paroreodon*, the tapir *Nexuotapirus*, and a rodent possibly representing the earliest known species of *Schizodontomys* (or, alternatively, a transitional form intermediate [?] between *Tenudomys* and *Schizodontomys*).

The rodent *Entoptychus individens*, the most advanced entoptychine reported by Rensberger (1971), occurs in the lower part of Unit 1 (fig. 4, Asher Section, 0 to 48 ft) ~250 to 280 ft below the dated tuffaceous siltstone (fig. 5, 25–45-ft interval, ~23.5–23.8 Ma; table 2) in Unit 2A of the Beardog Section. This rodent is common in the lowermost ~48 feet of Unit 1 as exposed along Balm Creek; however, because the lower contact of Unit 1 with subjacent rocks was not identified anywhere in the Balm Creek drainage, we are not able to determine the proximity of this rodent zone to the base of the revised Haystack Valley Member. We did not find entoptychines above Unit 1 in the Balm Creek sections.

The fauna together with the radiometric date from Unit 2A (table 2) indicate that the revised member is much older than previously believed, certainly older than the Rose Creek Member and its fauna south of Kimberly, which previously had been correlated by Fisher and Rensberger (1972) with rocks of the revised member in the Balm Creek area.

Fauna of the Balm Creek Member: A partial skull of a small peccary (cf. *Hesperhys*; appendix 1-6) was found in the lowest few feet of Unit 3 (fig. 5, 175–180 ft, Beardog Section: Lower); no additional fossil mammals are known from Unit 3, or from Units 4 and 5. The peccary indicates a late Arikareean age for the base of Unit 3, an age which probably pertains to the lithically uniform yellow-gray tuffaceous siltstones, claystones, and very fine sandstones comprising the lower half of the unit (fig. 5, 175–260 ft, Beardog Section: Lower and Middle) that produced this fossil. Because the lacustrine beds in the upper half of Unit 3 intertongue with the lower yellow-gray tuffaceous sediments, it seems likely that the entire unit is of late Arikareean age. The age of Unit 4 remains uncertain.

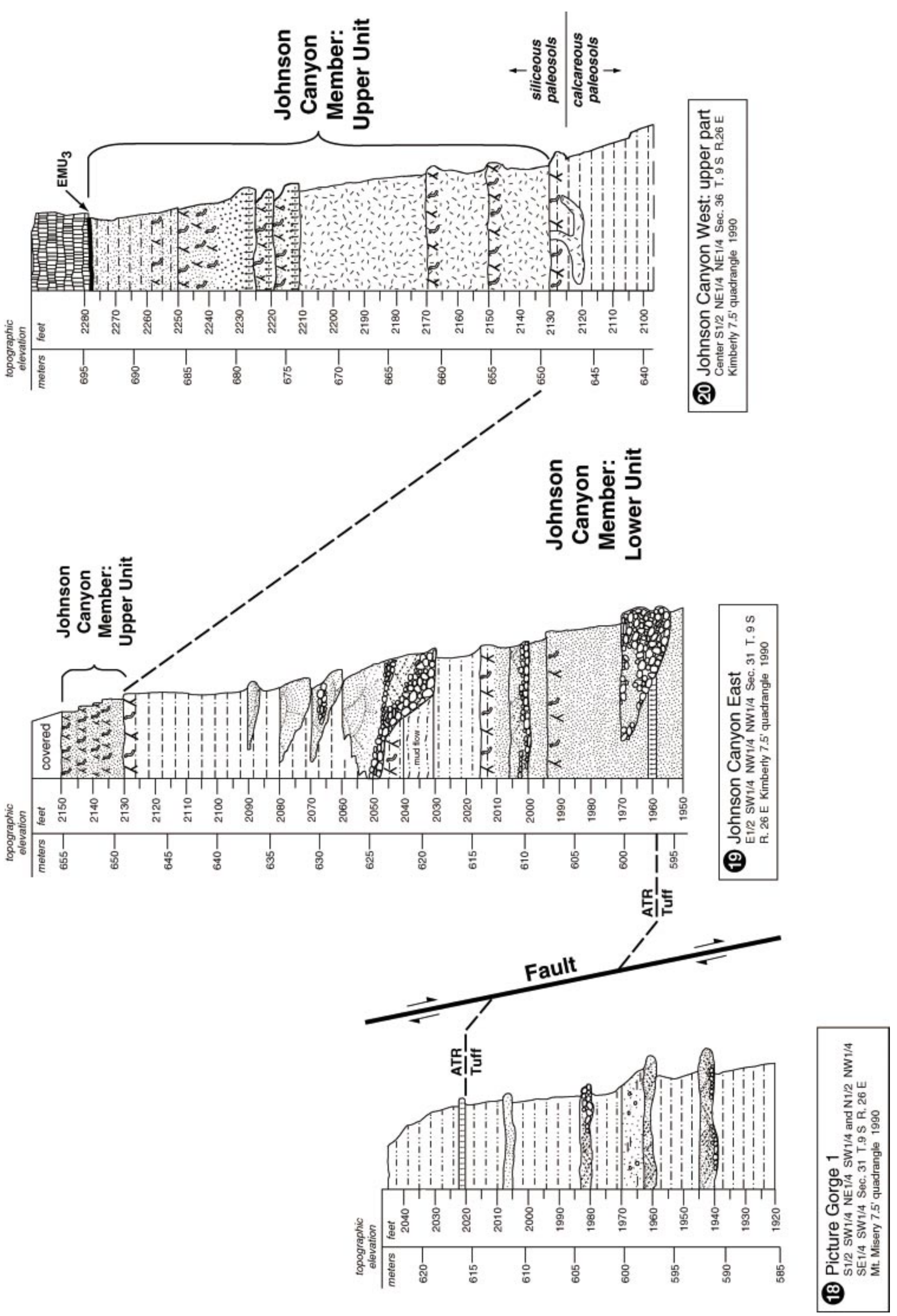
FAUNA OF THE JOHNSON CANYON MEMBER: Only the lower unit of the Johnson Canyon Member contains fossil mammals; none have been found in the near vertical exposures of the cliff-forming upper unit. Fossil mammals from the lower unit are frequently found in the intraformational conglomerates as stream-abraded specimens, but scattered and partially articulated individuals also occur in the fine-grained tuffaceous siltstones and sandstones. We examined specimens from this unit at the University of California-Berkeley and at the Los Angeles County Museum of Natural History, combining these identifications with those from our own fieldwork. Comparison of the fauna of the lower unit with the Great Plains sequence suggests a late to latest Arikareean age.

Age-indicative taxa of the Johnson Canyon Member include an advanced species of the oreodont *Paroreodon*; the camel *Paratylopus cameloides*; the peccary *Hesperhys*; an unidentified dromomerycid and the moschid deer *Parablastomeryx* cf. *advena*; the equids *Archaeohippus*, cf. *Kalobattipus*, and an anchithere; the small chalicothere *Moropus oregonensis*; the rhinoceroses *Diceratherium* and a small species of *Menoceras*; the tapir *Miotapirus harrisonensis*; the rodents *Schizodontomys* and *Mylagaulodon*; the small canids *Cynarctoides* cf. *luskensis* and *Desmocyon thomsoni*; and temnocyonine amphicyonids (table 4). We have not found *Miohippus*, parahippine horses, hypertragulids, or entoptychine and allomyine rodents in the Johnson Canyon Member. *Miohippus*, *Entoptychus*, and *Allomys* are presumably extinct by the time of deposition of the member; parahippine horses first appear in the deposits of the Rose Creek Member.

Fossils collected from the lower unit at the mouth of Johnson Canyon were plotted relative to the ATR tuff (~22.6 Ma), which serves as a useful stratigraphic datum. The mammalian fauna from below the ATR tuff does not appear to differ from the fauna collected above the tuff. However, we maintained these collections as two separate assemblages since future sampling of these rocks may indicate a difference. The assemblage below the tuff is designated here the *Picture Gorge 1 local fauna*; the assemblage above the tuff is named the *North Wall local fauna.* The North Wall local fauna includes not only the fossils from the lower unit of the member along the north wall of the canyon, but also the mammals from UCMP Locality V-6431 (Little Dike Locality) on the south side of the canyon where fossils were also found above the ATR tuff.

Almost all fossil mammals from the Johnson Canyon Member come from exposures at UCMP Picture Gorge 1 (V-6666) and Little Dike (V-6431) localities, and from the north wall outcrops (UCMP locality V-6432) at the mouth of Johnson Canyon (fig. 15; appendices 1-8, 1-9). The North Wall and Picture Gorge 1 local faunas compare with mammals collected by University of Nebraska and American Museum field parties from the Harrison Formation and Upper Harrison beds in Sioux County, Nebraska, and in adjacent Goshen and Platte Counties, Wyoming (Hunt, 1985, 1990). The Upper Harrison beds include the Eagle Crag Ash, a volcanic tuff dated by the fission track method (zircon) at 19.2 $\pm$ 0.5 Ma (Hunt et al., 1983). The Agate Ash within the Harrison Formation has recently been dated by the $^{40}Ar/^{39}Ar$ method to ~23 Ma (sanidine, 22.9 $\pm$ 0.08; Izett and Obradovich, 2001). In our view this provides an age range for the lower unit of the Johnson Canyon Member, and accordingly we have indicated its age in table 3 as within the ~19.2–22.6 Ma interval.

The fauna of the lower unit of the Johnson Canyon Member contains a number of taxa that indicate a younger age relative to that of the fauna from the Haystack Valley Member (revised). Johnson Canyon fossils of the oreodont *Paroreodon*, the camel *Paratylopus*, and the rodent *Schizodontomys* represent species more evolved than those of the same genera in the revised Haystack Valley Member along Balm Creek. The absence of *Miohippus* in the Johnson Canyon Member and the first appearance of dromomerycid and moschid cervoids also support this inference. Temnocyonine amphicyonids occur in both the revised Haystack Valley Member and the


Johnson Canyon Member: Upper Unit
EMU3
siliceous paleosols
calcareous paleosols
topographic elevation
meters
feet
20 Johnson Canyon West: upper part
Center S1/2 NE1/4 NE1/4 Sec. 36 T. 9 S R. 26 E
Kimberly 7.5' quadrangle 1990
Johnson Canyon Member: Lower Unit
Johnson Canyon Member: Upper Unit
covered
mud flow
19 Johnson Canyon East
E1/2 SW1/4 NW1/4 NW1/4 Sec. 31 T. 9 S
R. 26 E Kimberly 7.5' quadrangle 1990
ATR Tuff
Fault
ATR Tuff
18 Picture Gorge 1
S1/2 SW1/4 NE1/4 SW1/4 and N1/2 NW1/4
SE1/4 SW1/4 Sec. 31 T. 9 S R. 26 E
Mt. Misery 7.5' quadrangle 1990

Johnson Canyon Member but are absent and presumed extinct in the Rose Creek Member. The presence of a small species of *Menoceras*, temnocyonines, the canid *Cynarctoides* cf. *luskensis*, and tapir *Miotapirus harrisonensis*, and the absence of advanced parahippine horses in the lower unit at Johnson Canyon indicate a fauna older than that of the Rose Creek Member on the opposite wall of the John Day valley.

The heteromyid rodent *Schizodontomys* is represented in the lower unit at Johnson Canyon not only by the genoholotypic species (*S. greeni*, UCMP 39435, Rensberger, 1973: 62), which was almost certainly collected from below the ATR tuff at Picture Gorge 1, but also by several individuals of *Schizodontomys* found by us above the tuff at UCMP locality V-6432. The UNSM specimens of the genus are dentally advanced and compare with a species of *Schizodontomys* (*S.* cf. *harkseni*, UW 1298, Munthe, 1981) belonging to a fauna from the uppermost part of the Arikaree Group (Upper Harrison beds) at Uva, Platte County, Wyoming. We suggest that the Uva fauna is one of the youngest Arikareean assemblages yet discovered in the type area of the Arikareean NALMA and, based on the dated Eagle Crag Ash, probably falls near ~19 Ma. Thus, because of the near identity of *Schizodontomys* from Johnson Canyon and from Uva, we consider that the 22.6 Ma date for the ATR tuff may be a maximum age, and that the fauna from the lower unit in Johnson Canyon more likely falls somewhere within the younger part of the ~19.2–22.6 Ma interval.

FAUNA OF THE ROSE CREEK MEMBER: Study of mid-Cenozoic mammal faunas from the Arikaree and Hemingford Groups (late Oligocene to mid-Miocene) of the central Great Plains has resulted in a detailed biochronology calibrated by radiometric and paleomagnetic data (MacFadden and Hunt, 1998; Woodburne and Swisher, 1995; Tedford et al., 1987, 1996; Hunt, 1985, 1990). During our exploration of the Rose Creek Member on the east wall of the John Day valley south of Kimberly, we discovered fossil mammals useful in age determination at two localities. We were also able to examine specimens from this unit at the University of California-Berkeley collected in the 1960s by Lester Kent and John Rensberger. Comparison of these mammals with the Great Plains sequence suggests a precise correlation and supplements the earlier work of Rensberger using fossil rodents.

Age-indicative taxa discovered in the Rose Creek Member include the large oreodont *Merycochoerus magnus*; the dromomerycid *Barbouromeryx*; the small moschid deer *Parablastomeryx*; the camels *Paratylopus* and a larger species (cf. *Protolabis*); the equids *Parahippus pawniensis*, *Archaeohippus*, and an anchithere; the chalicothere *Moropus oregonensis*; a large beaver (cf. *Hystricops*); the rodents *Sewellelodon* and *Mylagaulodon*; and two new species of wolf-sized amphicyonid carnivorans (table 4; appendices 1-12 to 1-15). We have not found *Miohippus*, *Paroreodon*, temnocyonines, entoptychine and allomyine rodents, the heteromyid *Schizodontomys*, or tapirs in the Rose Creek Member.

These mammals are designated the *Picture Gorge 36 local fauna*. Almost all specimens have come from Rose Creek outcrops at UCMP locality Picture Gorge 36 (appendix 1-14) at the head of Bone Creek and UNSM

←

Fig. 15. Stratigraphic profile of the Johnson Canyon Member at the mouth of Johnson Canyon, west wall of the John Day valley south of Kimberly. The Johnson Canyon East and West sections are the thickest and most representative of the member in the vicinity of and south of Kimberly. The Picture Gorge 1 section is correlated with the Johnson Canyon East and West sections at the mouth of Johnson Canyon by the ATR tuff. The lower unit of the member is fossiliferous and characterized by fluvial sequences of monomictic vitric tuff-pebble conglomerate fining upward into tuffaceous yellow-gray fine sandstones and siltstones overprinted by calcareous paleosols. A marked change in the paleosols occurs at the contact with the upper unit: the airfall fine-grained gray tuffs and coarse obsidian-shard tuffs of the upper unit are overprinted by stacked siliceous paleosols. Superposition of the upper on the lower unit is also seen at Sutton Mountain (fig. 17).

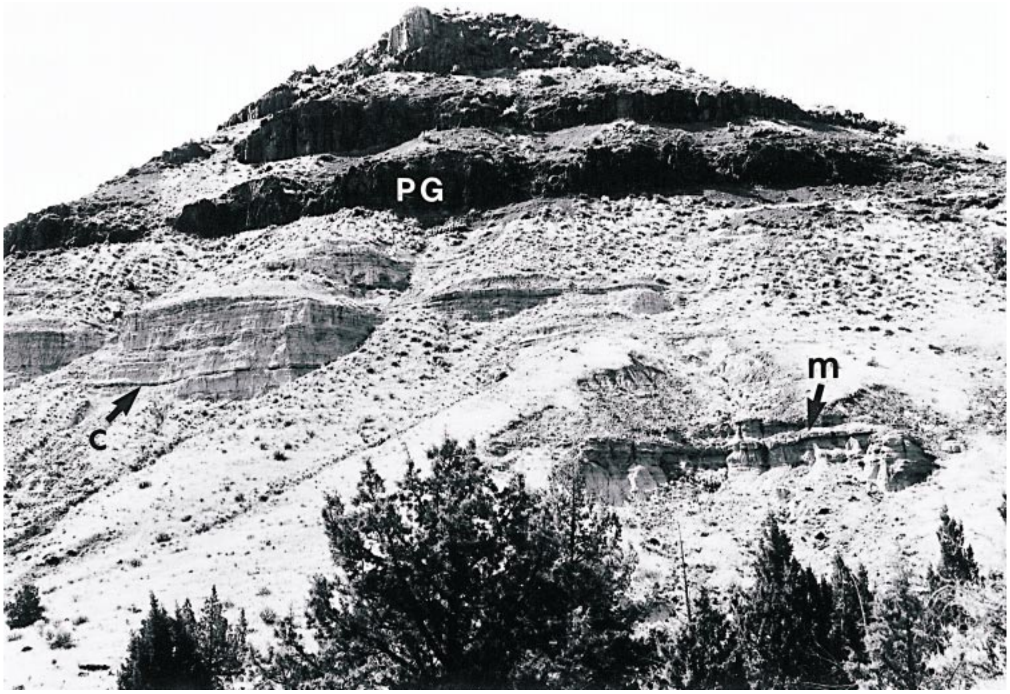


Fig. 16. The Johnson Canyon Member exposed along the north wall of Johnson Canyon southwest of Kimberly. The contact (**c**) between the lower and upper units of the member separates tuffaceous sediments with calcareous paleosols in the lower unit from tuffs overprinted by siliceous paleosols in the upper unit. Monomictic vitric tuff-pebble conglomerates (**m**) are restricted to the lower unit. PG, Picture Gorge Basalt Subgroup.

localities at the head of Rose Creek (appendices 1-12, 1-13). This local fauna compares with a fauna collected by University of Nebraska and American Museum field parties in Sioux County, Nebraska (*Northeast of Agate local fauna,* MacFadden and Hunt, 1998: 163). The Northeast of Agate local fauna occurs within sediments of the lower part of the Runningwater Formation paleomagnetically calibrated at ~18.2–18.8 Ma (MacFadden and Hunt, 1998: 162–163) and is stratigraphically above the Eagle Crag tuff in the Upper Harrison beds dated by fission-track (zircon) at 19.2 ± 0.5 Ma (Hunt et al., 1983). Consequently, we believe that the Picture Gorge 36 local fauna indicates an age of ~18.2–18.8 Ma for the Rose Creek Member south of Kimberly.

The association of several Rose Creek Member taxa support an early Hemingfordian age, equivalent to that of the lower part of the Runningwater Formation in Nebraska. Most important is the presence of the oreodont *Merycochoerus magnus*, which is found within a sharply restricted interval in the Great Plains and Rocky Mountains, the earliest Hemingfordian (fig. 18). In the Rose Creek Member this index oreodont is associated with the dromomerycid *Barbouromeryx*; the small moschid *Parablastomeryx schultzi*; a large beaver near *Hystricops*; the equid *Parahippus pawniensis*; and a large, long-limbed species of daphoenine amphicyonid, all closely related to similar species in the early Hemingfordian faunas of western Nebraska.

The Picture Gorge 36 local fauna is the youngest fauna known from the John Day Formation in the type area south of Kimberly. It dates the Rose Creek Member and provides an upper limit on John Day deposition at ~18 Ma for the eastern facies of the formation. The geographic extent of the Rose Creek Member also suggests, based on its presence (without fauna) in Haystack Valley (Balm Creek, Unit 5) and at Sutton Moun-

TABLE 4
Fossil Mammals of the Upper John Day Formation (exclusive of the Kimberly Member), Haystack Valley and Kimberly Areas, Oregon

HAYSTACK VALLEY MEMBER, REVISED (BALM CREEK SYNCLINE)	
Oreodontidae	*Paroreodon* cf. *marshi*
	cf. *Hypsiops*
Camelidae	*Paratylopus*
Hypertragulidae	cf. *Nanotragulus*
Tayassuidae	cf. *Hesperhys*
	Cynorca sociale
Equidae	*Miohippus*
Rhinocerotidae	*Diceratherium*
Tapiridae	*Nexuotapirus robustus*
Rodentia	*Schizodontomys* n. sp.
	cf. *Tenudomys* n. sp.
	Entoptychus individens
	Allomys tessellatus
Canidae	small species
Amphicyonidae	temnocyonines
Musteloidea	small species
BALM CREEK MEMBER (BALM CREEK SYNCLINE)	
Tayassuidae	cf. *Hesperhys*
JOHNSON CANYON MEMBER (SOUTH OF KIMBERLY)	
Oreodontidae	large oreodont
	Paroreodon n. sp.
Camelidae	*Paratylopus cameloides*
	small camelid
Dromomerycidae	dromomerycid
Moschidae	*Parablastomeryx* cf. *advena*
Tayassuidae	*Hesperhys*
Equidae	anchithere
	cf. *Kalobatippus*
	Archaeohippus
Rhinocerotidae	*Diceratherium*
	cf. *Menoceras*
Chalicotheriidae	*Moropus oregonensis*
Tapiridae	*Miotapirus harrisonensis*
Rodentia	*Schizodontomys greeni*
	Mylagaulodon angulatus
Lagomorpha	leporid
Canidae	*Cynarctoides* cf. *luskensis*
	Desmocyon thomsoni
Amphicyonidae	temnocyonines

TABLE 4
(Continued)

ROSE CREEK MEMBER (SOUTH OF KIMBERLY)	
Oreodontidae	*Merycochoerus magnus*
Camelidae	*Paratylopus*
	large camel, cf. *Protolabis*
Dromomerycidae	*Barbouromeryx*
Moschidae	*Parablastomeryx schultzi*
Equidae	*Parahippus pawniensis*
	cf. *Kalobatippus*
	anchithere
	Archaeohippus
Chalicotheriidae	*Moropus oregonensis*
Rhinocerotidae	*Diceratherium*
Rodentia	cf. *Hystricops*
	Sewellelodon cf. *predontia*
	Mylagaulodon
Canidae	*Desmocyon thomsoni*
	small canid
Amphicyonidae	large daphoenine n. sp.
	cf. *Amphicyon*

tain, that fluvial incision and deposition were geographically widespread at the beginning of the Hemingfordian in the Kimberly, Mt. Misery, and Sutton Mountain topographic quadrangles.

$^{40}Ar/^{39}Ar$ DATING

The early late Arikareean age determined on faunal evidence for the revised Haystack Valley Member along Balm Creek is supported by age determinations on feldspars from a tan tuffaceous unit sampled within the 25–45-ft interval of the Lower Beardog Section (fig. 5, UNSM sample JD-BC-3). Three to five crystals were used for each of four age determinations by Wm. McIntosh and L. Peters, New Mexico Geochronology Research Laboratory, New Mexico Bureau of Geology, Socorro (table 2). The higher K/Ca values for age determinations 7251-01 (23.8 ± 0.06 Ma) and 7251-03 (23.6 ± 0.07 Ma) suggest that all or most of the feldspar crystals in these samples were sanidines; these were considered the more reliable age data for the tuff. It is unlikely that detrital grains (xeno-

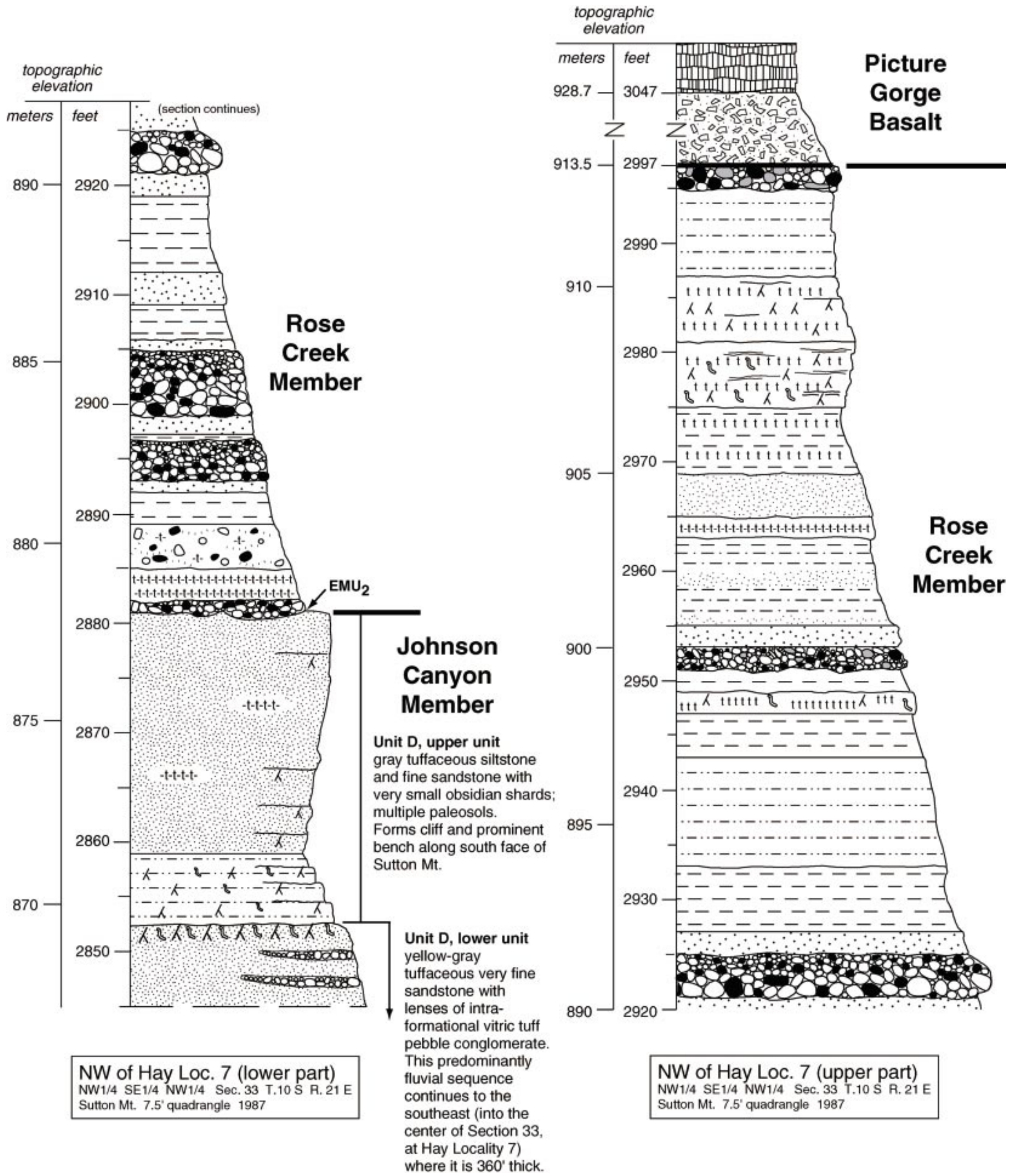


Fig. 17. Uppermost rock units of the John Day Formation at Sutton Mountain, Wheeler Co., Oregon. These exposures along the southern face of Sutton Mountain demonstrate the superposition of the Rose Creek Member on the Johnson Canyon Member (''Unit D'') in the N½, sec. 33, T10S, R21E, Sutton Mountain 7.5 min. quadrangle, in an area where Hay (1963: figs. 2, 4, section 11) also measured one of his thickest sections of upper John Day rocks.

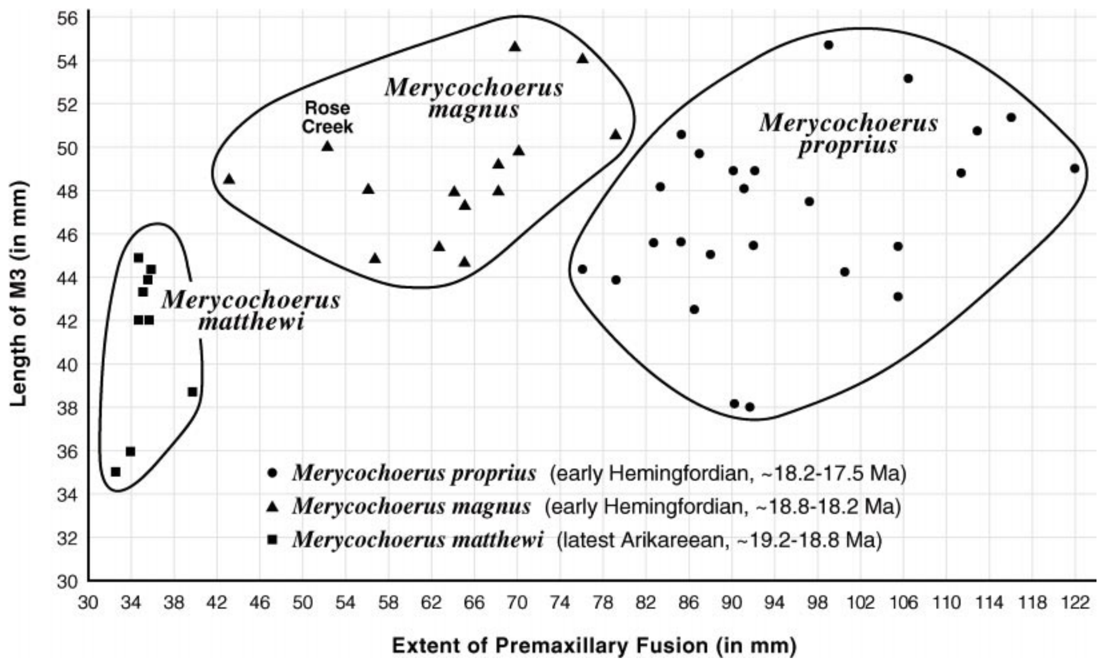


Fig. 18. The Great Plains oreodont *Merycochoerus* from the Childs Frick collection of the American Museum of Natural History provides biochronologic control for the occurrence of this indicator taxon in the upper John Day Formation, Oregon. Because many upper John Day taxa are represented by few individuals, the larger Frick samples of Arikareean/Hemingfordian mammals are critical to accurate age assessment. The graph measures the progressive fusion and posterior extension of the premaxillae in time, most likely related to ongoing development of a tapirlike proboscis in this large oreodont. The triangle labelled ''Rose Creek'' refers to UCMP 76848 from Picture Gorge 36.

crysts) were included: the tuff is massive, fine-grained, and appears to be made up largely if not entirely of air-fall debris.

The latest Arikareean age (~19 Ma) suggested by some species in the fauna from the lower unit of the Johnson Canyon Member appears somewhat discordant with a single-crystal laser-fusion $^{40}Ar/^{39}Ar$ date by C.C. Swisher (Rutgers University) of 22.6 ± 0.13 Ma from the Across-the-River Tuff (ATR Tuff, Fremd et al., 1994), but ongoing sampling and analysis may prove this to be a credible age for the lower unit.

REGIONAL AND LOCAL STRUCTURE

The tectonic setting of the John Day Formation has been discussed by Fisher (1967), Fisher and Rensberger (1972), Walker (1977), Robinson, Brem and McKee (1984), and Walker and Robinson (1990b); a regional overview following eruption of the flood-basalts is provided by Hooper and Conrey (1989) and references therein. Upper John Day rocks studied by us belong to the eastern facies of the formation and occur in Wheeler and Grant Counties, Oregon, south of the Blue Mountains uplift and north of the Ochoco and Aldrich Mountains (fig. 1). The structural pattern in this area was decribed by Fisher (1967). John Day rocks in the Haystack Valley-Kimberly area were deposited in a basin bounded on the north by the Blue Mountains and on the south by the Middle Mountain-Richmond anticlinal trend (Fisher, 1967: 119–120, fig. 2).

The tectonic history of the John Day Formation in the Haystack Valley-Kimberly area during the early Miocene involved both compressional and extensional episodes. Northwest-southeast to north-south compression, evidenced by folding and reverse faulting in Haystack Valley and by moderate warping south of Kimberly, deformed the older John Day units and involved rocks as young as the revised Haystack Valley Member and Balm Creek Member in Haystack Valley, and the Kimberly Member in its type area. This appears to have been a progressive, syntectonic compressional deformation that initiated the deposition of coarse upper John Day clastics along structural lows formed by synclinal folding. The master synclinal structures extended for tens of miles (Fisher, 1967).

An interval of stasis followed, punctuated by several eruptions of pyroclastic material from the Cascade Range (upper unit of the Johnson Canyon Member). We have not established whether a final compressional episode, or instead, an early phase of extensional deformation, triggered the deposition of the Rose Creek Member's coarse fluvial and debris flow facies, which clearly records a region-wide synchronous event. During the final phase of Rose Creek deposition, however, the fine-grained tuffs and stacked siliceous paleosols demonstrate that the familiar pattern of sporadic pyroclastic input, soil development, and erosion was again reestablished.

Nonetheless the evidence for post-Rose Creek extension is incontrovertible. Extensional tectonism down-dropped John Day sediments along normal faults in the Haystack Valley and Kimberly areas, creating a series of half-graben or grabens that seem to coincide with the earlier synclinal axes produced during compression (Mitchell and Monument synclines of Fisher). Basalt flows abutting nearly vertical fault scarps south of Kimberly, at Rose Creek and Dead Cow Gulch (fig. 14), suggest that the final phase of extensional faulting was soon followed by the initial basalt flooding in the region (Twickenham Basalt).

Our identification of regional unconformities extending over much of the study area contributed to the recognition of the major lithogenetic depositional units, designated here as members, within Fisher and Rensberger's (1972) Haystack Valley Member sensu lato. These members are of early Miocene age, and hence the bounding unconformities are designated in our measured sections as EMU_1 (early Miocene unconformity), EMU_2, and EMU_3. EMU_1 marks the unconformity at the base of the Johnson Canyon Member. EMU_2 is at the base of the Rose Creek Member. EMU_3 occurs at the base of the Picture Gorge Basalt Subgroup (PGBS), a subdivision of the Columbia River Basalt Group (CRBG).

The demonstration of an early Miocene angular unconformity (EMU_2, figs. 5, 6, 8–10, 13, 17) beneath the Rose Creek Member, separating it at several localities from the remainder of the John Day Formation, carries far-reaching implications for the stratigraphy of the formation and regional tectonics. In the Haystack Valley-Balm Creek area, upper John Day rocks of the revised Haystack Valley and Balm Creek Members were deformed and faulted before deposition of the Rose Creek Member. South of Kimberly, northward tilting, deformation, and subsequent erosion of the Turtle Cove and Kimberly Members of the John Day Formation preceded deposition of the Rose Creek Member. Angular unconformity of the Rose Creek Member on subjacent John Day rocks is best demonstrated south of Kimberly along the east wall of the John Day valley where the unit lies on Turtle Cove Member green claystones to the south and on Kimberly Member gray tuffs to the north (fig. 10). Later, the John Day Formation, including the Rose Creek Member, underwent extensive faulting and erosion during the late early Miocene (~18.0–?17 Ma) prior to the eruption of the Columbia flood-basalts. The oldest local flows are those of the Twickenham Basalt (Picture Gorge Basalt Subgroup) that filled valleys and other topographically low areas, eventually completely burying the varied topography developed on the John Day Formation (Bailey, 1989; Hooper and Swanson, 1990). The unconformity between the Columbia basalts and the John Day Formation in the study area is designated EMU_3 (figs. 5, 6–10, 13, 15).

Synclinal folding and subsequent downfaulting geographically isolated remnants of uppermost John Day rocks so that they escaped post-John Day erosion. Although much of the upper John Day in Haystack Valley has been removed by recent erosion, in the Balm Creek area the uppermost beds are preserved on a down-faulted block that incorporates the Balm Creek syncline and an adjacent anticlinal upwarp to the south (Fisher, 1967: fig. 5). Similarly, downdropped

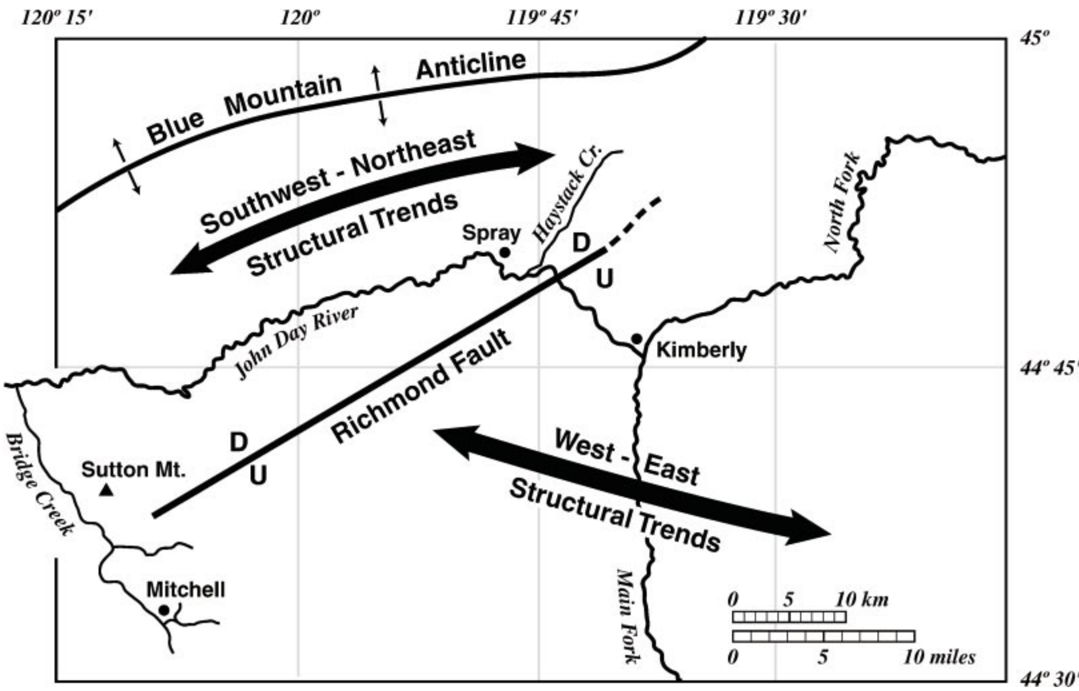


Fig. 19. Structural trends south of the Blue Mountains in the eastern subregion along the course of the John Day River (modified from Fisher, 1967). Upper John Day rocks east of Spray in Haystack Valley (Haystack Valley Member [revised] and Balm Creek Member) west of the Richmond fault differ from upper John Day rocks east of the fault in the vicinity of Kimberly (Johnson Canyon Member superposed on Kimberly Member). In both areas and at Sutton Mountain, however, the Rose Creek Member unconformably overlies and incises all of these upper John Day units and is the terminal member of the John Day Formation in the region.

fault blocks in the vicinity of Kimberly conserve the principal outcrops of the Johnson Canyon Member in its type area, this west-east trend apparently coinciding with Fisher's (1967) Monument syncline. Down-faulting of the Mitchell syncline along the trend of the Richmond fault also appears to be responsible for the preservation of uppermost John Day beds at Sutton Mountain (Gordon, 1988, and personal obs.).

HAYSTACK VALLEY—BALM CREEK: Fisher (1967) mapped the structural framework of the Haystack Valley area north of the Richmond fault. Haystack Valley lies on the south margin of a structural province situated between the Blue Mountains on the north and the nearly parallel trend of the Richmond fault on the south (fig. 19). In this area John Day sediments were warped into broad southwest-northeast trending synclines (Mitchell and Kahler synclines of Fisher, 1967: fig. 2) that parallel the trend of the Blue Mountain axis. Lesser anticlinal and synclinal folds of similar trend occur immediately north of the Richmond fault and south of the Kahler syncline in the Haystack Valley area (Fisher, 1967: fig. 5). Although he did not name it, the Balm Creek syncline belongs to this group of lesser folds and was mapped by Fisher (1967: fig. 5; Fisher and Rensberger, 1972: Map 3, secs. 26–28, T8S, R25E).

The Balm Creek and Rose Creek Members, the uppermost units of the John Day Formation identified in the Haystack Valley area, are preserved along the trend of the Balm Creek syncline. Southeast of the synclinal axis these members have been largely removed by erosion (fig. 20). However, in this same area the revised Haystack Valley Member is well exposed and can be traced from the syncline to the south and east where

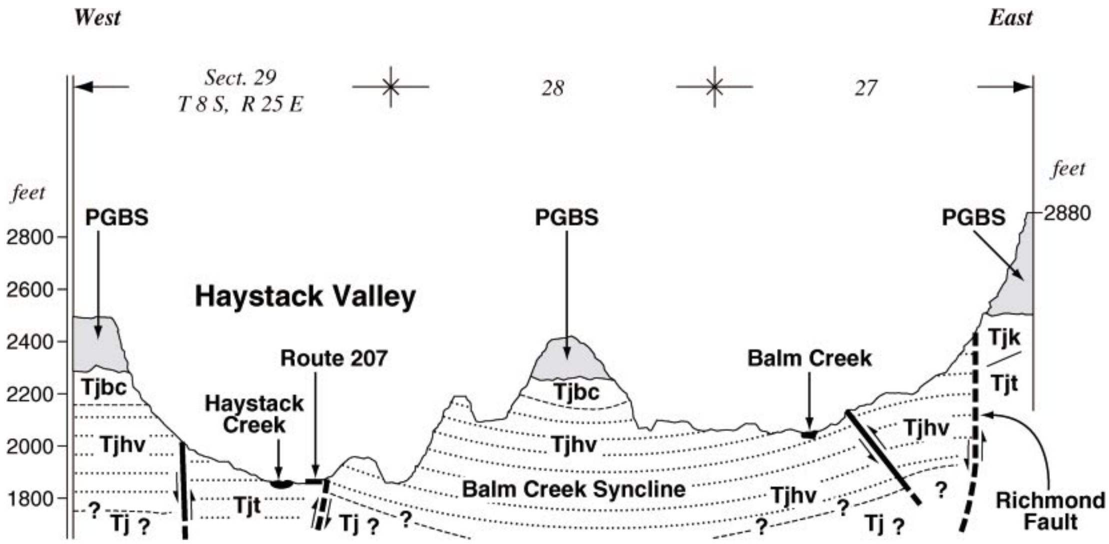


Fig. 20. Schematic cross-section from west to east across the valleys of Haystack Creek and Balm Creek, illustrating the interpreted structural relationships of fault blocks to the local stratigraphic sequence. Abbreviations: **Tj,** John Day Formation; **Tjt,** Turtle Cove Member; **Tjk,** Kimberly Member; **Tjhv,** Haystack Valley Member (revised); **Tjbc,** Balm Creek Member; **PGBS,** Picture Gorge Basalt Subgroup.

it is truncated by the projected trace of the Richmond fault. These exposures extending from the syncline to the fault form a rugged terrain of ridges and valleys that produced the greater part of the mammalian fauna from the member. They are broken by a prominent southwest-northeast trending reverse fault (not indicated on Fisher's maps) with vertical separation of ~20–50 ft that parallels the trend of the syncline. It extends from the NE¼, sec. 33 through the N½, NW¼, sec. 34, to the S½, SW¼, SE¼, sec. 27, T8S, R25E where it disappears beneath the Columbia basalts, which are not faulted. Regional northwest-southeast compression produced the synclinal folding and faulted the south limb of the syncline prior to eruption of the basalts, warping and offsetting rocks of the revised Haystack Valley Member and Balm Creek Member immediately northwest of the Richmond fault.

The Rose Creek Member apparently lies with angular unconformity on the Balm Creek Member along both the synclinal axis and to the south of the axis adjacent to the Richmond fault (in fig. 20 the Rose Creek Member does not occur along the cross-sectional transect). A measured section (HS-1 Section, fig. 8) in proximity to the fault shows that the upper part of the Balm Creek Member has been upwarped and removed by erosion, and the unconformity is overlain by welded-tuff conglomerate and tuffaceous units of the Rose Creek Member. Similar Rose Creek incision into the Balm Creek Member also occurred along the axis of the syncline but there the upper part of the Balm Creek Member was preserved (Beardog Section: Middle-Upper, figs. 5, 6).

Northwest of the Balm Creek syncline along the floor of Haystack Valley itself, uppermost John Day units have been removed by erosion and only the lower part of the formation (fig. 20, *Tjt*, Turtle Cove Member) is present (Fisher and Rensberger, 1972: Map 3). These outcrops are fossiliferous and produce a fauna that includes the large oreodont *Promerycochoerus*, *Miohippus*, hypertragulids, less advanced entoptychines, and the temnocyonine *Mammacyon*, indicating an age more typical of the middle of the formation above the Picture Gorge ignimbrite. On the west wall of Haystack Valley, cliff-forming exposures of upper John Day units are down-faulted against these older John Day rocks. The west wall preserves a section that includes the revised Haystack Valley Member and in places the lower part of the Balm Creek Member (fig. 20). These outcrops of uppermost John Day rocks can be traced westward to the village of Spray where prominent exposures occur north of the town.

JOHN DAY VALLEY SOUTH OF KIMBERLY: Southeast of the Richmond fault the regional structural pattern (fig. 19) is characterized by a more westerly to easterly grain of anticlines and fault trends (Fisher, 1967: fig. 2—the John Day, Middle Mountain, and Hamilton faults; Richmond and Black Butte anticlines). A structural profile based on Fisher's (1967: fig. 5) transect from Middle Mountain on the south to Kahler Basin on the north passes through the John Day valley south of Kimberly and includes the uppermost John Day rocks of this report (fig. 21). Fisher's profile shows John Day sediments filling a shallow basin ~25 mi (~40 km) in north-south extent. The John Day strata south of Kimberly are gently downwarped according to Fisher's interpretation; faulting is limited to the trace of the Richmond fault and is not identified south of Kimberly. Somewhat more pronounced folding is shown northwest of the Richmond fault where, at the scale of the profile, John Day strata have been warped into southwest-northeast trending synclines and anticlines.

Fisher's (1967) structural interpretation can be augmented by our field observations that identified extensive faulting south of Kimberly along both east and west walls of the John Day valley. The location of the faults is important in interpreting the lithostratigraphy of the formation south of Kimberly. From Johnson Canyon on the north to Rose Creek on the south, a distance of ~3 mi (~4.8 km), faulting is evidenced by vertical offset of marker units in measured sections, by the presence of springs in the valley walls, and by basalt-filled valleys approximately coincident with suspected fault trends. Faults are normal, down to the north, with vertical offsets from ~40 to >400 ft (~12 to >120 m). Fault trends are difficult to determine in several locations because of the covering basalts, but can be limited to northwest-southeast to west-east alignments. These faults apparently continue to the east into the Rudio Creek drainage where John Day exposures along the creek in secs. 25, 26, and 36, T9S, R26E are also down-faulted to the north along similar trends, preserving a thick accumulation of Kimberly Member sediments near the mouth of Rudio Creek.

Measured sections on the west wall of the John Day valley south of Kimberly (figs. 13, 15) indicate significant down-faulting of the Johnson Canyon Member and the subjacent Kimberly Member, beginning at Dead Cow Gulch in the N½, NE¼, sec. 12, T10S, R25E, and continuing northward to Johnson Canyon (W½, NW¼, sec. 31, T9S, R26E). The Kimberly Member appears to be downfaulted on the north at least 200 ft (60 m) at Dead Cow Gulch (fig. 13), the southernmost fault we have identified along the west wall. Immediately north of the fault the contact of the Johnson Canyon Member on Kimberly gray tuffs is present in Dead Cow Gulch at UCMP locality V-6668, and can be traced 0.8 mile (1.25 km) to the north at approximately the same elevation into the Big Valley section. If the Johnson Canyon Member is then followed farther north along the west wall, the member is apparently down-faulted >400 ft (>120 m) between the Big Valley section and Johnson Canyon (fig. 13). This suggests to us that the considerable thickness of the Johnson Canyon Member in the vicinity of Johnson Canyon and Kimberly post office is due to preservation of the member in a half-graben or graben setting.

Measured sections along the east wall of the John Day valley indicate a similar structural setting. Although there is some variation in the elevation of the lower contact of the Rose Creek Member from its southernmost outcrops at McCarty Creek (Foree) to Rose Creek on the north, the unit lies at a consistently high topographic elevation along the east wall (fig. 10). At Rose Creek, however, the section is abruptly down-faulted with nearly 200 ft (60 m) of vertical offset (Rose Creek fault, fig. 9). One mile (1.6 km) farther north at Spring Creek (fig. 9, section 7), the Rose Creek Member has been down-dropped an additional 160 ft (48 m). Beyond Spring Creek to the north, basalt flows descend to low elevations along the east wall and the Rose Creek Member is absent; if outcrops of the Rose Creek Member were once

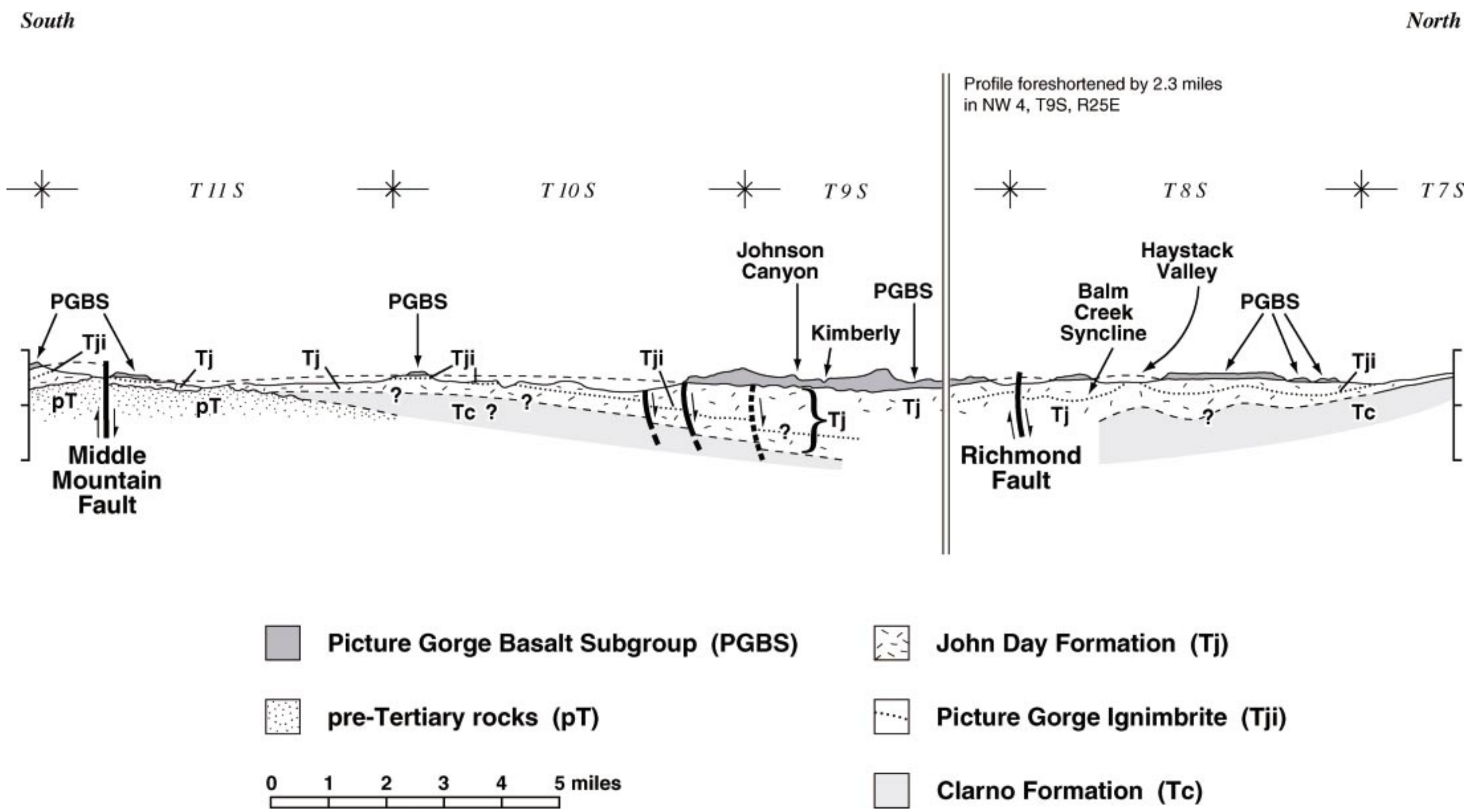


Fig. 21. Schematic cross-section of the John Day basin from Middle Mountain to ~3 mi south of the Blue Mountains uplift (based on Fisher, 1967: fig. 5). Note the thick upper John Day strata (i.e., above Tji) near the center of the transect in the vicinity of Kimberly (Kimberly, Johnson Canyon, and Rose Creek Members), and to the north of the Richmond fault in the Balm Creek syncline (Haystack Valley Member [revised], Balm Creek and Rose Creek Members). Length of cross-section: ~25 mi (~40 km). Abbreviations: **Tj,** John Day Formation; **Tji,** Picture Gorge ignimbrite; **Tc,** Clarno Formation; **pT,** pre-Tertiary rocks; **PGBS,** Picture Gorge Basalt Subgroup.

present, they were removed by pre-basalt erosion.

The down-to-the-north offset of John Day lithostratigraphic units on both walls of the John Day valley south of Kimberly suggests that uppermost John Day rocks were preserved from erosion on down-faulted blocks within a graben or half-graben system (fig. 22) that extends roughly parallel to Fisher's (1967: fig. 2) Monument syncline. The graben includes Kimberly Member and Johnson Canyon Member outcrops (1) along the John Day river northwest of Kimberly as far as Bologna Creek, with exposures possibly extending northwest to the Richmond fault; (2) north of Kimberly to the basalt rim of the John Day valley; and (3) east and northeast an unknown distance, probably as far as Portuguese Canyon (Fisher and Rensberger, 1972: Map 3, NE corner, T9S, R26E), and including the down-faulted exposures at the mouth of Rudio Creek. Pronounced erosional relief on the John Day Formation occurs along this graben system associated with the Monument syncline, and Fisher (1967: 121) realized that this relationship suggested that local drainages first developed along these topographic lows in post-John Day, pre-Columbia basalt time.

ERUPTION OF COLUMBIA FLOOD BASALTS: Shortly after the deposition and extensional faulting of the early Hemingfordian Rose Creek Member, the first flows of the Columbia flood basalts in the region erupted from the Monument dike fissures between Kimberly, Monument, and Courtrock, and from fissures in the vicinity of Picture Gorge. These flows belong to the Picture Gorge Basalt Subgroup (PGBS) of the Columbia River Basalt recently discussed by Bailey (1989). The ages of the oldest PGBS flows are unknown since the available radiometric dates are from flows at the type section in Picture Gorge where the lower third of the PGBS is absent (Bailey, 1989). Initial potassium-argon ages on flows at the type section ranged from 14.4 to 16.1 Ma (Baksi, 1974: 432, based on basalt crushed to coarse to very coarse sand size for argon extraction); more finely crushed samples yielded ages from 14.4 to 15.9 Ma but unfortunately these ages obtained from 14 flows did not correspond to the stratigraphic succession. Watkins and Baksi (1974) averaged the ages after combining these samples and identified an age range of 14.7 $\pm$ 0.2 to 15.9 $\pm$ 0.3 Ma. Baksi (1989) later adjusted these dates, arriving at an age range from 15.1 to 16.3 Ma, in an attempt to account for loss of radiogenic ^{40}Ar due to inclusion of fine-grained basaltic material in the samples. It is conceivable that the earliest PGBS flows, which do not occur at Picture Gorge, may be much older.

The oldest flows of the PGBS are assigned to the Twickenham Basalt made up of three members, from oldest to youngest: the Donnely Basin, Bologna Creek, and Muleshoe Creek Members (Bailey, 1989). The thickness of the oldest flows in the study area varies considerably in conformity with their eruption on a John Day surface of high relief. Bailey's (1989) study suggests that the Twickenham Basalt flows emerging from the Monument dike fissure system migrated along the synclinal/graben topographic lows, west to Donnely Basin and Alder Mountain, eastward to Monument Mountain and Zion Scope, and as far south of Kimberly as Holmes Creek. This flow pattern closely corresponds to the trend of the Mitchell-Monument synclines of Fisher (1967: figs. 2, 4) and his 2000-ft contour drawn at the base of the PGBS.

Evidently, the earliest PGBS flows of the Twickenham Basalt were following the structurally controlled, topographically low synclinal and/or graben structures that today correspond closely to the course of the John Day River from the vicinity of Monument westward to Kimberly, Haystack Valley, and southwest to Donnely Basin, Twickenham, and Sutton Mountain. Of particular interest in support of this view is that south of Kimberly the first flows of the Twickenham Basalt extended to the south only as far as the vicinity of Holmes Creek (fig. 2). These early flows do not extend southward beyond the Rose Creek fault system because they evidently abut against the fault scarps that existed at the conclusion of John Day deposition south of Kimberly. For example, in sec. 12, T10S, R25E, PGBS flows abut the Dead Cow Gulch fault, demonstrating the existence of the fault scarp at the time of eruption of these early flows (figs. 13, 14). Bailey's (1989) data can be interpreted to suggest that

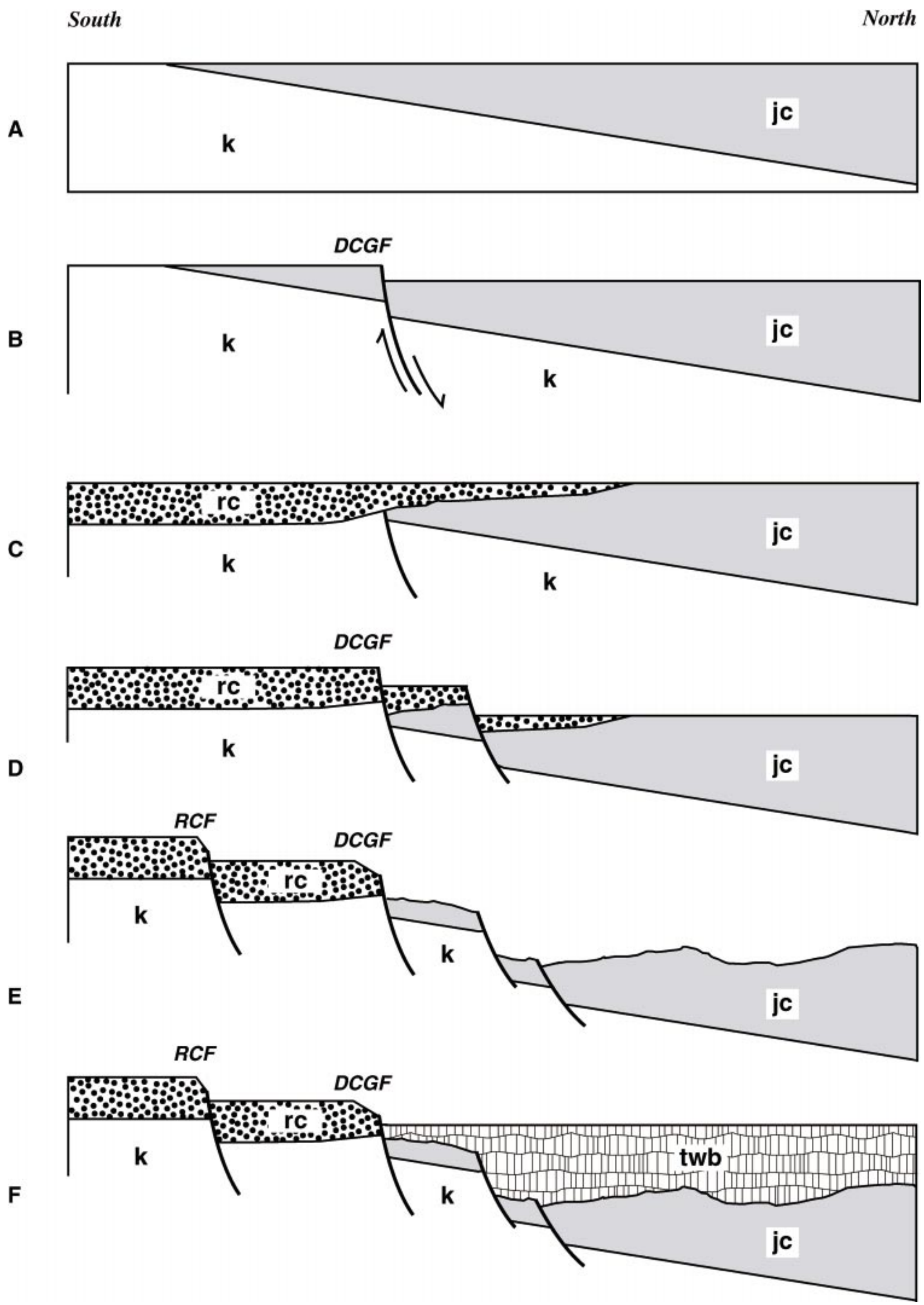


Fig. 22. Schematic diagram showing the hypothetical development (A–F) of an early Miocene half-graben or graben system in the vicinity of and south of Kimberly post office, John Day valley, Oregon. Abbreviations: **k,** Kimberly Member; **jc,** Johnson Canyon Member; **rc,** Rose Creek Member; **twb,** Twickenham Basalt; **DCGF,** Dead Cow Gulch fault; **RCF,** Rose Creek fault.

in time younger flows of the Monument Mountain Basalt (above the Twickenham Basalt) overtopped the faults and extended south to Middle Mountain. Over time the irregular John Day topography was filled by later flood-basalt to create a nearly level terrain: flows of the Monument Mountain Basalt are of considerable areal extent and by this time indicate low topographic relief throughout the basin (Bailey, 1989: 79).

Bailey (1989) remarked on the unusual thickness of flows of the Twickenham Basalt near their type locality along the John Day River, and his sections show that the earliest flows coincide with the present course of the river along the North Fork from Lower Camas Creek to Monument and Kimberly, thence westward to Bologna Creek, Haystack Valley, Donnely Basin, and Twickenham. It becomes evident that the present-day North Fork of the John Day River and its continuation west to Twickenham follow this ancient structural trend occupied by the earliest PGBS flows. This could only occur if at least some degree of moderate warping and/or faulting of the PGBS has continued along this structural trend.

Further evidence in support of this line of reasoning is found in the structural setting of the PGBS from Kimberly south along the John Day River to Picture Gorge. Fisher (1967: fig. 4) indicated that the modern course of the river followed a north-south linear topographic low filled by PGBS flows from Kimberly to Middle Mountain, and several tectonic maps of this area indicate the presence at this location of a north-south trending syncline (Walker, 1977; Brown and Thayer, 1966). This synclinal axis does not extend south beyond Middle Mountain, cut off by the east-west trend of the Richmond anticline (Fisher, 1967). That the Richmond anticline was elevated and eroded toward the end of John Day time is indicated by the angular unconformity of Rose Creek Member gravels on lower John Day rocks and the close stratigraphic approach of the Rose Creek Member to the Picture Gorge marker ignimbrite north of Middle Mountain (fig. 10, measured section 14). Thus, at the time that the earliest Twickenham flows erupted from the Monument dike fissures, the Middle Mountain-Richmond anticline area was a structural and topographic high, and only later did much younger flows of the PGBS eventually onlap this trend (Bailey, 1989: fig. 7, Branson Creek section). South of the Richmond anticline a separate fissure system erupted PGBS flows in the Picture Gorge area. The Richmond anticline-Middle Mountain high appears to have separated the flows of the Monument dike system from those of the Picture Gorge system to the south, ''substantiated by the many flows at Picture Gorge that cannot be correlated with the thicker sequences in the central portion of the basin'' (Bailey, 1989: 82).

DISCUSSION AND CONCLUSIONS

Lithostratigraphic mapping of the upper John Day beds by Fisher (1967) and Fisher and Rensberger (1972) provided a useful framework for additional studies of these rocks. Our examination of upper John Day rocks above the Kimberly Member in Haystack Valley and south of Kimberly suggests that the Haystack Valley Member can be divided into four lithostratigraphic units that convey the history of sedimentation, tectonic activity, and mammalian faunal change from ~24 to ~18 Ma. We propose that these units be informally designated as ''members'' pending acceptance by other investigators familiar with the geology of the John Day region.

We believe that revision of the *Haystack Valley Member*[5] contributes to the identification of genetic, unconformity-bounded lithostratigraphic units within upper John Day rocks in the Haystack Valley and Balm Creek drainages (North American Stratigraphic Code, 1983: article 23d, e). Our intent is to restrict the member in its type area to the lowermost of three superposed upper John Day rock units that are best exposed in the southern limb of the Balm Creek syncline (fig. 23; figs. 4–5, 8). Upper John Day beds of the syncline are preserved in a southwest-northeast trending ridge held up by Columbia basalt that separates Balm Creek from Haystack Creek. Prominent exposures of the revised member occur along the southern limb of the syncline and extend to the southeast where they are truncated by the Richmond fault of Fisher (1967). These outcrops occu-

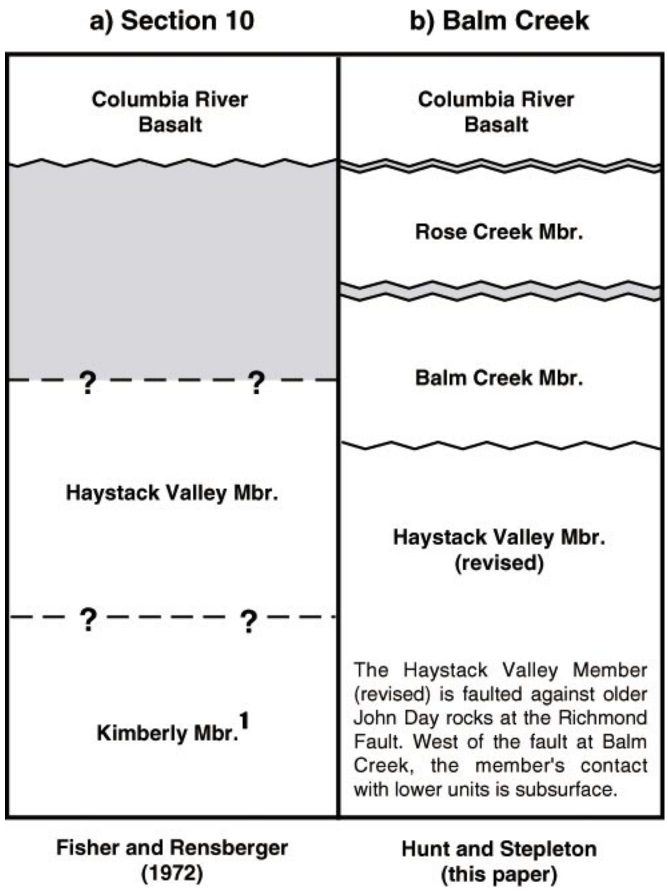


Fig. 23. Stratigraphic nomenclature applied to the upper John Day Formation in the Balm Creek syncline east of Haystack Valley: **a,** Fisher and Rensberger's section 10 (equates to the Asher Section of this report); **b,** upper John Day strata of the Balm Creek syncline as interpreted in this study. [1] Later assigned by Rensberger (1983) to the Haystack Valley Member.

py the NE¼, sec. 33; NW¼, sec. 34; S½, sec. 27; and SE¼, sec. 28, T8S, R25E, Kimberly 7.5-minute topographic quadrangle. Additional exposures form cliffs along the west and east walls of Haystack Valley where they are in fault contact with lower John Day rocks of the Turtle Cove Member that form the floor of Haystack Valley (fig. 20). The strata here allocated to the revised member include Units 1 and 2 of our Balm Creek measured sections. The upper boundary of the member is placed at a disconformity above the prominent paleosol developed on the gray massive airfall tuff (GMAT) of Unit 2 which is a mappable marker bed in the Haystack and Balm Creek valleys. The Haystack Valley Member as revised would continue to include local, monomictic welded tuff-bearing conglomerates in the lower part of the Balm Creek section in the syncline and along the west and east walls of Haystack Valley in agreement with the initial definition of the member by Fisher and Rensberger (1972: 17). But in our revision the base of the member in the Haystack Valley area is not identified by a particular welded tuff conglomerate because these conglomerate lenses occur more or less at random within the ''ribbed tuff'' lithology which characterizes the revised rock unit exposed along Balm Creek.

The lowest ~160 ft of our revised Haystack Valley Member in the Balm Creek drainage comprise greenish-gray to olive-gray zeolitized tuffaceous rocks, chiefly claystones and siltstones with some scattered fluvial sandstone lenses; the *Entoptychus individens* zone of Rensberger (1971) corresponds to the lowest ~40–50 ft of the unit. He considered this large, robust entoptychine rodent the most advanced species of the genus, arguably more evolved than most species of *Entoptychus* found in the Kimberly Member. This rodent and other mammals associated with it in the lowest ~160 ft of our revised member represent a younger fauna than that found in similar greenish zeolitized rocks of the Turtle Cove Member (Fisher and Rensberger, 1972: Map 3, map symbol *Tjt* in secs. 21, 22, 28, T8S, R25E) forming the floor of Haystack Valley to the west (fig. 20, *Tjt*, sec. 29, T8S, R25E). Although the lower contact of the revised Haystack Valley Member with subjacent John Day rocks has not been observed in the Balm Creek area, the presence of a mammal fauna (table 4) from the *E. individens* biozone along Balm Creek, temporally younger than the fauna from greenish zeolitized rocks (*Tjt*, Turtle Cove Member) forming the floor of Haystack Valley, confirms that the revised Haystack Valley Member is younger. The two units are mostly in fault contact along the east and west walls of Haystack Valley (fig. 20), however we believe that a superpositional relationship is preserved in sec. 21, T8S, R25E (see addendum).

Rocks in the Balm Creek syncline that occur above the revised Haystack Valley Member and below the Rose Creek Member are herein named the *Balm Creek Member*. The unit (fig. 23; figs. 4–6, 8) is composed of fluvially reworked yellowish-gray tuffaceous siltstones, sandstones, and claystones in its lower part that are interbedded with overlying thinly bedded lacustrine tuff. These sediments are overlain by a series of fining-upward sequences of tuffaceous dark gray fluvial sandstones, interbedded with rather thick gray massive airfall tuffs. The age of the unit is uncertain due to the scarcity of fossil mammals, but the rocks show no compelling lithologic resemblance to the Johnson Canyon Member, particularly the lacustrine beds which are unique to the Balm Creek area. A fossil peccary from the base of the unit suggests a late Arikareean age.

The stratigraphically highest unit of the John Day Formation is best exposed along the east wall of the John Day valley south of Kimberly. The unit is named the *Rose Creek Member* for the central location of outcrops at the head of Rose Creek relative to other outcrops to the north and south. The member lies with angular unconformity on subjacent rocks of the John Day Formation along the east wall where the lower contact of the member is evident at most outcrops (figs. 9, 10, 24). To the south at McCarty Creek (Foree) the Rose Creek Member lies on the eroded surface of green zeolitized claystones of the Turtle Cove Member (fig. 24c). Farther north the member rests on gray tuffs of the Kimberly Member (fig. 24d). The basal Rose Creek strata comprise stream channel deposits incised into underlying John Day rocks and typically include coarse pebble-to-cobble, polymictic welded tuff conglomerates, cross-stratified fluvial sandstones, and debris flows. Ashfall events are indicated at various levels in the member by coarse obsidian-shard tuffs. The upper part of the member is commonly made up of fine-grained air-fall and fluvially reworked olive-gray to yellow-gray tuff overprinted by silica-cemented paleosols. Calcareous cementation is rare to nonexistent in the paleosols and throughout the unit.

A lithofacies association typical of most outcrops includes polymictic welded-tuff conglomerate, debris flows, coarse obsidian-shard tuffs, and stacked siliceous paleosols developed on olive-gray fine-grained tuffaceous claystone. Debris flows are invariably composed of fine-grained gray tuff with matrix-supported, well-rounded pebbles and cobbles, many of them welded tuff. These flows are often overprinted by paleosols. In addition to particularly common densely welded tuff clasts with dark pumice fiamme, the conglomerates also include pebbles and cobbles of other partially to densely welded rhyolitic/dacitic volcanics derived from the Picture Gorge ignimbrite, including gray lapilli tuff and coarse obsidian shard tuff with buff pumice lapilli (table 1). Also present are clasts of the Deep Creek tuff. The conglomerates from the member along the east wall of the John Day valley are among the coarsest known from the eastern facies of the John

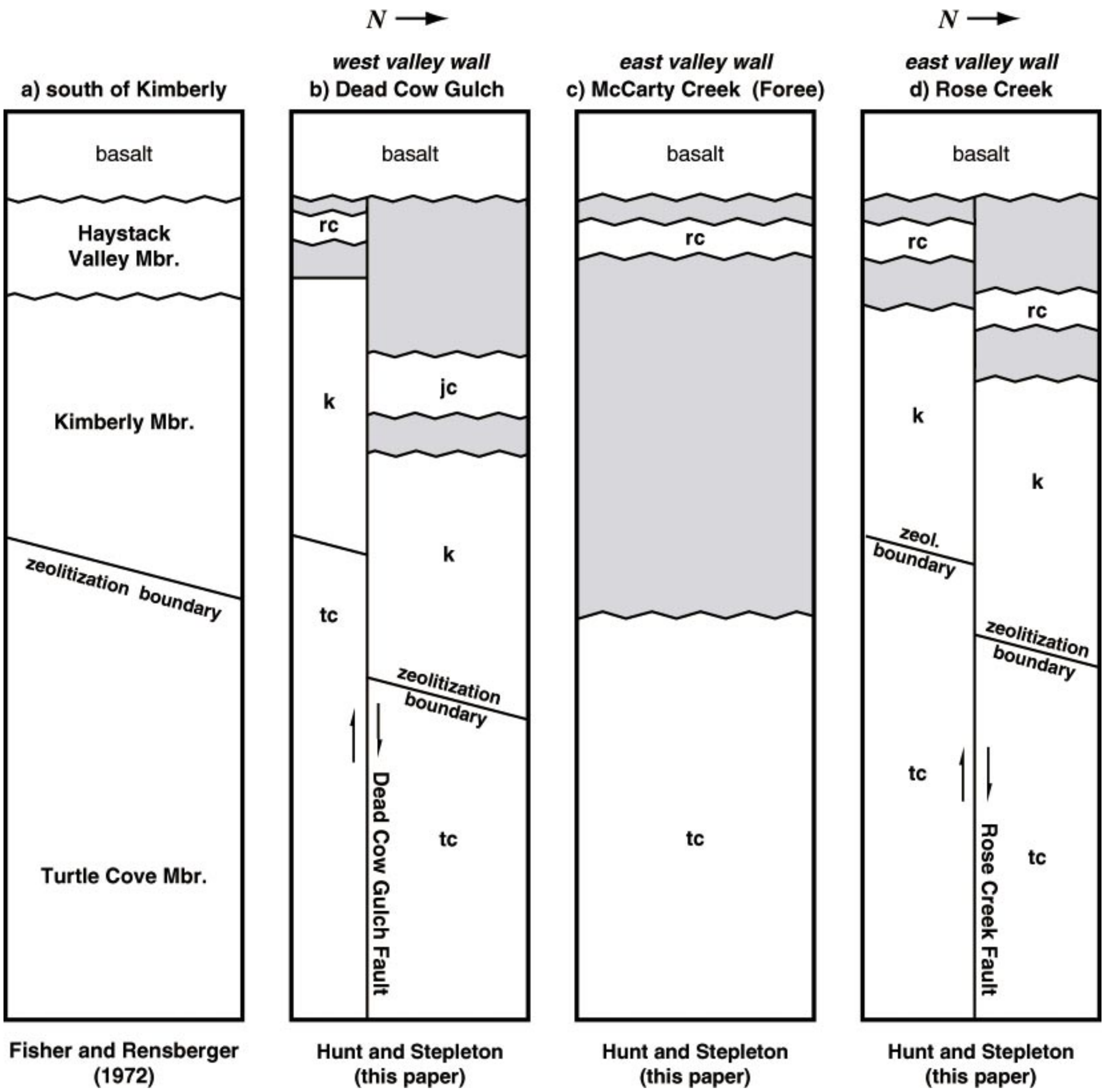


Fig. 24. Stratigraphic nomenclature applied to the John Day Formation south of Kimberly, Oregon: **a,** Fisher and Rensberger (1972); **b–d,** this report. Abbreviations: **tc,** Turtle Cove Member; **k,** Kimberly Member; **jc,** Johnson Canyon Member; **rc,** Rose Creek Member.

Day Formation, having mean intermediate clast diameters consistently >7 cm, with 12.9 cm as the average mean intermediate diameter from 12 localities (table 1). Most Rose Creek Member conglomerate clasts are derived from the Picture Gorge ignimbrite, which was exposed to erosion by the deformation of John Day rocks prior to deposition of the member, or are indurated vitric tuff clasts derived from the subjacent Kimberly and Turtle Cove Members.

Only a single exposure of the Rose Creek Member has survived along the west wall of the John Day valley south of Kimberly (fig. 24b). At Dead Cow Gulch a terminal paleosol developed at high elevation on the Kimberly Member is overlain by olive-gray tuffaceous claystones, coarse obsidian-shard tuff, debris flows, and siliceous paleosols of the Rose Creek Member (fig. 13, section 15). Welded tuff conglomerate is absent from this section and there is no evidence of stream incision by a Rose Creek channel. Here the basal unit of the Rose Creek Member is olive-gray tuff deposited directly on the terminal Kimberly paleosol. John Day rocks have been eroded to the north and south of this outcrop and the resulting topographic lows filled by flows of the Columbia River Basalt Group, suggesting that here the Rose Creek Member was preserved on an isolated hill or ridge. The absence of conglomerate and fluvial sandstones at this outcrop suggests that the west wall exposures at Dead Cow Gulch represent an interchannel location relative to the east wall outcrops of the Rose Creek Member that sample an alluvial facies.

The association of polymictic welded tuff conglomerate, debris flows, coarse obsidian-shard tuffs, and stacked siliceous paleosols, not only along the east wall of the John Day valley south of Kimberly but also at the top of the John Day Formation at Balm Creek and at Sutton Mountain, demonstrates the widespread distribution of this lithostratigraphic unit. It records the final phase of John Day deposition in the eastern facies of the formation before the eruption of the Columbia flood-basalts. The early Hemingfordian age of the Rose Creek Member is established by the mammal fauna found in outcrops along the east wall of the John Day valley south of Kimberly (table 4). Other outcrops of the unit we have examined at Balm Creek and Sutton Mountain have not produced fossil mammals.

The beds overlying the Kimberly Member along the west wall of the John Day valley for 2.5 mi (4 km) south of Kimberly are designated the *Johnson Canyon Member*. This unit (fig. 24b; figs. 13, 15) is based on the outstanding exposures at the mouth of Johnson Canyon and on correlated outcrops to the south along the west wall of the valley. Additional exposures of the Johnson Canyon Member are also found 1 mi (1.6 km) northwest of the Kimberly post office on the Broken Hammer ranch, and 2.5 mi (4 km) northwest along the John Day River at Bologna Creek. Basalt-filled valleys now separate these once laterally contiguous outcrops where late John Day erosion created a deeply dissected topography.

The lower contact of the Johnson Canyon Member is evident where the southernmost exposures of the unit occur along the west wall in the SE¼, NE¼, sec. 1 and in the NE¼, NE¼, sec. 12, T10S, R25E, Mt. Misery 7.5-minute quadrangle. Here the member is incised into the gray Kimberly Member tuffs with a relief of at least 50 ft (15.2 m). Fine-grained yellow-gray tuffaceous siltstones and sandstones reworked by fluvial processes fill these narrow valleys. Only intraformational monomictic conglomerates made up of locally derived, rounded gray vitric tuff clasts occur in the channel infills; welded tuff pebbles or other exotic clasts are absent. Average clast size is much smaller than in the Rose Creek conglomerates (table 1). Clasts from the coarsest conglomerate lens identified in the Johnson Canyon Member attain only 6.2 cm average intermediate diameter, and no clasts in any Johnson Canyon conglomerate lens exceed 9–10 cm.

The Johnson Canyon Member is downfaulted to the north along the west wall of the valley (figs. 22, 24b) so that the lower contact of the member is not visible in Johnson Canyon. These faults apparently trend approximately west-east and are situated along the southern boundary of the SW¼, sec. 31, T9S, R26E, and in the N½, NE¼, sec. 12, T10S, R25E. Offset of strata to the north is documented by the white marker tuff (ATR tuff, ~22.6 Ma) at Johnson Canyon: the tuff occurs high in the exposures at UCMP locality Picture Gorge 1 and is progressively downfaulted so that 0.5 mi (0.8 km) to the north, it occurs 60 ft (18 m) lower at the base of the exposures at the mouth of the canyon.

The cliff-forming outcrops on the north wall of Johnson Canyon at its mouth are the thickest exposures of the member that we have measured (fig. 16). In Johnson Canyon the member can be divided into a lower and upper part (fig. 15). The lower unit includes predominantly yellow-gray fluvially reworked tuffaceous siltstones and sandstones with interbedded lenses of intraformational monomictic vitric tuff conglomerate. Calcareous cementation is present throughout the lower unit and is particularly characteristic of the paleosols. The upper unit is separated from the lower unit by a disconformity without evidence of erosion; this surface is marked by a highly developed siliceous paleosol horizon suggesting a prolonged temporal hiatus. The upper unit above the disconformity is composed of thick gray airfall tuff units overlain by a series of obsidian-shard tuffs, each terminating in a paleosol horizon. All paleosols of the upper unit are siliceous. The upper unit concludes with yellow-gray tuffaceous sediments overlain by Columbia basalt flows.

Along the walls of the John Day valley south of Kimberly we have not observed the Rose Creek Member in superposition on the Johnson Canyon Member. The closest geographic approach of the two units is in Dead Cow Gulch on the west wall where a Johnson Canyon Member paleovalley is cut into Kimberly tuff on the north side of the gulch, and ~820 ft (250 m) to the south the topographically high, solitary Rose Creek outcrop rests on a terminal Kimberly Member paleosol without intervening Johnson Canyon beds (figs. 13, 14, 24b). The two outcrops are situated on opposite sides of the Dead Cow Gulch fault. The lithologies and lithofacies of the two members on the north and south sides of the fault are entirely different, and thus the Rose Creek and Johnson Canyon Members at this location are unlikely to be coeval facies.

However, there is a similarity between the Rose Creek Member outcrop at Dead Cow Gulch and the upper part of the Johnson Canyon Member in the canyon. Coarse air-fall obsidian-shard tuffs are present in both sections, and we noted earlier that such coarse tuffs are common in the Rose Creek beds. Yet we doubt that these tuffs support a temporal correlation between the Rose Creek Member and the upper part of the Johnson Canyon beds, based on the following observations. In the basal polymictic conglomerates of the Rose Creek Member on the east wall of the John Day valley, occasional rounded clasts of *air-fall* obsidian-shard tuff are found intermixed with dark gray, *welded* obsidian-shard tuff and other pebbles derived from the Picture Gorge ignimbrite. These pale yellowish-gray, obsidian-shard air-fall tuff clasts are porous and uncompacted, hence readily distinguished from the partially to densely welded, dark gray obsidian-shard tuff clasts derived from the ignimbrite. Instead, they closely match the obsidian-shard air-fall tuff in the upper part of the Johnson Canyon Member. Rose Creek streams must have incised both the ignimbrite and air-fall obsidian-shard tuff units of the Johnson Canyon Member, and locally transported these clasts in Rose Creek drainages south of Kimberly (table 1, both types occur together in the basal conglomerate of the member at Rose Creek North-2560 ft).

Because no fossil mammals are known from the Johnson Canyon Member's upper unit, its exact age remains in doubt. The abundant fauna from the lower unit (table 4) and the dated white marker tuff allow the age of the lower unit to be more reliably determined as late to latest Arikareean (table 2), hence older than the early Hemingfordian fauna of the Rose Creek Member.

The ages of the four members recognized in this report that occur above the Kimberly Member are of particular interest in establishing the history of tectonic activity, sedimentation, and erosion immediately prior to the eruption of the Columbia plateau basalts in the region. We note the following relevant observations on the age of these units and on their correlation with the established NALMA faunal sequence in the North American midcontinent:

(1) The revised Haystack Valley Member in Haystack Valley is dated by a reasonably abundant early late Arikareean mammal fauna, and by a dated tuff ($^{40}Ar/^{39}Ar$) closely associated with the monomictic welded tuff-bearing conglomerates mentioned by Fisher and Rensberger in their original description of the unit. The two most reliable ages on feldspar crystals (23.6 ± 0.07, 23.8 ± 0.06 Ma, table 2) from the tuff indicate the member is of earliest Miocene age, in proximity to the Paleogene-Neogene boundary (~23.8 Ma, Berggren et al., 1995), and the fossil mammals are in agreement with this. Sometime after this, the member was zeolitized, then later folded and faulted during a time of regional northwest-southeast compression. This compression produced the northeast-southwest trending anticlinal and synclinal folds typical of the region southeast of the Blue Mountains such as the Mitchell and Kahler synclines (Fisher, 1967: fig. 2). Folding of the Balm Creek syncline and devel-

opment of the low-angle reverse faulting that parallels the syncline probably occurred at this time. The creation of the graben (or half-graben) that Haystack Creek and Balm Creek apparently occupy today must have occurred during a later interval of extensional faulting, resulting in preservation of the uppermost John Day units. We conclude then that the regional compression that folded the redefined Haystack Valley Member took place after ~23–24 Ma, but prior to the deposition of the Rose Creek Member which lies with apparent angular unconformity across the older John Day rocks. Since the Rose Creek Member can be reliably dated by its fauna from outcrops south of Kimberly at ~18.2–18.8 Ma, the northwest-southeast compression and consequent folding must have taken place prior to that time in the early Miocene.

(2) The Turtle Cove and Kimberly Members along the east and west walls of the John Day valley south of Kimberly were tilted and warped at some time prior to the deposition of the Rose Creek Member which overlies them with angular unconformity. The Rose Creek Member was not involved in the folding of the older John Day rocks. The member is dated by its early Hemingfordian mammal fauna at ~18.2–18.8 Ma. Thus if the deformation south of Kimberly and the folding in Haystack Valley are part of the same episode of regional compression, this took place between ~24 and ~18.2 Ma in the early Miocene.

(3) The Johnson Canyon Member rests with erosional disconformity on the Kimberly Member south of Kimberly post office along the west wall of the John Day valley. Bedding within the member is essentially horizontal. There is no evidence that the member was tilted or faulted during the deformational event that warped the Kimberly and Turtle Cove Members. Except for normal faulting that offsets the member south of Kimberly, it appears to be largely undisturbed throughout its outcrop area. The lower part of the Johnson Canyon Member contains the ATR tuff of Fremd et al. (1994) dated by the $^{40}Ar/^{39}Ar$ method at 22.6 ± 0.13 Ma, and the fauna from this part of the unit is of late or latest Arikareean age, at least as old as ~19.2 Ma (based on biocorrelation with Great Plains Arikareean faunas). The age of the member then is thought to fall somewhere between these two dates. Hence the faulting that cuts these rocks occurred after 22.6 Ma, and more probably after 19.2 Ma.

(4) We have not found Rose Creek Member sediments south of Kimberly deposited in topographic lows developed on the Johnson Canyon beds as might be expected if Rose Creek dissection occurred after the conclusion of Johnson Canyon Member deposition. In fact, Columbia basalts fill an eroded topography cut in the Johnson Canyon Member (Fisher and Rensberger, 1972: pl. 6). A possible explanation for this is that the Rose Creek Member may represent a lateral facies of the Johnson Canyon Member and hence is age-equivalent to all or part of it. We doubt this because the lower part of the Johnson Canyon Member is lithically distinct from the Rose Creek beds, not only in the different clast content of their respective conglomerates, but because of the absence of coarse obsidian-shard tuffs and debris flows in the Johnson Canyon lower unit. Also, fossil mammals from the lower unit appear to belong to an older assemblage than the fauna from the Rose Creek Member; the dated ATR tuff (~22.6 Ma) in Johnson Canyon supports this. Unfortunately, the upper unit in Johnson Canyon has not yielded a mammal fauna and has not been radiometrically dated, and thus its age is uncertain. However, because obsidian-shard air-fall tuffs in the upper part of the Johnson Canyon Member are the likely source for similar obsidian-shard tuff clasts that occur in the basal conglomerates of the Rose Creek Member, it seems that Rose Creek streams incised and hence postdate the upper part of the Johnson Canyon Member. We suspect that the profound interval of erosion that preceded deposition of the Rose Creek Member removed a significant part of the upper John Day Formation from Middle Mountain north to Spring Creek and Dead Cow Gulch, and this may have included units of the Johnson Canyon beds. Rose Creek sediments were then deposited across the truncated erosion surface on the older John Day units.

We also have observed that at Sutton Mountain (sec. 33, T10S, R21E, Sutton Mountain 7.5-minute quadrangle) Rose Creek beds are superposed on a thick unit of yellow-gray tuffaceous siltstones, sandstones, and monomictic intraformational conglomerates that resembles the Johnson Canyon Member south of Kimberly. We suggest that the Sutton Mountain section documents the superposition of the two members that is absent south of Kimberly.

(5) After deposition of the Rose Creek Member, pedogenesis preceded normal faulting of the member south of Kimberly from Rose Creek northward to Spring Creek; this faulting produced escarpments that are abutted and preserved by the earliest PGBS flows (Twickenham Basalt). Younger basalt flows then completely buried the existing John Day topography.

The oldest flows of the PGBS at the type section at Picture Gorge are possibly as old as ~16 Ma (Baksi, 1989; Bailey, 1989); thus, there is reason to suggest that the stratigraphically lowest flows of the PGBS (Twickenham Basalt), which are not present in the Picture Gorge type section, are older than ~16 Ma (e.g., Tolan et al., 1989: 17), perhaps as old as ~17 Ma. If Rose Creek deposition ended by ~18 Ma, followed by erosion and weathering of the resulting land surface, then the terminal Rose Creek paleosols marking the end of John Day deposition in the region developed during this ~1 million-year interval, prior to eruption of PGBS flows from the Monument feeder dikes.

(6) The Balm Creek Member includes the fluvial and lacustrine volcaniclastics and airfall tuffs that occur stratigraphically above the revised Haystack Valley Member and below the Rose Creek Member in the Haystack Valley-Balm Creek area. If the Haystack Valley Member is dated at ~23–24 Ma, and the Rose Creek Member is as old as ~18.2 Ma, then the Balm Creek Member falls within this interval in the early Miocene. Although it is possible that the Balm Creek Member, all or in part, is the same age as the Johnson Canyon Member, we lack definitive evidence of this at present.

(7) Mammalian faunas from the youngest stratigraphic units of the John Day Formation have been involved in estimates of the amount of time that elapsed between the cessation of John Day deposition in the region and the initiation of the Columbia lava flows. The youngest John Day mammal faunas previously reported (19–22 Ma, Robinson et al., 1984) were from the western facies of the formation in the Warm Springs area (Woodburne and Robinson, 1977). A precise determination of biochronologic age for the youngest stratigraphic units within the classic eastern facies of the John Day Formation has been lacking since the earliest investigations of these rocks. This situation resulted from inadvertently combining the mammal faunas from the Rose Creek, Johnson Canyon, and revised Haystack Valley Members into a composite fauna that spanned more than five million years within the early Miocene (~18.2–23.8 Ma).

Fossil mammals discovered during our field studies from 1992 to 2001, supplemented by specimens in museum collections, establish a biochronologic age of ~18.2–18.8 Ma for the youngest fauna from the eastern facies of the John Day Formation. This fauna, herein designated the *Picture Gorge 36 local fauna*, comes from a laterally continuous, mappable stratigraphic unit, the Rose Creek Member, located at high elevations immediately below the Columbia basalts on the eastern margin of the John Day valley south of Kimberly. Outcrops of the Rose Creek Member that have produced the defining mammal assemblage are from two localities in the west half of sec. 17, T10S, R26E. The first is along Rose Creek in the NW¼, NW¼, NW¼, sec. 17, and the second on Bone Creek in the NE¼, NW¼, SE¼, SW¼, sec. 17, continuing into the SW¼, SE¼, NE¼, SW¼, sec. 17, T10S, R26E, Grant County, Oregon.

(8) Is there a significant interval of time between the conclusion of Rose Creek Member deposition and the initiation of Columbia flood basalt flows in the region? The oldest lava flows of the Columbia River Basalt Group were believed to be the Imnaha basalts of eastern Oregon and western Idaho dated at ~17.0–17.5 Ma (Reidel and Tolan, 1992; Baksi, 1989; Hooper, 1982; McKee et al., 1981). More recent $^{40}Ar/^{39}Ar$ dating of tholeiitic basalts in southeastern Oregon has identified flows of the Steens Basalt and the basalt of Malheur Gorge as the earliest eruptions of the Columbia River flood-basalt province with ages from 16.6 ± 0.02 Ma to 16.9 ± 0.8 Ma (Swisher et al., 1990; Hooper

et al., 2002). Newer dates of ~15.4–15.5 Ma have been obtained on Imnaha basalts, and the earlier dates at ~17.0–17.5 Ma are considered less reliable (Hooper et al., 2002).

Flows of the Picture Gorge Basalt Subgroup were erupted from the Monument dike swarm (Bailey, 1989) situated in the area south of Kimberly and as far east as the town of Monument (Fisher, 1967; Wilcox and Fisher, 1966). Bailey (1989) proposed a separate eruptive center near Picture Gorge south of the Monument dike complex for the flows in Picture Gorge. The K/Ar-dated flows of the PGBS that occur in Picture Gorge are reported to be as old as ~16 Ma (Bailey and Conrey, 1992; Baksi, 1989; Bailey, 1989). However, the oldest PGBS flows (Twickenham Basalt) probably predate the flows at Picture Gorge and it is these flows that occur in proximity to Rose Creek Member sediments along the east wall of the John Day valley south of Kimberly. Dating these flows would be of considerable interest. If the Twickenham basalts are as old as 17 Ma, and the Rose Creek sediments as young as ~18 Ma, the interval in question is brief.

Incision of the Rose Creek Member into older John Day strata may record regional elevation of the Richmond Anticline (Fisher, 1967: fig. 2) in early Hemingfordian time, perhaps somehow related to magmatic inflation prior to eruption of the PGBS, resulting in northward tilting and local folding of the John Day Formation. Northward tilting of John Day strata and PGBS flows from Middle Mountain to Kimberly may have continued during post-PGBS tectonism in the mid- to late Miocene.

(9) Recognition of the different ages of the revised Haystack Valley, Johnson Canyon, and Rose Creek Members clarifies the timing of zeolitization in the Haystack Valley Member of Fisher and Rensberger (1972: 18). Zeolitization in the Rose Creek and Johnson Canyon Members is, if present at all, extremely rare. It appears to be restricted to the revised Haystack Valley Member in the Haystack Valley-Balm Creek area where the member was zeolitized before the beds were deformed and faulted. Beds of the revised Haystack Valley Member are the youngest John Day rocks to have undergone extensive zeolitization in the local area, and are dated at ~23.5–23.8 Ma. Thus, zeolitization occurred after ~23.5 Ma and ended before regional compression deformed the member, which took place prior to deposition of the overlying Rose Creek beds at ~18.2–18.8 Ma. Zeolitization of John Day sediments in the region may have concluded by ~23 Ma if the ATR marker tuff in the unzeolitized Johnson Canyon Member is reliably dated at 22.6 Ma.

(10) The mammal fauna of the revised Haystack Valley Member is clearly more archaic in its taxonomic composition than the faunas from the Johnson Canyon and Rose Creek Members. Miohippine horses, entoptychine and allomyine rodents, and hypertragulids are conspicuous holdovers from older John Day faunas, whereas advanced taxa such as parahippine horses, *Archaeohippus*, dromomerycid and moschid cervoids, the chalicothere *Moropus*, large beavers, the rodents *Mylagaulodon*, *Sewelleladon*, and advanced species of *Schizodontomys*, and the large index oreodont *Merycochoerus* are absent.

(11) The upper John Day faunas of Oregon indicate more mesic and better vegetated environments in the Pacific Northwest relative to the seasonally arid grassland plains of the North American midcontinent in the early Miocene. Almost all channel conglomerates in the revised Haystack Valley, Johnson Canyon, and Rose Creek Members contain fossil wood together with fossil mammal remains, whereas fossil wood of any kind in Arikaree Group rocks of the Great Plains is extremely scarce. It is not until the early Hemingfordian deposits of the Runningwater Formation that stream deposits carry more abundant fossil wood in the midcontinent.

(12) The Hemingfordian Land Mammal ''age'' is used here in a different sense from that originally proposed by the Wood Committee of the Paleontological Society (Wood et al., 1941) and followed by Fisher and Rensberger (1972: fig. 8). We place the Arikareean-Hemingfordian boundary in the early Miocene at ~18.8 Ma (see MacFadden and Hunt, 1998, for discussion), based upon recent reevaluation of the succession of mammalian faunas from Arikaree and Hemingford rocks of western Nebraska in the

type area of these ages. The following observations are relevant:

The defining fauna of the Arikareean NALMA is the Agate local fauna found in the base of the Upper Harrison beds in western Nebraska (Wood et al., 1941: 11–12; Hunt, 1990). Many of its component taxa first occur in the subjacent Harrison Formation and continue into the Upper Harrison beds, a formation-rank term now replaced by Anderson Ranch Formation (Hunt, 2002). Thus, the mammals of the Harrison and Upper Harrison beds constitute an integral fauna that is central to the definition of the Arikareean Land Mammal ''age''. Note that this fauna is not necessarily confined to the geochron of the Harrison and Upper Harrison rock units, and is recognized as a biochronologic entity entirely on the basis of its component taxa.

Despite the lithologic similarity of the Upper Harrison to the Harrison Formation and lower stratigraphic units of the Arikaree Group (Hunt, 1990), the Upper Harrison beds were included as the basal unit of the overlying Hemingford Group under the term ''Marsland Formation'' (Lugn, 1939, and references therein)[7]. The Hemingfordian age was implicitly considered as the geochron of the Marsland and Sheep Creek Formations of the Hemingford Group by the Wood Committee (1941), and as a result the fauna of the Upper Harrison beds was regarded by some investigators as the basal or earliest Hemingfordian fauna, notwithstanding its clearly Arikareean aspect. This usage of the term Hemingfordian was consequently applied by Fisher and Rensberger (1972: fig. 8) to the identification of John Day faunas; this was a reasonable approach, for this was accepted practice at the time.

More recently it has been recognized that the mammalian faunas of the Runningwater Formation of western Nebraska, which overlies the Upper Harrison beds, represent a readily identifiable biochronologic datum within the early Miocene of the Great Plains (Tedford et al., 1987; MacFadden and Hunt, 1998; Woodburne and Swisher, 1995: 345). Numerous genera of mammals appear for the first time in these Runningwater faunas and serve as biochronologic markers for the beginning of the Hemingfordian NALMA. Also, a number of Arikareean genera continue into the Runningwater Formation where distinctive early Hemingfordian congeneric species can be identified by their more advanced stage of evolution. This faunal complex continues in time and can be recognized in the mammals of the late Hemingfordian Box Butte and Sheep Creek Formations of western Nebraska. Thus, the sequential faunas from the Runningwater, Box Butte, and Sheep Creek Formations are currently regarded as representative of the Hemingfordian age (Tedford et al., 1987).

Key indicator taxa marking the beginning of the Hemingfordian in the Great Plains include the oreodonts *Merycochoerus magnus* and an advanced form of *Merychyus*; the equid *Parahippus pawniensis* and a second larger parahippine, *P. tyleri* (the first hypsodont species of *Parahippus* in the Great Plains); the small moschid deer *Machaeromeryx*; the first merycodont antilocaprids; a large long-limbed daphoenine amphicyonid; an ancestral mylagaulid *Mesogaulus paniensis* and species of the large beavers *Anchitheriomys* and *Hystricops*; a species of the rhinoceros *Menoceras* somewhat evolved beyond *M. arikarense* from the Agate Quarries; and various species of camelids (*Michenia*, *Protolabis*, *Oxydactylus longirostris*) and protoceratids (*Syndyoceras*). The absence of certain taxa is also significant: these include

[7] The Marsland Formation, as used by Lugn (1939) and Schultz (1938), combined the Upper Harrison beds (Peterson, 1909), an upper Arikaree rock unit primarily composed of volcaniclastic eolian fine-grained sandstones, with an overlying rock unit comprising fluvial sands and granitic gravels marking the initiation of Hemingford Group deposition in western Nebraska. They referred to the Upper Harrison beds as the ''lower Marsland'' and the fluvial sands and gravels as the ''upper Marsland'' beds. Cook (1965) recognized that the Upper Harrison beds were lithically more similar to rocks of the Arikaree Group, and separated them from the ''upper Marsland'' sands and gravels, which he then named the Runningwater Formation. He regarded the Runningwater Formation as evidence of a major tectonic episode to the west, resulting in stream transport of granitic sands and gravels from the Rocky Mountains onto the Great Plains. Because of the confusion surrounding the term ''Marsland'' and the lithologic heterogeneity of the lower and upper rock units included in the ''formation'', its use is no longer recommended, and a new formation-rank term (Anderson Ranch Formation) has been proposed to replace ''Upper Harrison'' (Hunt, 2002).

the oreodont *Promerycochoerus*; merychippine horses with cement-covered cheek teeth, and terminal Arikareean parahippines (*P. nebrascensis*, *P. wyomingensis*); felid and nimravid cats; the large mustelid *Megalictis*; and temnocyonine beardogs. Several small arctoid carnivores also first appear in North America in the fluvial channels of the Runningwater Formation. The earliest Hemingfordian fauna in the type area in western Nebraska is the *Northeast of Agate local fauna.* Paleomagnetic calibration of rocks that yielded this fauna suggests an age of ~18.2–18.8 Ma (MacFadden and Hunt, 1998). It is with species in this local fauna that the mammals of the Rose Creek Member of the John Day Formation show the closest correspondence.

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ADDENDUM

During our 1993–1996 study of the upper John Day Formation, we examined the Haystack Valley Member in its type area along Balm Creek, where Fisher and Rensberger had placed their defining section. But, as noted, along Balm Creek the base of the member was not evident in any Balm Creek outcrop (figs. 4–5). In 2003 we attempted to resolve the relationship of the basal contact of the member to older John Day units. Only in Haystack Valley itself, which lies immediately west of the Balm Creek valley, can this stratigraphic relationship be determined due to the presence of older John Day beds in proximity to the revised Haystack Valley Member. The revised member, as represented in our study, has not been mapped outside of the Haystack Valley-Balm Creek Valley exposures.

Our structural cross-section of the Haystack and Balm Creek valleys (fig. 20) shows green zeolitized claystones of the Turtle Cove Member forming the floor of Haystack Valley. These beds are in certain fault relationship with beds of the Haystack Valley Member (revised) along the west wall of the valley. We also show in figure 20 a hypothetical fault (at Route 207) along the east side of the valley at its southern end. In 2003 we found conclusive evidence of faulting here and also farther north along the east valley wall. The sense of these faults could not always be determined due to cover, but reverse faulting of green Turtle Cove Member rocks (hanging wall) on younger beds (footwall) was certainly established at one locality (center, sec. 23, T8S, R25E). These faults, and the presence of springs, seeps, and zones of shattered and jointed rock along the east side of Haystack Valley (from SW¼, sec. 28 northeast to SE¼, sec. 22, thence eastward into sec. 23, T8S, R25E) suggests the east side of the valley is fault-controlled. The trend of this fault zone is from southwest to northeast (Map E, east Haystack Valley fault zone). Reverse faulting observed here is coincident with reverse faulting of the revised Haystack Valley and Balm Creek Members in the valley of Balm Creek, where northwest-southeast compression of the formation produced the anticlinal-synclinal folds mapped by Fisher (1967).

However, a basal contact of the revised Haystack Valley Member with older John Day rocks is not evident along the east Haystack Valley fault zone. Green zeolitized beds of the Turtle Cove Member are in proximity to rocks of the revised Haystack Valley Member but the faults leave open the question of whether some part of the John Day Formation is missing along these fractures.

This problem appears to be resolved by exposures along the west wall of Haystack Valley in secs. 20, 21, and 29, T8S, R25E, Spray and Kimberly 1:24,000 quadrangles that occur in proximity to the west Haystack Valley fault (Map E). Four principal outcrops (A–D) are observed along the west valley wall, separated by vegetated topographic ridges. The southernmost outcrop (A) is a cliff section exposing about 140 ft (43 m) of the revised Haystack Valley Member, equivalent to rocks of Unit 2 along Balm Creek. This section occurs *west* of the west Haystack Valley fault, here obscured by vegetation. The lower 60–80 ft (18–24 m) are tan to pale greenish-gray ribbed tuffs with several levels of dark green, coarse fluvial sandstones like those observed along Balm Creek in Units 1 and 2A.

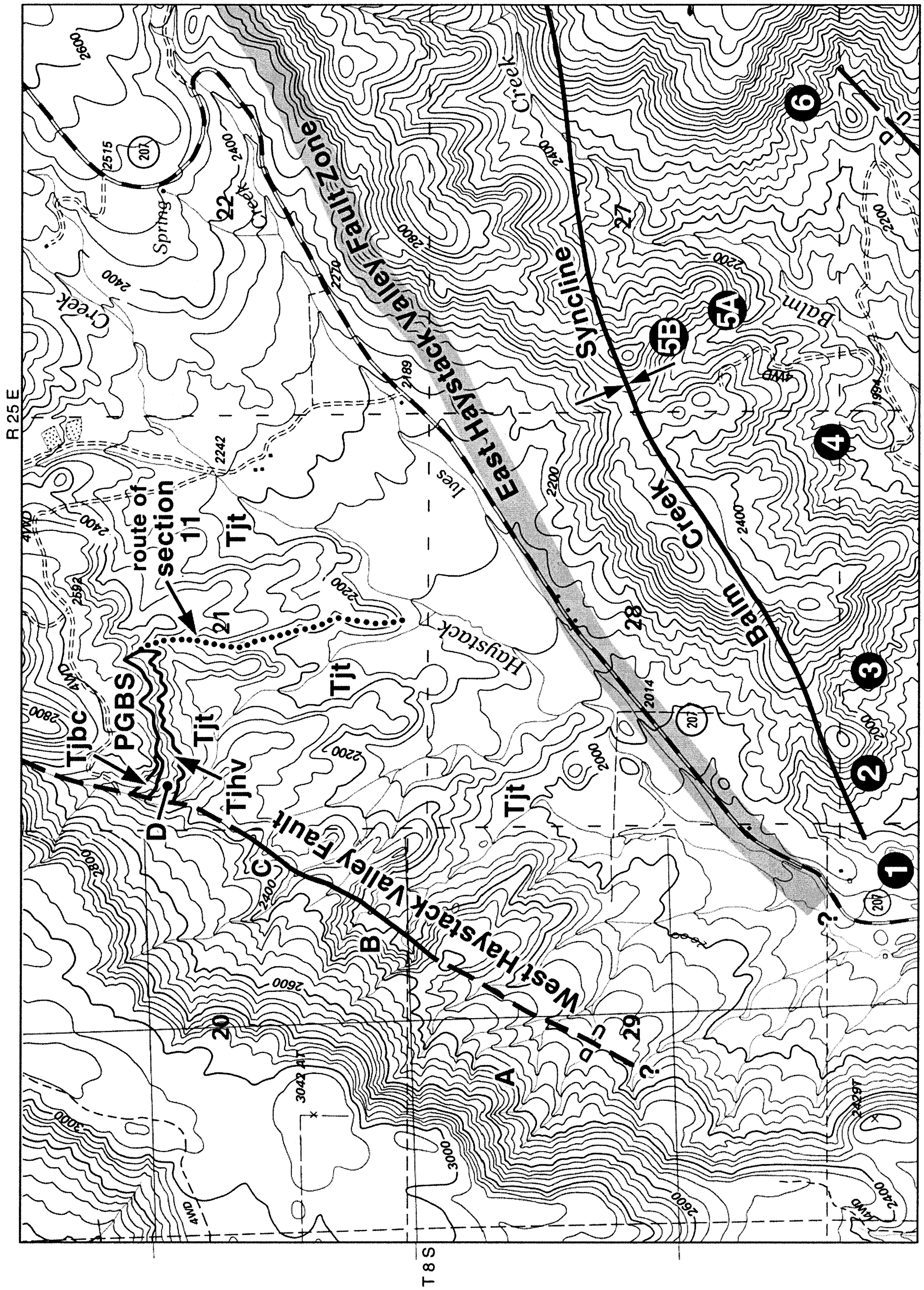
The revised Haystack Valley Member can be traced to the northeast 0.4 mi (0.64 km) to a second, particularly conspicuous outcrop (B), a spectacular cliff in the SE¼, SW¼, SE¼, sec. 20, T8S, R25E, Spray 1:24,000 quadrangle. Here one can observe the same section that was seen at outcrop A, but now visibly faulted against green claystones of the Turtle Cove Member (the fault appears to be normal as illustrated in fig. 20). The exposures of the revised member represent Unit 2 of the Balm Creek valley. But here, once again, outcrops A and B have not established the stratigraphic relationship of the revised Haystack Valley Member to the green Turtle Cove beds occupying the center of Haystack Valley. Critical to that end are Fisher and Rensberger's (1972) ''Section 11'' and our outcrops C and D (Map E).

Fisher and Rensberger (1972: fig. 3) published only one measured section from Haystack Valley itself, Section 11. It lies to the *east* of the west Haystack Valley fault, as mapped by Fisher. Section 11's upper part occurs just north of the center of sec. 21, T8S, R25E; the outcrop continues along a ridge extending to the southern boundary of section 21. Fisher and Rensberger's section includes 620 ft (189 m) of green Turtle Cove Member rocks (including the Deep Creek Tuff) above the Picture Gorge ignimbrite, overlain by 140 ft (43 m) of gray nonzeolitized Kimberly Member tuff. In the field, we observed a yellowish gray transition zone (~60–80 ft) between the green and gray rocks.

We walked from Section 11 to the west, following the trend of the gray ''Kimberly tuff'', and discovered that the westernmost outcrop of gray tuff (outcrop D in Map E) includes gray, coarse fluvial sandstone grading along strike into dark green, coarse sandstone typical of Unit 2 of the Haystack Valley Member (revised). Also present were green celadonite siltstone ''benches'' similar to those in the revised Haystack Valley Member. At D, as at Section 11, the gray tuff unit overlies green claystones typical of the Turtle Cove Member. But also at outcrop D, overlying the gray tuff unit and separated by a sharp disconformable contact, are the typical olive to yellow-brown siltstones, sandstones and granule to pebble gravel of the Balm Creek Member.

We observed, in effect, that what had been regarded as massive Kimberly tuff, near the center of sec. 21, T8S, R25E, now contained coarse sandstones and celadonite siltstones like those of the revised Haystack Valley Member. We suspected that a previously unappreciated facies relationship was being demonstrated along the west wall of Haystack Valley: massive-appearing gray tuffs that had been regarded as the Kimberly Member graded, to the south, into gray tuff with more numerous fluvial sandstone interbeds, eventually continuing southward into a thicker, predominantly fluviatile sequence made up of the gray massive tuff (GMAT), ribbed tuffs, more abundant fluvial coarse green sandstones, and monomictic welded tuff conglomerates of the Balm Creek outcrops (in the NE¼, sec. 32, T8S, R25E). The ''Kimberly'' gray tuff of Fisher and Rensberger's Section 11 apparently correlated with the upper part of the revised Haystack Valley Member.

This supposition received additional support when we examined a section intermediate in distance between outcrops B and D. At outcrop C


R 25 E
T 8 S
East Haystack Valley Fault Zone
West Haystack Valley Fault
Syncline
Balm Creek
route of section 11
PGBS
Tjbc
Tjhv
Tjt
A
B
C
D
1
2
3
4
5A
5B
6
20
21
22
27
28
29
Spring
Creek
Haystack
Balm

(SE¼, SW¼, NE¼, SE¼, sec. 20, T8S, R25E) gray massive tuff is faulted against green claystones of the Turtle Cove Member. The gray tuff, which might be mistaken for the Kimberly Member, contains interbeds of coarse detrital sandstone. This in itself means little: such coarse fluvial sandstones appear in typical Kimberly Member exposures. However, microscopic examination of the detrital sandstone from C shows grains of welded tuff among a variety of other clast types, suggesting this unit correlates with the coarse sandstones and welded tuff gravels of Unit 2B along Balm Creek (fig. 8, Section HS-1). Thus, several lines of evidence suggest that the revised Haystack Valley Member in south Haystack Valley, a correlative of Unit 2 at Balm Creek, if traced to the north overlies the green claystones attributed to the Turtle Cove Member.

Placing these observations in perspective, the John Day Formation in Haystack Valley and along Balm Creek emerges as a distinctive sequence of beds best segregated into a set of member-rank lithostratigraphic units unique to this geographic area. Turtle Cove-like green zeolitized rocks are overlain by the revised Haystack Valley Member, in turn succeeded by the Balm Creek and Rose Creek Members. The revised Haystack Valley Member reflects a significant detrital input into beds of this age, herein dated at ~23.5–23.8 Ma, hence postdating Turtle Cove Member rocks south of Kimberly in Turtle Cove that are probably mostly older than ~25 Ma (see Fremd et al., 1994: fig. 14). Thus we can establish definite evidence of stream incision and filling in the John Day Formation in the Haystack Valley region at 23.5–23.8 Ma. The intraformational gravels within Kimberly Member channels south and southeast of Kimberly may be somewhat older, based on Rensberger's entoptychine rodent faunas from these rocks, when compared to rodents from the lower part of the revised Haystack Valley Member (*E. individens*—*A. tessellatus* zone). However, the presence of welded tuff conglomerate in the revised Haystack Valley Member (both Units 2A and 2B) does mark the earliest record of these ignimbrite clasts in the eastern facies of the John Day Formation.

APPENDICES 1-1 to 1-15

The biochronology of the upper John Day Formation presented in this study is documented by the stratigraphic placement of fossil mammals detailed in the appendices. Lithic descriptions of stratigraphic units and allocation of mammalian taxa to specific horizons are indicated for each measured section to facilitate collection of fossils at critical localities in future studies.

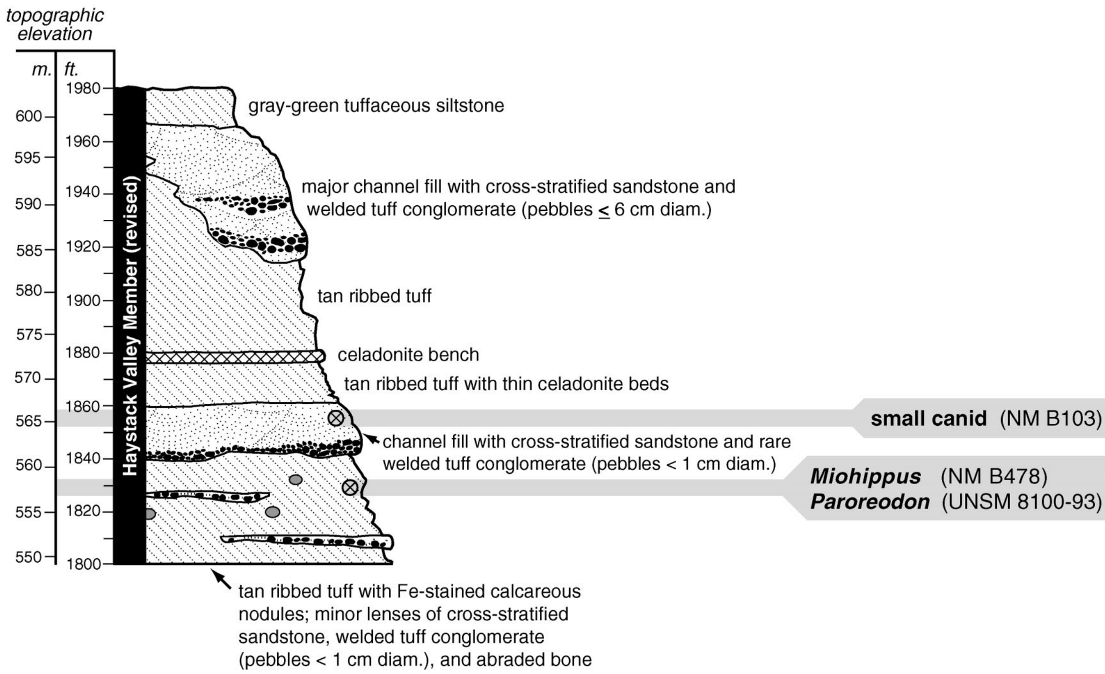
Institutional Abbreviations: JODA and TF, John Day Fossil Beds National Monument, Kimberly, Oregon; LACM-CIT, Los Angeles County Museum of Natural History, Los Angeles, California; NM, Northwest Museum, Portland State University, Portland, Oregon; UCMP, University of California Museum of Paleontology, Berkeley, California; UNSM, University of Nebraska State Museum, Lincoln, Nebraska; UW, University of Wyoming, Geology and Geophysics, Laramie, Wyoming.

←

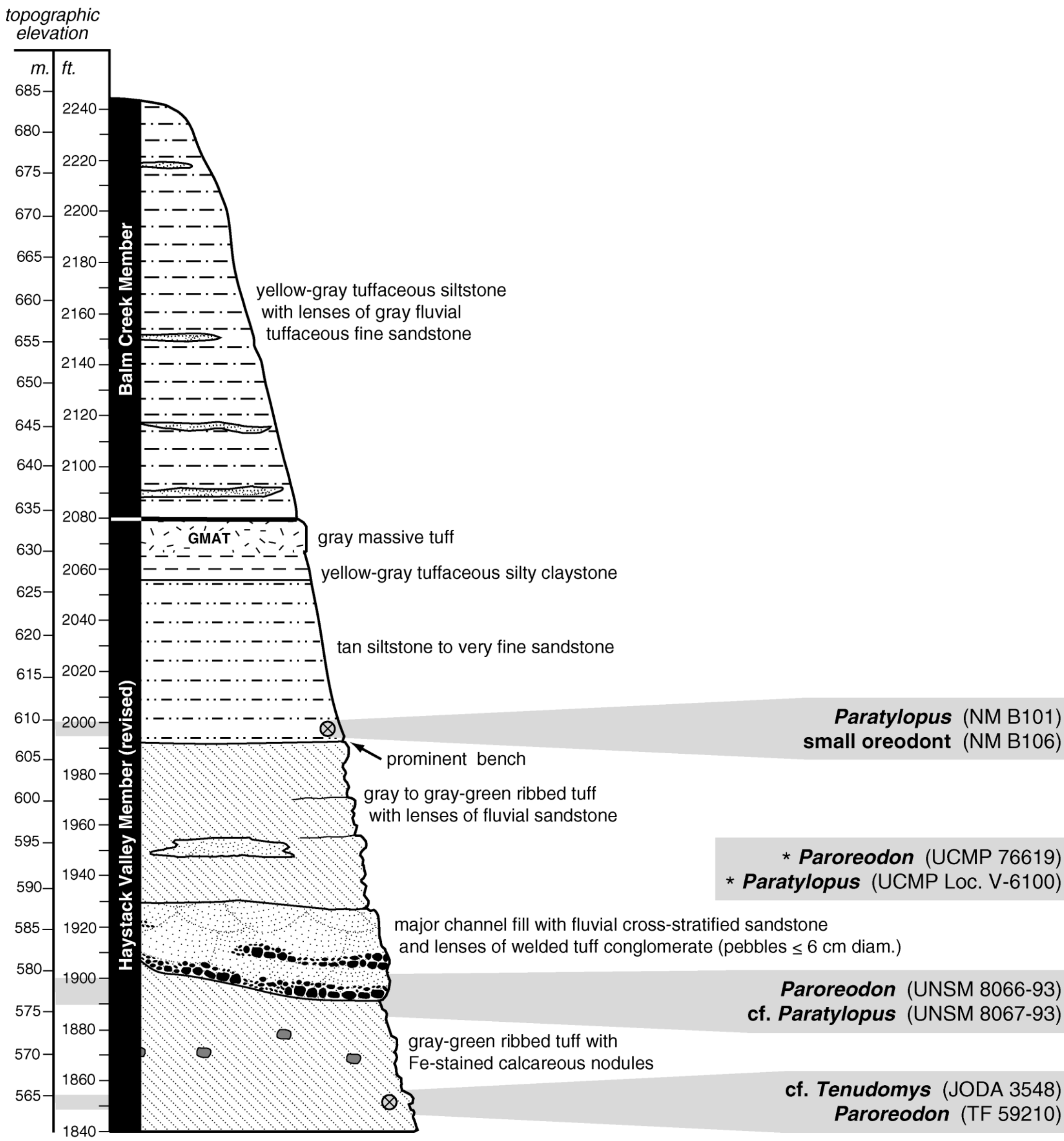
Map E: Topographic map of the Haystack Creek and Balm Creek area, John Day valley, Oregon, Spray and Kimberly 7.5-minutes quadrangles showing Haystack Valley, bounded by the west and east Haystack Valley faults, adjacent to the Balm Creek syncline. Outcrops A–D in proximity to the west Haystack Valley fault collectively support the inference that the revised Haystack Valley Member is superposed on green Turtle Cove Member rocks in the NW¼, sec. 21, T8S, R25E. Abbreviations of rock units as in fig. 20.

Crazy Woman Knob
NE1/4 NE1/4 Sec. 32 T. 8 S R. 25E
Spray 7.5' quadrangle 1990

Appendix 1-1



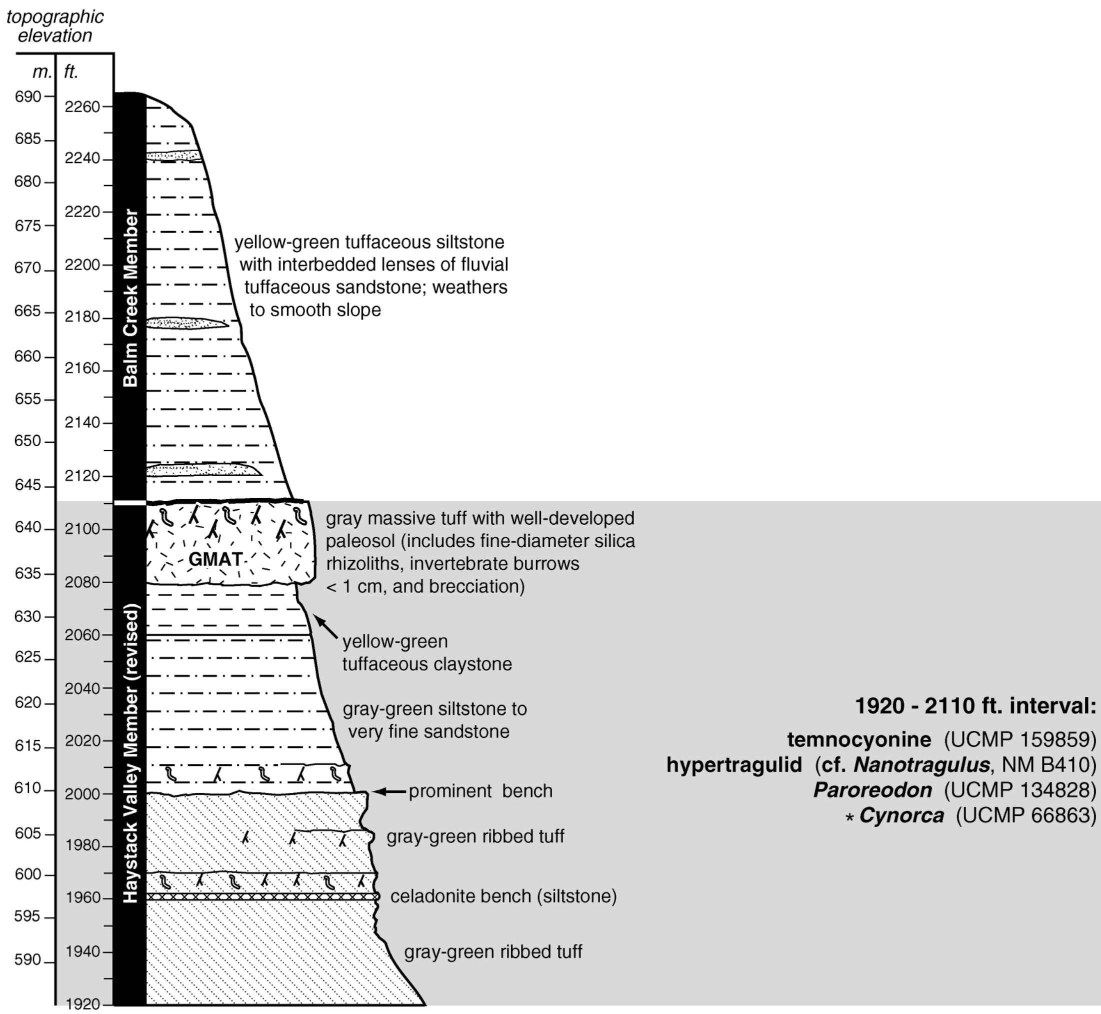
Paratylopus Hill Appendix 1-2
N1/2 NW1/4 NW1/4 Sec. 33 T. 8 S R. 25 E
Kimberly 7.5' quadrangle 1990



* UCMP specimens from Haystack Valley Member (revised) lacking exact stratigraphic level

Hopper Section Appendix 1-3

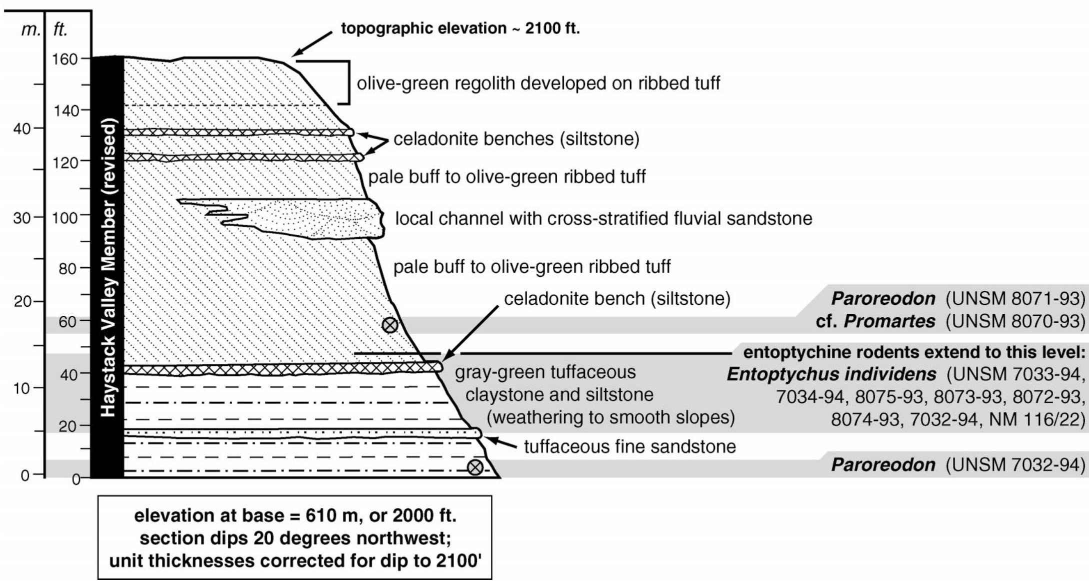
NE1/4 NW1/4 Sec.33 T. 8 S R. 25 E
Kimberly 7.5' quadrangle 1990



* Collected ~ 0.3 mile southeast of Hopper Section

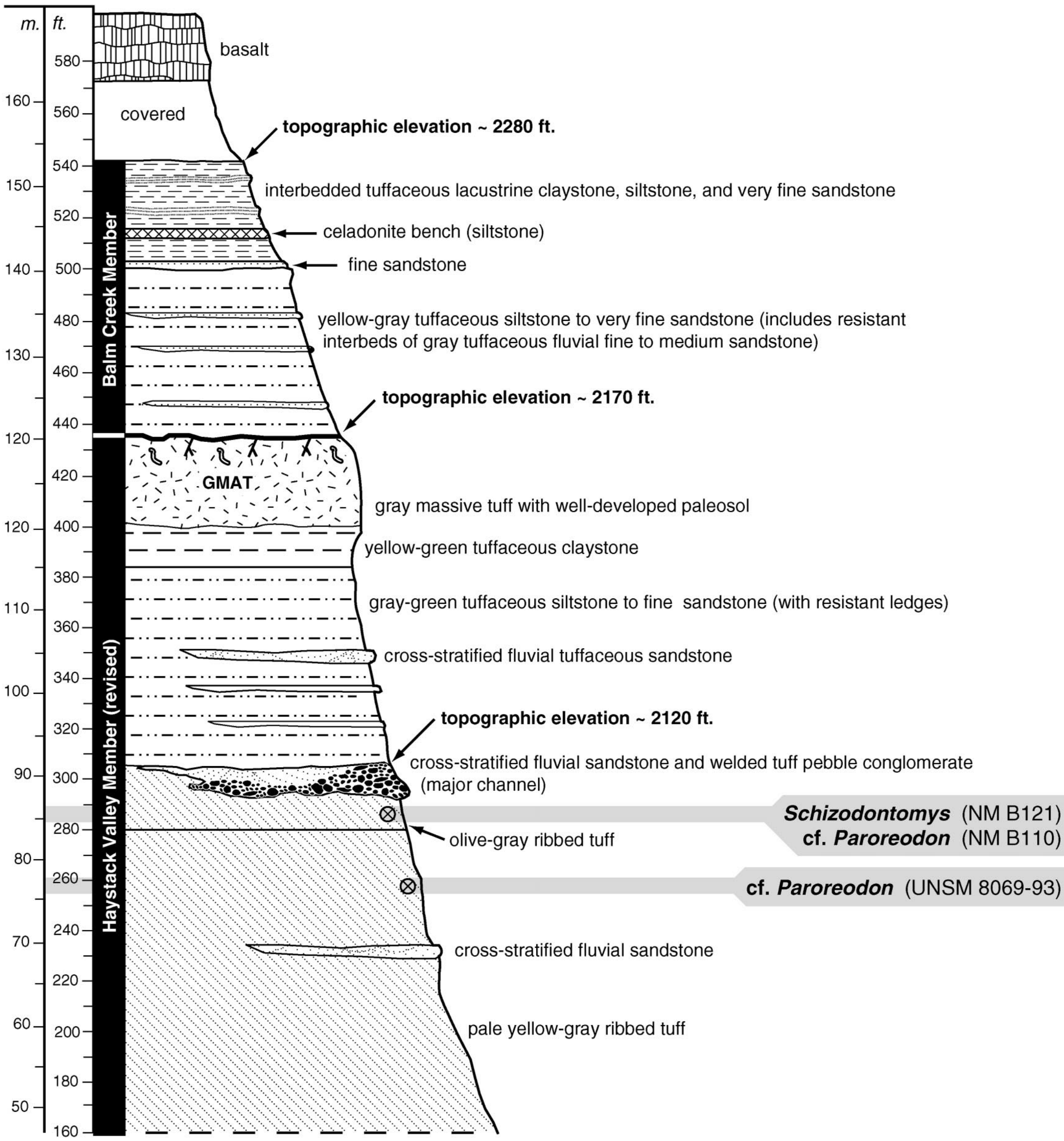
Asher Section: lower part Appendix 1-4

Center E1/2 NE1/4 NE1/4 Sec. 33 T. 8 S R. 25 E
Kimberly 7.5' quadrangle 1990



Asher Section: upper part Appendix 1-5

N1/2 NE1/4 NE 1/4 NE1/4 Sec. 33 T. 8 S R. 25 E to S1/2 SE1/4 SE1/4 Sec 28 T.8S R.25E
Kimberly 7.5' quadrangle 1990

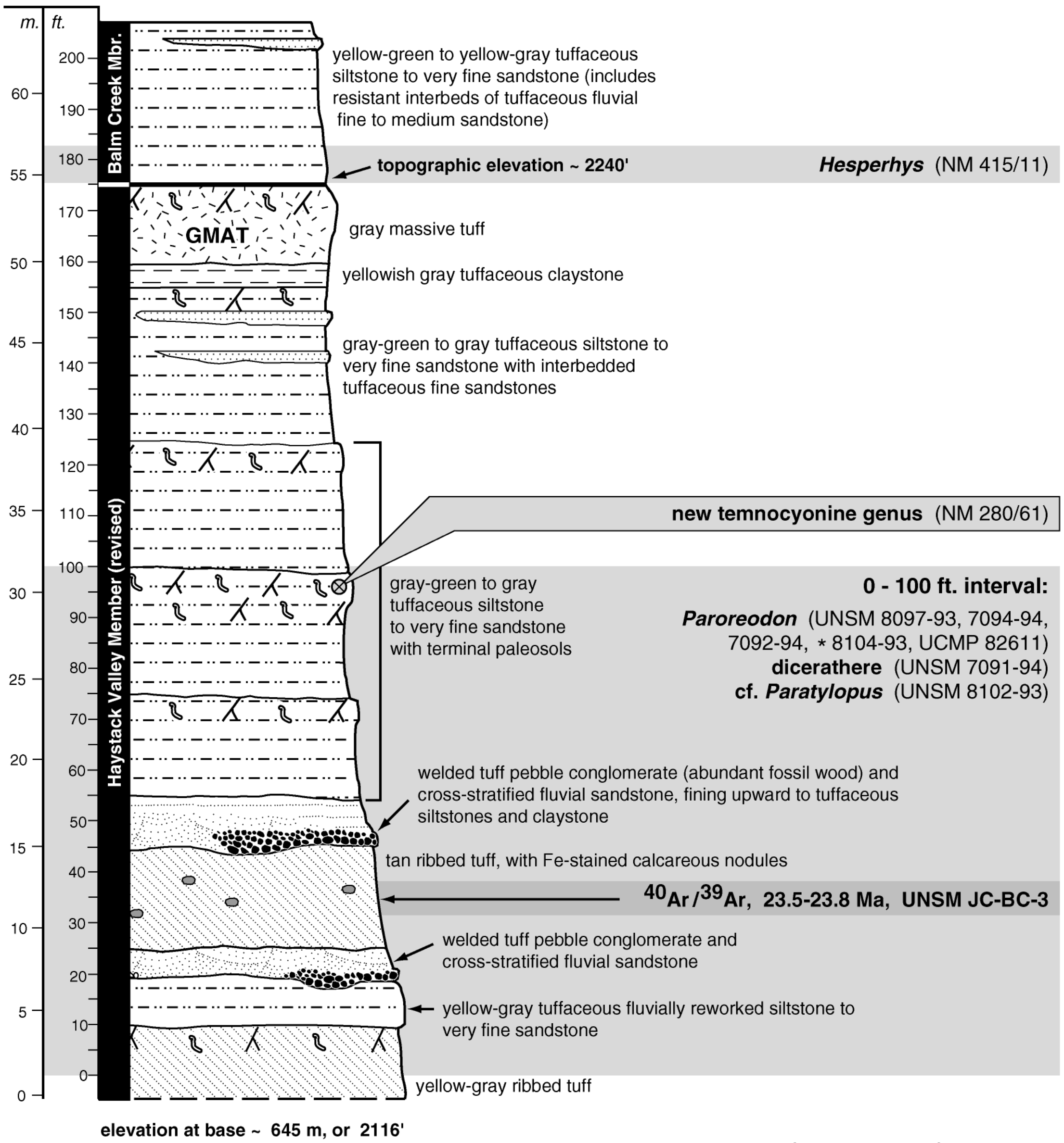


section dips 15-20 degrees northwest; unit thicknesses estimated

Beardog: Lower Appendix 1-6

E1/2 NE1/4 SW1/4 SW1/4 Sec. 27 T. 8 S R. 25 E

Kimberly 7.5' quadrangle 1990

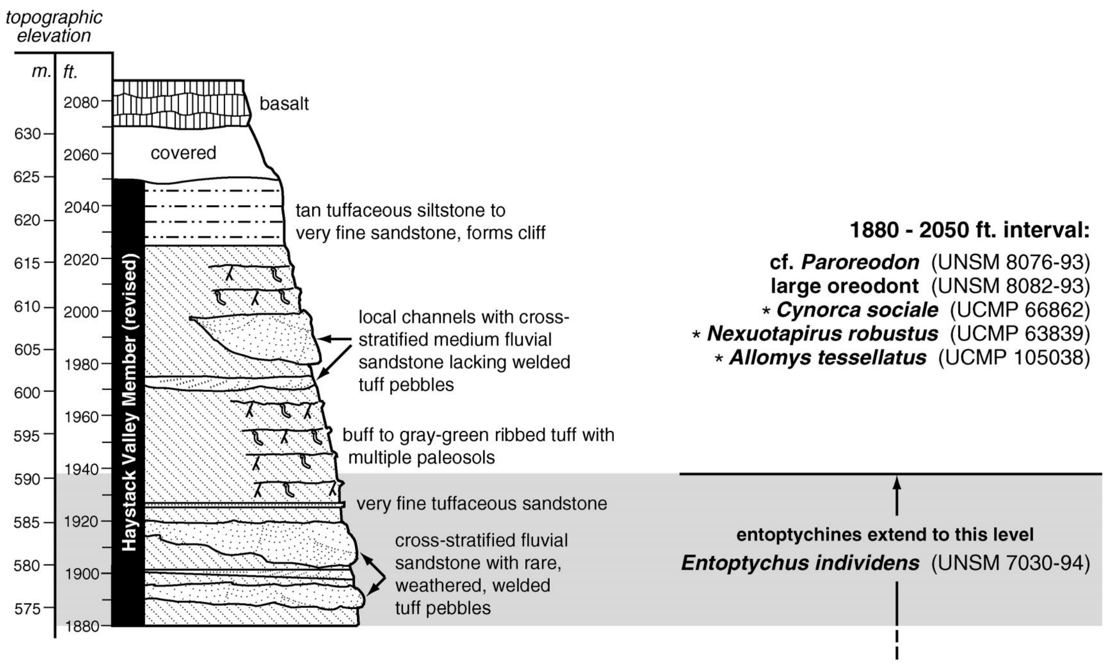


* This specimen occurs 80 ft. below base of this section 0.5 mile to the southeast in Haystack Valley Member (rev.) — other UNSM fossils from the 0–100 ft. interval were collected 0.1 mi. east of the base of section in NW1/4, SE1/4, SW1/4, Sec. 27.

Asher Re-entrant Appendix 1-7

E1/2 NE1/4 SE1/4 Sec. 33 T. 8 S R. 25 E

Kimberly 7.5' quadrangle 1990

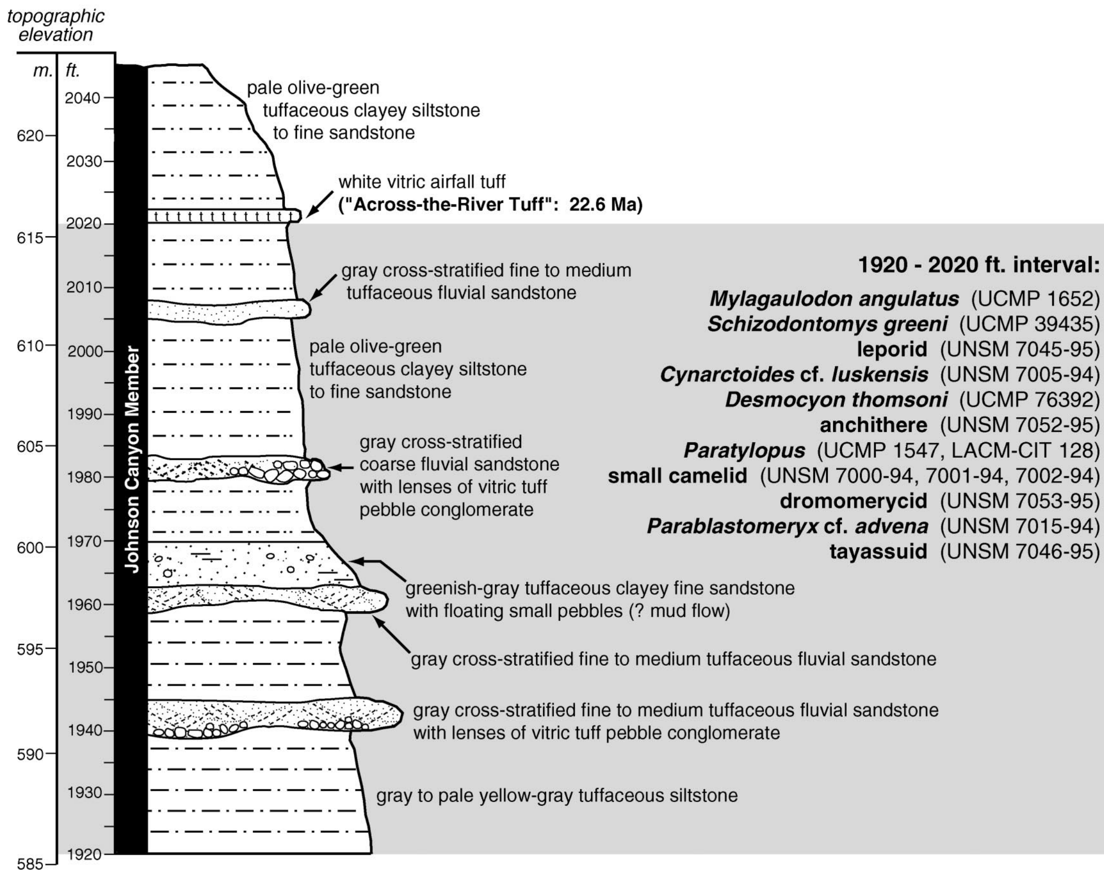


* In proximity to this section but not at this location

Picture Gorge 1 Appendix 1-8

S1/2 SW1/4 NE1/4 SW1/4 and N1/2 NW1/4 SE1/4 SW1/4 Sec. 31 T.9 S R. 26 E

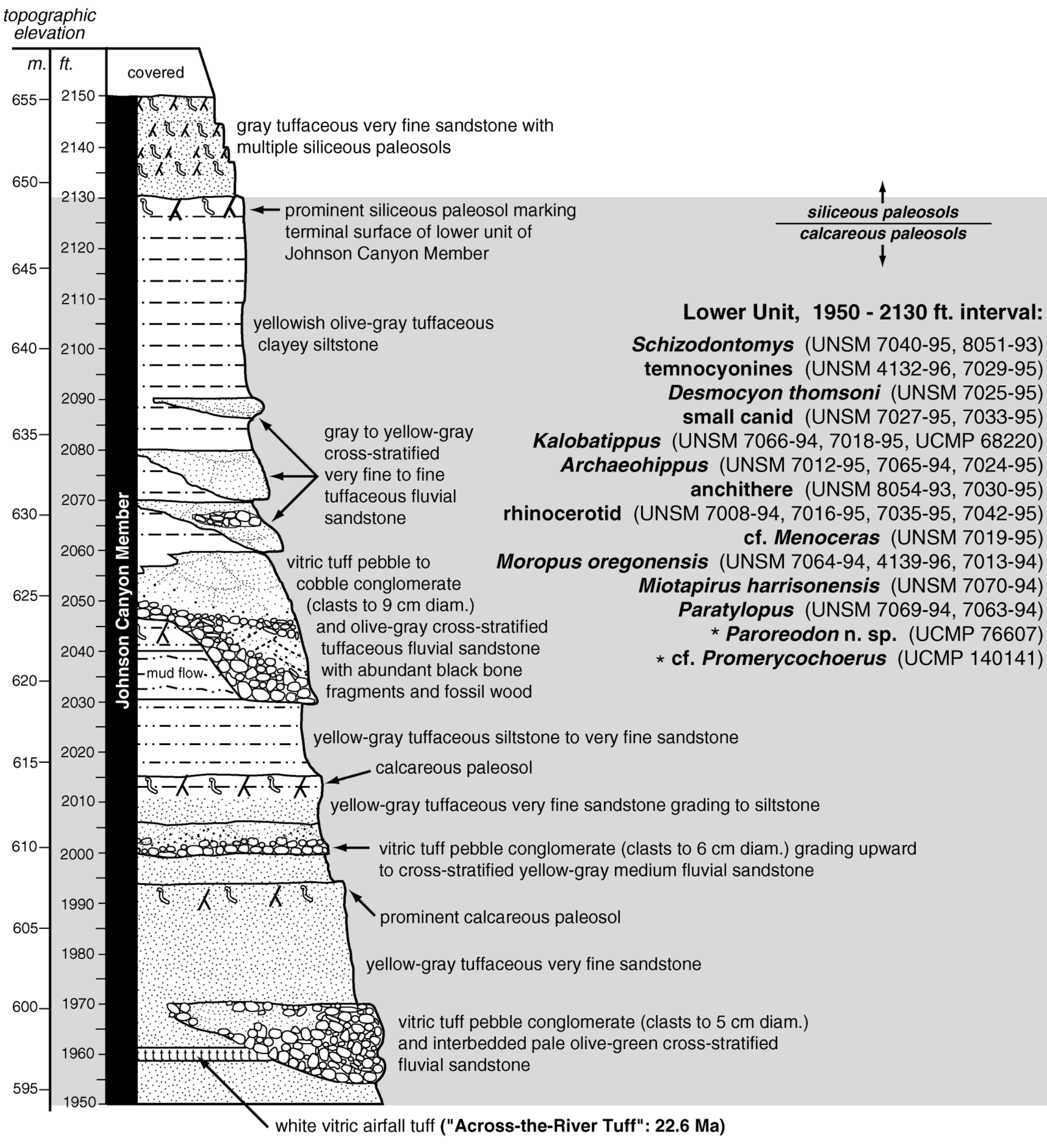
Mt. Misery 7.5' quadrangle 1990



Johnson Canyon East Appendix 1-9

E1/2 SW1/4 NW1/4 NW1/4 Sec. 31 T. 9 S R. 26 E

Kimberly 7.5' quadrangle 1990

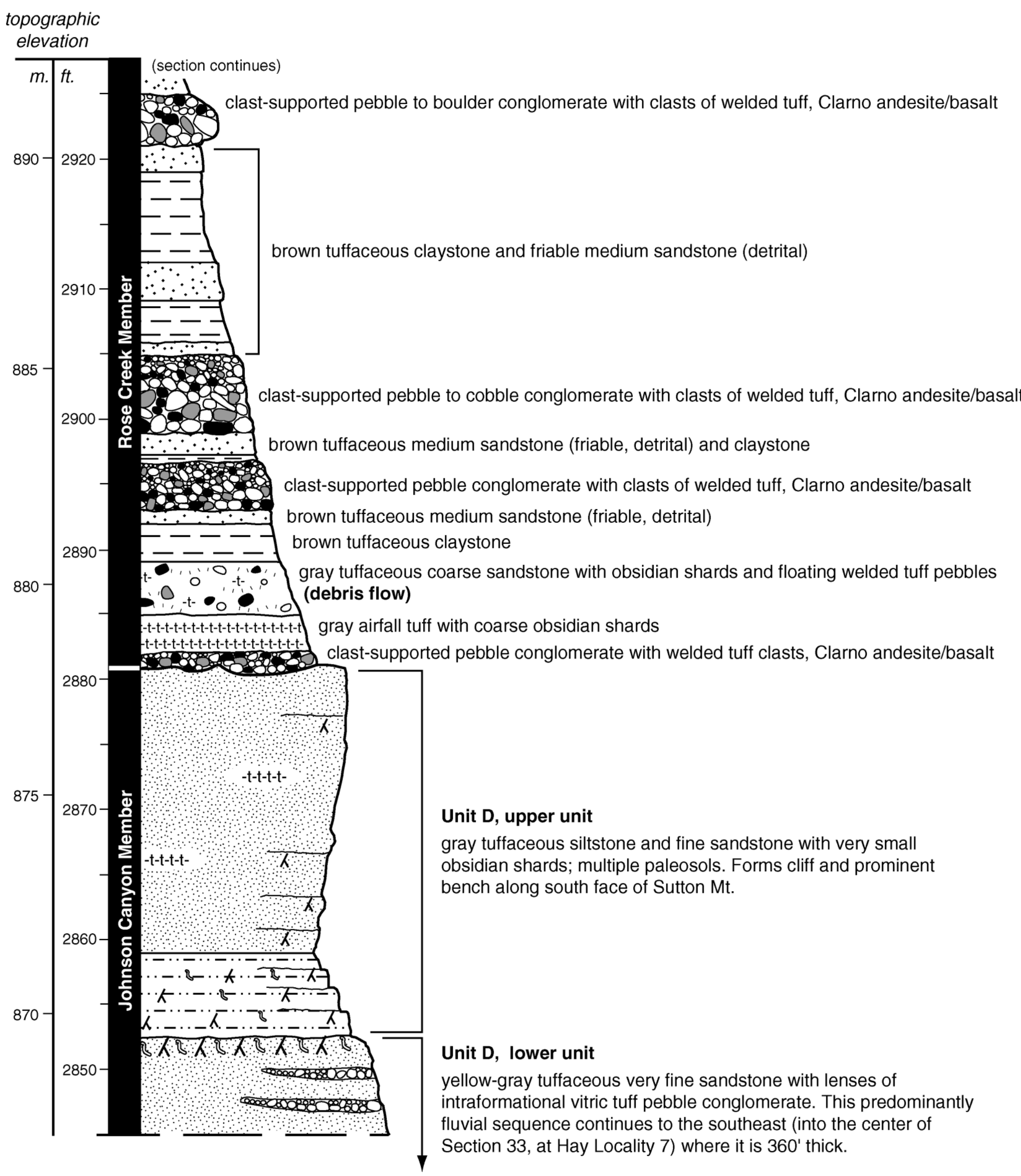


* From UCMP Loc. V-6431 on south side of Johnson Canyon

NW of Hay Loc. 7 (lower part) Appendix 1-10

NW1/4 SE1/4 NW1/4 Sec. 33 T.10 S R. 21 E

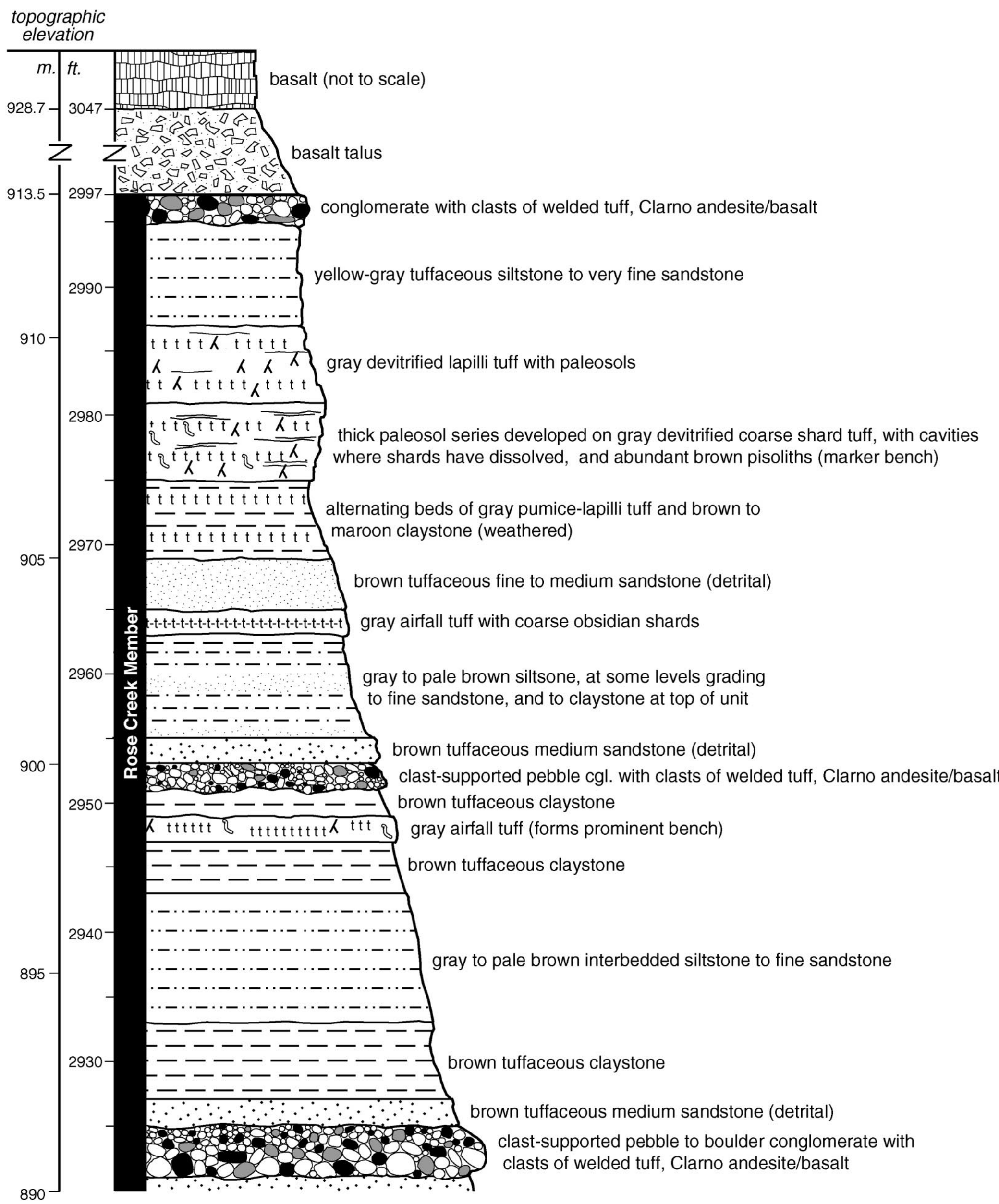
Sutton Mt. 7.5' quadrangle 1987



NW of Hay Loc. 7 (upper part) Appendix 1-11

NW1/4 SE1/4 NW1/4 Sec. 33 T.10 S R. 21 E

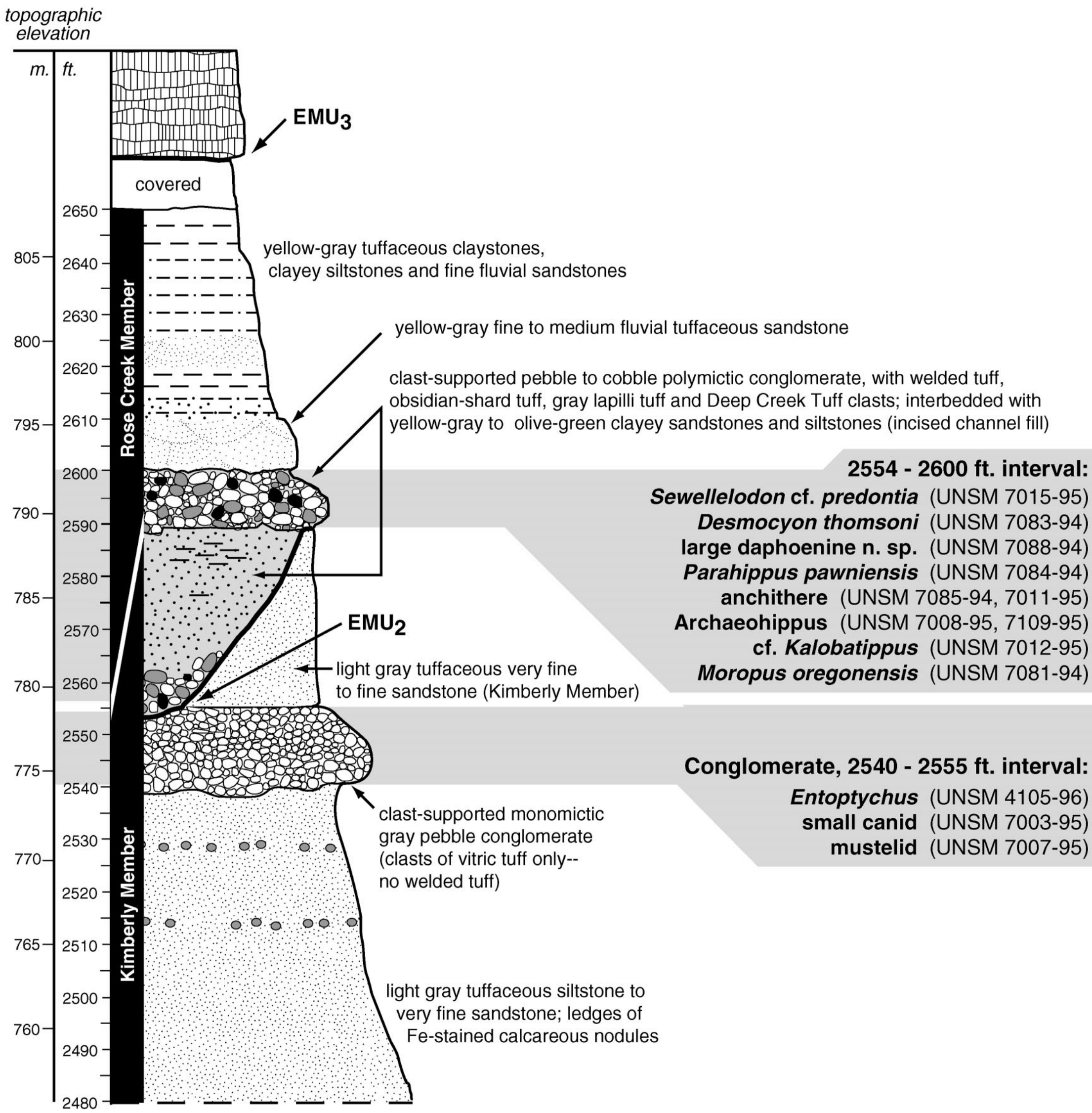
Sutton Mt. 7.5' quadrangle 1987



Rose Creek North Appendix 1-12

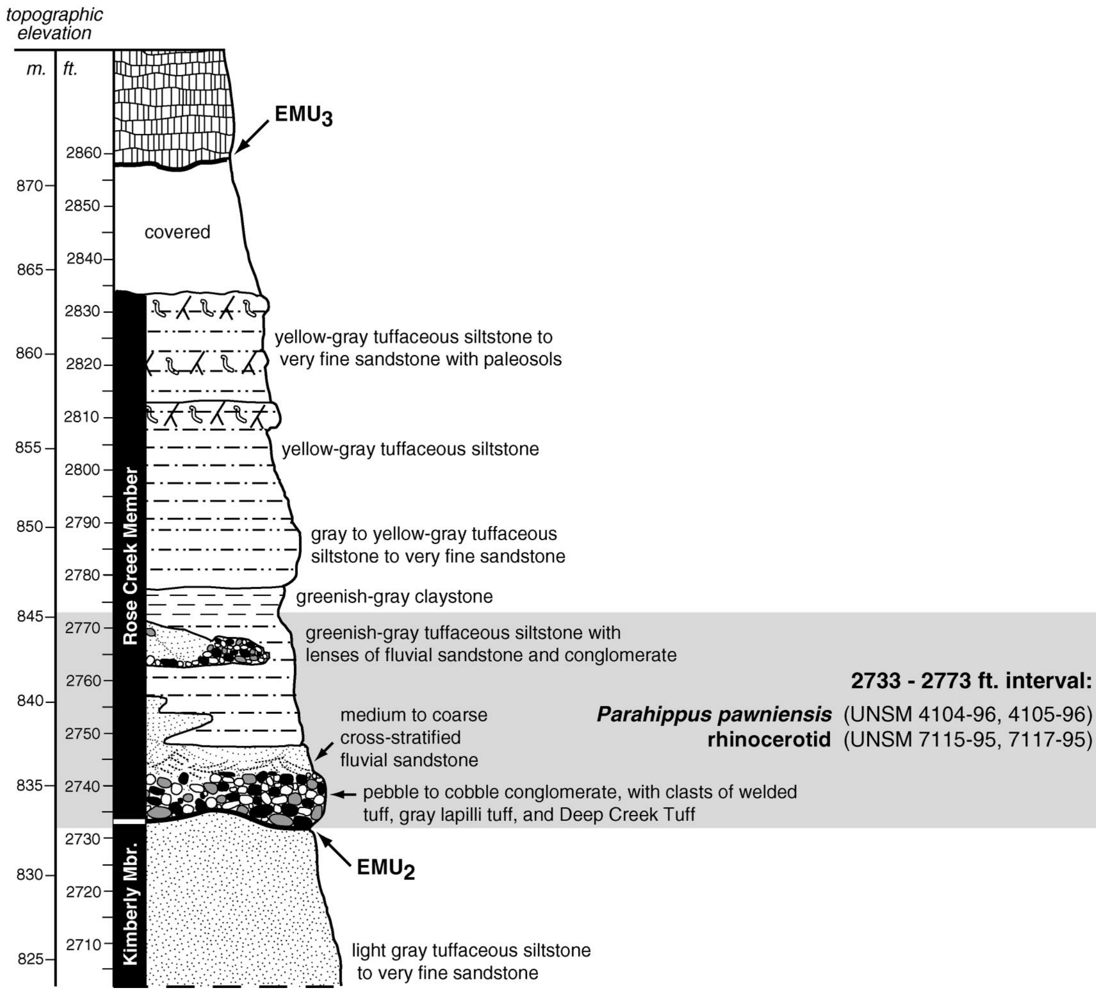
NW1/4 SW1/4 SW1/4 SW1/4 Sec. 8 T. 10 S R. 26 E

Mt. Misery 7.5' quadrangle 1990



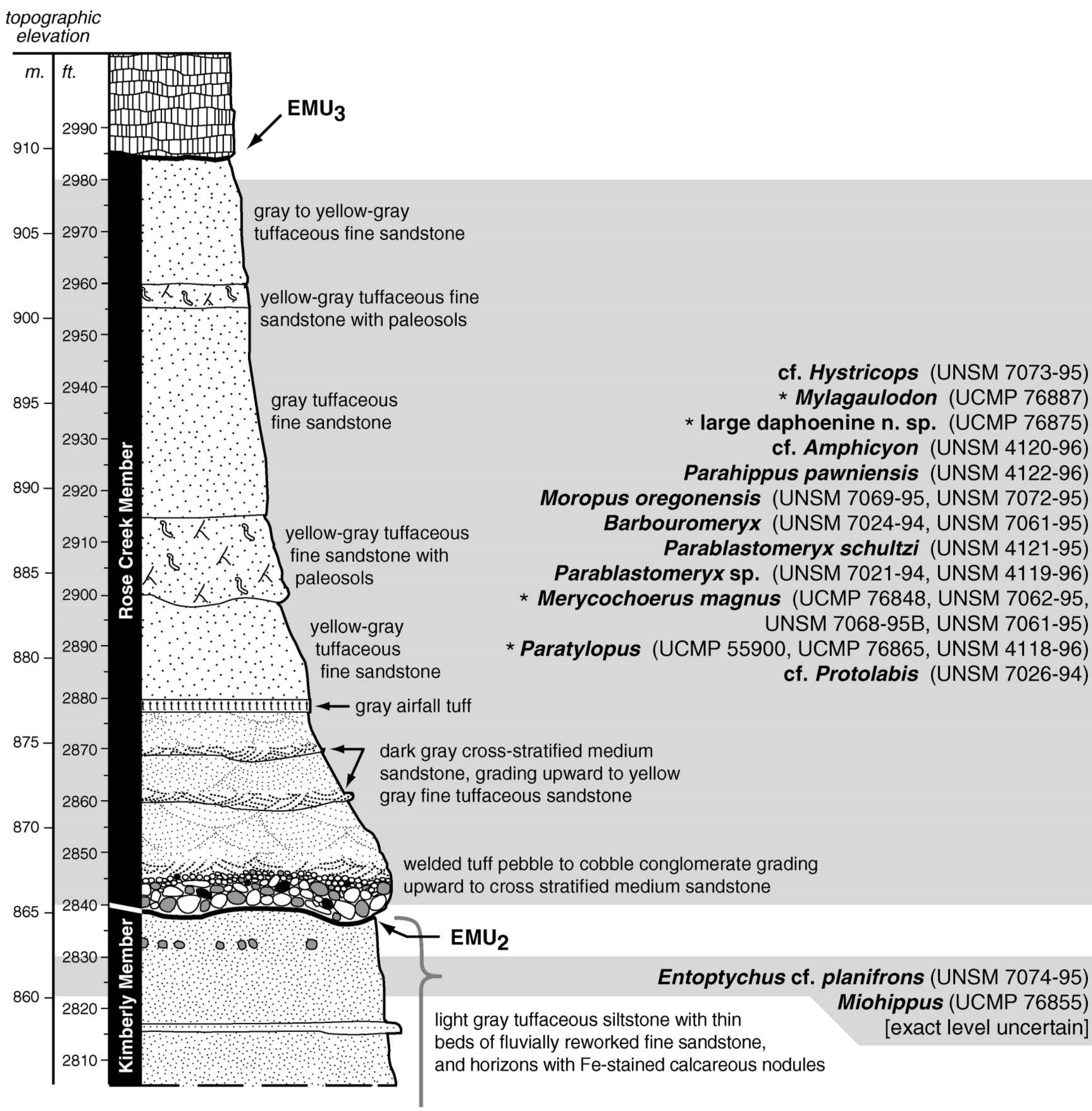
Rose Creek South Appendix 1-13

SE1/4 NW1/4 NW1/4 NW1/4 Sec. 17 T. 10 S R. 26 E
Mt. Misery 7.5' quadrangle 1990



Picture Gorge 36 Appendix 1-14

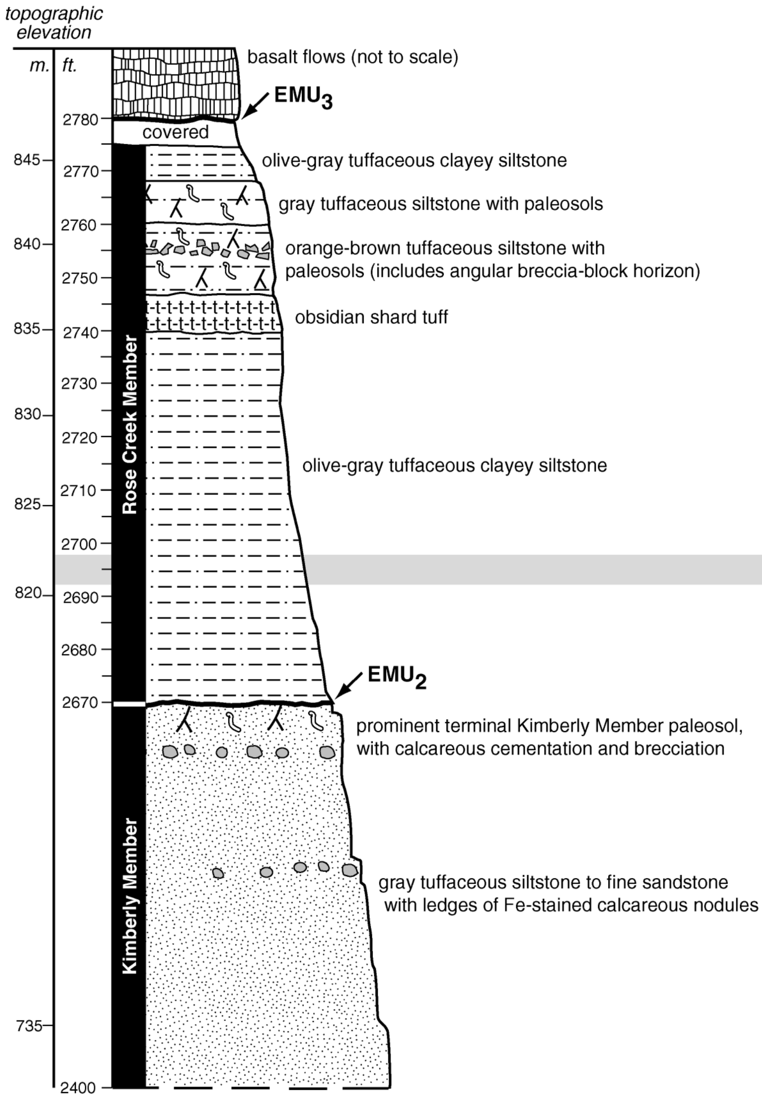
SE1/4 SE1/4 SW1/4 NE1/4 SW1/4 Sec.17 T.10 S R.26 E
Mt. Misery 7.5' quadrangle 1990



* UCMP specimens were collected within the 2840-2980 ft. interval; UNSM specimens were all collected from 2840-2875 ft.

Dead Cow Gulch Appendix 1-15

SE1/4 NW1/4 SW1/4 NE1/4 Sec. 12 T. 10 S R. 25 E
Mt. Misery 7.5' quadrangle 1990



At 2695 ft:
cf. *Paratylopus* (UNSM 7104-95),
compares with ***Paratylopus*** from
PG-36 (UCMP 55900)