Tertiary sedimentary facies depositional environments and structure Jefferson Basin southwest Montana

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The University of Montana

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TERTIARY SEDIMENTARY FACIES, DEPOSITIONAL ENVIRONMENTS,
AND STRUCTURE, JEFFERSON BASIN,
SOUTHWEST MONTANA

By

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The north-trending Jefferson Basin is one of several north, northeast-trending Tertiary basins of southwest Montana. These basins are extensional structural depressions filled with Eocene to Recent continental sediments of diverse origin reflecting complex intrabasinal filling histories. Understanding the distribution of these sediments within individual basins provides a more accurate regional perspective of Tertiary basin evolution for the northern Rocky Mountains in general.

The north-trending Tobacco Root normal fault separates east-dipping homoclinal strata on the west from north, northeast-trending folded and faulted Tertiary sediments to the east. Contrasts in structural style west and east of this fault result from differential basement subsidence, and reflect differences in basement rock composition and/or previous structural history. Structures within the Tertiary sediments are a drape fold and fault response to listric normal faulting of the underlying basement. Some basin margin faults are reactivated pre-Eocene (Laramide) reverse or tear faults. Faulting and basin growth occurred incrementally since late Eocene time and culminated in a significant late Pliocene or early Pleistocene structural event.

The previously mapped Renova (late Eocene-late Oligocene) and Six-Mile Creek (middle Miocene-middle Pliocene) formations are divided into lithostratigraphic units comprising variable amounts of ash, mud, silt, sand, conglomerate, and limestone deposited in several depositional environments: alluvial plain, alluvial fan, floodplain, shallow lacustrine, and aeolian.

Widespread deposition of ash-rich sediment was initiated in late Eocene time by mass-flow and lesser fluvial depositional processes. Fluvial processes increased through Oligocene time draining newly uplifted, western highlands. Ponds and shallow lakes periodically formed along the southeast margin of the basin. A late Oligocene or early Miocene erosional event removed a variable and unknown amount of sediment from the basin. Miocene-Pliocene sedimentation patterns show increase in local source derivation. Aeolian deposits locally present in Oligocene age strata are more widespread in Miocene-Pliocene age units.

Theories which interpret Tertiary basin evolution of this northern Rocky Mountain region as exclusively tectonic or climatic controlled are not supported by this author.
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INTRODUCTION

The Jefferson Basin sub-parallel Laramide structural trends (Ruppel, 1981) as part of a north-south trending complex of intermontane basins dissecting the fold and thrust terrain of western Montana and east-central Idaho (Robinson, 1961) (Fig. 1). These intermontane basins are extensional structural depressions filled with thick (to 5000m) Eocene to Recent continental sediments of diverse sedimentary and volcanic origin (Thompson et al., 1982). Tertiary sediments which fill these basins provide a unique stratigraphic record with significant implications for interpreting both Tertiary basin evolution and the Tertiary geologic history of the northern cordillera.

Paleontology and general stratigraphy have been the focus of most previous work in these basins. One common geologic history has been proposed to account for the evolution and sedimentation record for all of these intermontane basins (Thompson et al., 1982). Basic to this common geologic interpretation is the supposed presence of a regional, middle Tertiary (late Oligocene or early Miocene) unconformity (Robinson, 1960; Kuenzi and Richard, 1969; Kuenzi and Fields, 1971; Rasmussen, 1973; Thompson et al., 1982) separating a lower fine-grained sediment sequence from an upper coarse-grained sediment sequence. Climate and tectonics have been viewed as significant influences governing the proposed regional basin relations, yet very little work has attempted to relate these influences to the complex and varied distribution of Tertiary sediments within the basins. In addition, very few studies have emphasized the interpretation of depositional
Figure 1. Tertiary intermontane basins of southwest Montana (ruled). Study area is enclosed within the block outlined around Whitehall, MT. Key to basins: 1) Jefferson; 2) Three Forks; 3) Lima; 4) Townsend; 5) Beaverhead; 6) upper Ruby; 7) Big Hole; 8) Deer Lodge; 9) Flint Creek; 10) Bitterroot; 11) Madison (modified from Kuenzi and Fields, 1971).
environments from detailed facies relationships (Monroe, 1981). Unfortunately, detailed intrabasinal stratigraphic studies have been de-emphasized in light of this proposed unifying view of Tertiary basin evolution. A regional perspective of the stratigraphy of these basins necessitates a detailed understanding of depositional histories within individual basins. In this paper I outline results of detailed geologic mapping (1:24000 scale) of Tertiary rock types in the Jefferson Basin, southwest Montana.

The purpose of this study is to decipher the Tertiary evolution of the Jefferson Basin utilizing 1) my detailed geologic mapping (1:24000 scale) of Tertiary lithostratigraphic units (Plate 1), 2) salient sedimentary and structural characteristics of the Tertiary sediments, and 3) depositional-environmental interpretations of the mapped lithostratigraphic units. The distribution of rock types are interpreted in a depositional-environmental framework to enhance our understanding of 1) the Tertiary basin filling history, and 2) controls on sedimentation by climate and tectonics. Further, this environmental approach provides a stratigraphic framework applicable to the magnetic, absolute, and paleontologic time scales.

The Jefferson Basin is morphologically distinguished by Precambrian to early Tertiary age basement rock uplifts. The northern Highland Range and Boulder Batholith define the west and northwest boundaries of the basin. A pronounced eastward embayment of the basin separates Bull Mountain on the northeast from the Tobacco Root Mountains to the southeast, coincident with the westward extension of the Willow Creek Fault Zone (Robinson, 1963) or "Transverse Zone" of Schmidt.
Figure 2. General physiographic map of study area (dashed line) and surrounding basin margin uplifts.
Post Laramide history of these uplifts significantly influenced the structural development, sediment source and distribution patterns, and overall sediment accumulation throughout the basin.

To aid intrabasinal lithofacies correlation, the Jefferson Basin is divided into three informally named Regions; West, Central, and East (Fig.3), comprising six, physically separate intrabasinal Areas; Little Pipestone, Big Pipestone, Palisades, Central basin, Bull Mountain, and Parrot Bench (Fig.4). Together these Areas enclose approximately 100 square miles. Outcrops useful to sedimentological information are limited within Areas, and nowhere are rock units physically traceable between Areas.

The previously mapped Renova (late Eoc.-middle Olig.) and Six Mile Creek (middle Mio.-middle Plio.) formations (Kuenzi and Fields, 1971) are divided into six primary sediment types: ash, mud, silt, sand, conglomerate, and limestone. In this report, the distribution of Tertiary sediments are discussed in reference to these six sediment types. Mapped lithostratigraphic units consist of one or more of these six primary sediments. Thus, lithostratigraphic units define rock type groups or associations which identify 1) the most abundant constituent sediment type, and 2) any definitive sediment texture (Table 1, and Plate 1). Lithofacies are interpreted from characteristics of the lithostratigraphic units and several depositional environments are recognized: alluvial fan, alluvial plain, floodplain, shallow lacustrine, and aeolian.
Figure 3. Subdivision of study area into three informally named intrabasinal Regions.
Figure 4. Subdivision of Regions (Fig. 3) into six informally named intrabasinial Areas.
### Table 1. Identification of six primary sediment types and their associations which comprise the Lithostratigraphic units used in mapping the Tertiary sediments of the Jefferson Basin. The distribution of lithostratigraphic units is shown by Area (X). Sediment texture modifiers (lower right) are added to further describe many lithostratigraphic units (see Plate 1 for examples).
Stratigraphic correlations used to decipher the basin filling history depend largely on 1) composition, texture, sedimentary structures, and bedding characteristics within lithostratigraphic units, 2) lateral or vertical structural projection within and between Areas or Regions believed structurally congruent, 3) structural style within or between Areas and Regions, and 4) the biostratigraphic framework of Kuenzi and Fields (1971). Ages which define this biostratigraphic framework are adjusted in this paper to the more recent geologic time scale of van Eysinga (1978). Limited or poor outcrop exposures constrain many vertical and lateral facies relations, particularly in areas of rapid facies change. In addition, most sediment exposures are confined to basin margin areas, somewhat biasing observation at the expense of understanding important central basin facies.

The Jefferson Basin is divided into a structural framework of two provinces west and east of the Tobacco Root Fault (Fig. 9). Criteria which distinguish these two provinces are 1) the structural configuration of the pre-basin (basement) rock, and 2) structural style within the overlying Tertiary basin fill. This basement structure controls the overlying Tertiary sediment deformation. Thus, recognition of structure within Tertiary sediments provides insight to the structural development of this underlying basement. Basin structure in the West Province consists of a relatively simple, hinged, listric normal, fault block downdropped on the east. A more fragmented, listric normal, block faulted basement controls structure in the East Province and includes the east embayment of the Jefferson Basin. Composition and/or previous structural history are factors responsible for the
different basement block behavior. Contrasts in the structural style of Tertiary sediments west and east of the Tobacco Root Fault result from differential basement rock response to late Cenozoic extension.

Detailed mapping and re-interpretation of structure (this study) necessitates re-evaluation of previous interpretations (Kuenzi, 1966; Kuenzi and Fields, 1971) regarding time-space relations for both structural development and the distribution and extent of the middle Tertiary unconformity. Climate, tectonics, and volcanic activity are recognized factors controlling the Tertiary evolution of the Jefferson Basin.
WEST REGION

The West Region encompasses thirty square miles comprising three geographical Areas (Figs. 3 and 4). Tertiary sedimentary units define a north-trending, east-dipping sequence. Attitudes vary locally where sediments disconformably onlap both Elkhorn Mountain Volcanic rocks, and granitic rocks of the Boulder Batholith in the Palisades, and Little and Big Pipestone Areas respectively. Cumulative thickness estimates are tenuous depending on lateral correlation interpretation and range from 400 to 600m.

Little and Big Pipestone Areas - Description

Lowermost or oldest (Chadronian age) deposits of the West Region are exposed in the Little and Big Pipestone areas. Fine-grained sediment in this lowermost section consists of mud or ash dominated units. Ash rich units are most abundant. Massive and ill-defined bedding are common and usually recognized in subtle variation of ash, mud, silt, or sand content. Some interbedded coarse-grained sands with basal scoured surfaces cut into these fine-grained sediments. Sand interbeds are thin (generally < 1m), dominated by angular granitic-lithic detritus, and rare, chaotic, matrix-supported pebble-cobble sandy breccia or conglomerate.
Mud-dominated units exhibit variable clay to silt ratios with more granitic rock fragments and less fresh volcanic glass. Many units are poorly sorted with bedding ill-defined or not discernible. Kuenzi (1966) identifies montmorillonite as the dominant clay constituent here and throughout all other Oligocene age sediments within the basin.

Marked increase in volcanic glass and pumice distinguish the ash-dominated units. Sorting varies from moderate to poor. Bedding varies from thin (few to several cm) more homogeneous interbeds to thick (1m+) beds, internally massive, crudely bedded, or locally inversely graded. Some layers exhibit low-angle cross-bedding. Fresh volcanic glass shards and angular to rounded pumice fragments are locally abundant. A few layers are particularly rich in well-rounded accretionary lapilli. Admixtures of mud and granitic-lithic sand clasts are common and usually associated with more poorly sorted units. Intraformational conglomerates sporadically occur along the base of some units.

Basal fine-grained sediments in the Little and Big Pipestone areas are overlain by a thicker (several to few 100m) coarse-grained sand package. Best exposures occur in scattered outcrops along roadcuts and stream gullies in the Little Pipestone Area. These sands are poorly sorted, angular to subrounded, granitic-lithic rich arkoses. Grain size ranges from fine-grained sand to granule. Many sands are locally pebbly with pebble clast compositions analogous to those of the conglomerates described below (page 13). Horizontal or very low-angle tangential and trough cross-bedded sands are characteristic. Some sands exhibit planar tabular cross-bedding. Scour surfaces distinguish most
bedding. Some sands are interbedded with muddier units but most commonly form multistory sand packages. Sheet-like geometries distinguish these sand packages regardless of their thickness.

Admixed and locally interbedded with the sands are pebbles, cobbles, and occasional boulders in a pronounced westward coarsening facies. Westernmost exposures exhibit sand interbedded with, and filling the interstices of cobble-boulder conglomerates. Conglomeratic units grade laterally and upward to the sand dominated sequences (described above—page 12) within two miles to the east. Pebble and larger sized fractions are rounded and consist mostly of metamorphic and lesser granitic rock clasts.

Palisades Area — Description

Approximately 200m of Oligocene sediment fill the Palisades Area (Fig.4). Fossil dating (Kuenzi, 1966; Kuenzi and Fields, 1971) suggests a middle Oligocene (Orellan-Whitneyan) age, thus a probable younger sequence than lowermost Chadronian age deposits in the Little and Big Pipestone areas. Tertiary deposits trend north-northeast, dip gently to the east and disconformably overlie Elkhorn Mountain Volcanic rocks. Silt and sand size sediment dominate. General paucity of mudstone distinguishes these deposits from sediment in the Little and Big Pipestone areas to the south. Fine-grained sand or silt sized ash and fine to coarse-grained granitic-lithic sands, notably middle to uppermost exposures, comprise the bulk of this overall coarsening upward sequence.
Bedding within the fine-grained, ash-rich units varies from massive and indistinct to moderately well-bedded layers exhibiting crude horizontal or undulatory wavy to irregular stratification. Subtle textural changes marked by coarser and finer-grained sediment aid bedding distinction. Increases in pumice and/or lithic fragments of Elkhorn Mountain Volcanic rock is associated with the coarser ash-rich sediments. Bulk compositions comprise fresh volcanic glass shards, crystalline ash, pumice, and fine-grained sand to silt size volcanic rock fragments. Fine-grained lowermost units contain sparry calcite either as irregular blebs in a very fine "dirty" ash-rich matrix, or, as partial to complete replacement of some lithic and/or pumice clasts. Fine-grained unaltered glass or glass and feldspar crystals coexist with this altered volcanic detritus. Local intraformational conglomerates contribute to basal portions of some massive or crudely bedded units.

Angular to subrounded granitic-lithic arkosic sands occur in middle and upper exposures. These resemble some sands exposed in the Little and Big Pipestone areas. However, most bedding features are of smaller scale and most sands are associated with more silt and ash. Thin, low-angle, horizontal, and trough cross-bedded sands are common. Many of these sands exhibit alternating coarser and finer laminations. Many include small scours and channels filled with fining-upward sequences where sands fine and are overlain by silt or mud drapes.

Scattered throughout the lower units and increasing upward in the section are discontinous or lenticular deposits of coarse sand, granule, and pebble-cobble breccia and conglomerate. Scoured bases and variably shaped channels are filled with either clast-supported debris merging
upward into matrix-supported sandy ash with floating granule-pebble volcanic-lithic clasts, or, filled with granule-pebble volcanic-lithic clasts and pumice fragments floating in a matrix of fine-grained sand to silt sized ash. Bedding in these coarser units lower in the section are more crudely horizontal. Trough cross-bedded sands contribute to channel-filling higher in the section.

Interbedding of coarse-grained sand increases upward to eventual dominance of coarse sand and cobble conglomerate at the top of the section. Sands here exhibit scoured bases, moderate lateral continuity, and consist internally of variably bedded, multistory, horizontal to low-angle and trough cross-bedded sands. Common U-shaped, steep sided channels scour into underlying fine tuffaceous sediment along the base of these coarser units. Cobble and occasional boulder conglomerate contribute to the larger channel-fill deposits.

Soft sediment deformation occurs in some thick-bedded, ash rich units in the upper part of the section. Irregular wavy beds occur in broad open to tight recumbent folds with amplitudes greater than one meter. Most deformed beds exhibit truncation by overlying coarser or finer units. Some deformed units bend and fold beneath large, scoured channels filled with coarse sand, granule, and pebble-boulder conglomerate. Occasional thin (few cm+), laterally continuous, light colored crystalline ash layers occur throughout the section.
Interpretation - West Region

Basal mud and ash rich units record the oldest (Chadronian age) sedimentation within the West Region. Somewhat older facies probably occur buried beneath these Tertiary deposits to the east. A composite vertical sequence illustrates the transition from dominant mud, silt, and ash rich facies upward to coarser sand and conglomeratic facies (Fig. 5). While this coarsening upward trend is apparently older and more abrupt in the Little and Big Pipestone areas, it is somewhat younger and more transitional in the Palisades Area. Mass-flow with mixed airfall and lesser fluvial sedimentation are processes responsible for deposition of these lowermost finer-grained sediments. Upper, coarser deposits are interpreted to have formed from increased fluvial sedimentation processes in a mixed braided and meandering fluvial system.

Laterally continuous mud and ash facies suggest a readily accessible fine-grained source and a relatively low-relief depositional surface. Some massive, poorly sorted clay rich units probably represent floodplain deposition. Primary ash airfall is recorded in thin laterally continuous glass or crystal ash rich beds, or, in somewhat more irregular bedded accretionary lapilli or other pumice-rich, glass dominated layers. The crude horizontal to irregularly bedded ash rich units locally pumiceous and/or rich in other fragmental volcanic debris are interpreted to have formed under mass-flow depositional processes (Fisher, 1971), perhaps similar to mud deficient, better sorted, mass-flow deposits described by Fritz and Harrison (1983b), for similar recent deposits around Mount St. Helens. The ubiquitous association of
Figure 5. Schematic sediment facies correlation, West Region. Note the overall coarsening upward trend.
fresh glass within montmorillonitic mud (Little and Big Pipestone areas), or montmorillonitic mud and other altered volcanic detritus (Palisades Area), indicate the montmorillonite or other detrital alteration formed prior to deposition of the present sedimentary units. I interpret these sediments to represent reworked fine-grained material transported from previous sediment accumulations in highlands to the west. Fresh volcanic airfall materials were incorporated either during transportation or closely preceding transportational event(s). Intraformational sediments indicate reworking of earlier cohesive deposits along the front or base of some flows. Composition, texture, and bedding characteristics suggest probable rapid sedimentation rates (Schminke, 1966).

Small (several cm to 0.5m deep) channels along the tops of some fine-grained units indicate reworking of their upper surfaces by fluvial processes. Some of this reworking was probably influenced by dewatering of mass-flow units deposited underneath or upslope from these channel-fill sediments. Angular-subrounded pre-basin rock clasts in some channels indicate partial through-flowing drainage from exposures west of the Palisades Area. Mud or other mass debris-flow deposits contributed sediment to many of these channels. Occasionally, debris-flow sediments choked these channels forcing the development of new channel systems. Increasing coarse-grained sand and conglomerate dominated by Elkhorn Mountain Volcanic and Boulder Batholith granitic-lithic compositions upward in the Palisade Area indicate increasing exposure of these pre-basin rocks to the west. The upward increase in coarse-grained sediment, sheet-like sand geometry, and
cross-bedded sand and coarse channel-fill sequences all suggest increasing fluvial sedimentary processes. Paleocurrent data from the Palisades Area (Fig. 6), indicate east-southeast predominant flow direction.

Coarse-grained sand and conglomerate facies in the upper Little Pipestone Area record an earlier change to dominantly fluvial sedimentary processes. These coarse-grained facies formed from small sand bar migration and channel-fill processes in an east-flowing, mostly braided fluvial system (Walker, 1980). Angular granitic-lithic sand shed from immediate batholith exposures mixed with rounded pebble or larger metamorphic and granitic-lithic clasts reflecting more diverse source (N. Highland Range). Associated sandy mud facies represents either reworking of older fine-grained Oligocene sediment, or minor floodplain deposition marginal to the dominant sandy fluvial system. Paleocurrent indicators (Fig. 6) suggest eastward transport in agreement with the eastward fining grain size trends. Trough cross-bed dip directions at oblique angles to the primary channels are interpreted to represent oblique channel-filling processes. Traces of this coarse granitic-lithic sand facies are found in uppermost exposures in the Big Pipestone Area and laterally adjacent to lower-middle levels of the Palisade Area suggesting a continuous sheet geometry roughly parallel to the trend of the present Jefferson Basin.

With some hesitation, Kuenzi (1966), and Kuenzi and Fields (1971) include the middle Tertiary unconformity at the base of a gray, sandy conglomeratic unit near the top of the Palisade Area section. The youngest fossil collected below this unit yields a middle Oligocene age.
Figure 6. Rose diagrams from Oligocene age sands of the Jefferson Basin. Shaded areas represent trough cross-bed measurements. Striped arcs designate ranges of paleochannels and the direction of flow which created the channels. Note how trough cross-bed orientations deviate from paleochannel flow directions. Roses are centered over outcrop localities.
(Kuenzi, 1966; Kuenzi and Fields, 1971). No fossils have been collected within the coarse unit itself. I interpret structural conformity, sediment compositions, and interbedded relationships to describe this unit as the coarsest facies in a continual coarsening upward trend characteristic to the section. I therefore cannot support inclusion of the middle Tertiary unconformity within the Palisade Area section.

CENTRAL REGION

Central Basin Area - Description

The Central Region comprises one large Central Basin Area in an elongate thirty-two square mile belt north and south of Pipestone Creek and along the present axis of the Jefferson Basin (Fig. 4). Exposed Tertiary sediments range from middle Miocene to early or middle Pliocene age (Kuenzi and Fields, 1971). Total thickness estimates range from 350 to 450m. Some Basal units in the northwest corner of the Area rest disconformably on Elkhorn Mountain Volcanic rocks. Any basal contact with underlying older Tertiary sediments elsewhere along the Area's western margin are buried or obscure. A combination of poor or no exposure, erosion along present creek or river drainages, and/or faulting, preclude understanding relationships to Tertiary sequences exposed east of the this Central Basin Area.

A north trending, gently east dipping sequence describes most deposits. One notable exception occurs in the northwest corner of the Area where variably low-angle dips flank exposures of Elkhorn Mountain
Volcanic rocks (Plate 1, sec 24 T2N R5W). Sediment types vary in an overall vertical sequence of decreasing ash and increasing conglomerate. A combination of poor and limited outcrop exposure inhibits observations, placing obvious constraints on sedimentological interpretations. Most observations come from sediments exposed north of Pipestone Creek (Fig.4, and Plate 1).

A mud, silt, and cross-bedded sand facies includes most sediment lower in the section. Sand units are coarse and locally pebbly. Trough, low-angle tangential, and local horizontal cross-bedded sands occur in discontinuous lenses and wedge shaped sets separated by scour surfaces. Channels are common and may contain basal pebble lags. Channel-fill consists of cross-bedded sand, granule, and occasional pebbly sand. Sandy pebble conglomerate layers exhibit very low-angle or horizontal cross-bedding with some alternating coarser and finer laminated sets.

Silt and/or mud may individually comprise certain thick (to 1m+) beds, but they more commonly occur as thinner (mm to cm scale) beds or laminations overlying basal scoured sands or pebbly sand layers. Some of these fine-grained sediments contain root casts, thin (mm to cm scale) irregular caliche layers, and dark red-brown to brownish-black oxidized zones.

Volcanic ash contributes to some deposits in the lower-middle part of the section north of Pipestone Creek. Ash also occurs in more easterly facies southward in the Area. Granitic and volcanic-lithic silt and sand dominate with ash (locally pumiceous) admixing in moderate
to poorly sorted "dirty" appearing units. A few thin (few to several cm), laterally extensive ash layers occur. Fresh volcanic glass, some pumice, and lesser crystal and lithic fragments dominate their composition. Pale grey, white and grey-blue colors distinguish these extensive layers. One layer was locally thickened (to 2m+) into horizontal and tangential cross-bedded sets. While better developed in "cleaner" sandy deposits, bedding in "dirtier" units is less well developed, often massive, and sometimes crudely horizontal. Massive or crudely bedded units contain coarse-grained, granitic-lithic sand clasts floating in a more homogeneous silt, mud, or silty ash matrix. Often this matrix is rich with biotite. Mud occurs in thin draped laminations.

Outcrops higher in the section consist of small widely spaced exposures in shallow eastward-draining arroyos. Silt, sand, and pebble-cobble conglomerates interbed and dominate the section in dark, red-brown color. Moderate to well-rounded clast-supported cobble conglomerates occur as basal channel lag and in sheet-like horizontal or low-angle cross-bedded layers. Horizontal, low-angle, and trough cross-bedded sands interbed and mix with conglomerate, silt, and occasional mud rich units. While sands throughout the section are more granitic-lithic based, greater than 95% of material pebble size or larger consists of Elkhorn Mountain Volcanic rock debris.
Interpretation - Central Region

Sediments lower in the section were deposited in a mixed braided and meandering fluvial system. Coarse-grained sand facies suggest dominant in-channel depositional processes. Finer silts and muds culminated channel-fill sequences and contributed to overbank floodplain sedimentation. With time, more extensive braided fluvial systems developed on a broader alluvial plain. Primary and/or reworked volcanic ash contributions lower in the section have been removed, not observed, are much less common, or never existed within conglomeratic facies upward in the section. Abundant volcanic ash in similar age deposits in the Parrot Bench Area suggest erosion may be responsible for the lack of ash rich facies in the north Central Basin Area.

Coarse-grained sand and pebbly sand facies represent primary channel-fill depositional processes. Lateral migration or abandonment of smaller subsidiary channels produced fining upward sequences. Poorly sorted mud and silt facies accumulated in overbank areas on an active floodplain. Occasional red, clay rich zones indicate variable soil development in abandoned channels or particular areas of the floodplain. Thin caliche layers suggest evaporation in small isolated ponds on the floodplain or subsurface precipitation processes within or along paleo-groundwater systems.

Primary airfall depositional processes are responsible for the thin, laterally continuous volcanic ash layers. Primary ash was locally reworked into small aeolian dunes. Admixtures of ash with other terrestrial clastics indicate reworking and mixing from either primary
airfall or other aeolian sources external or within boundaries of the present Jefferson Basin.

More dynamic, braided fluvial systems are responsible for sand and conglomerate facies higher in the section. Coarse migrating bars filled many stream channels. Sand from migrating bedforms or other channel-fill processes filled many cross-bar channels scoured into the coarse bars. Though channel systems were fairly extensive laterally, finer-grained facies suggest some less active overbank areas existed. Often these fine-grained facies are scoured by thin sand and sand to pebble channel-fill sequences from subsidiary or tributary fluvial processes.

The overwhelming dominance of Elkhorn Mountain Volcanic materials in coarser facies north of Pipestone Creek indicate substantial exposure of this pre-basin rock northwest of the field area. Transport of this coarse material in an expanding alluvial pulse from the northwest may account for the apparent extension of finer ash rich facies southeast around the middle part of the Central Basin Area. Presumably, such ash-rich units to the north and east were eroded or buried by the coarse prograding system. Metamorphic, and much lesser granitic-lithic clasts dominate the few conglomerate exposures observed south of Pipestone Creek. Preliminary observations suggest southwestern source areas (Highland Range, and southern Boulder Batholith) contributed significantly to Pliocene age alluvial sequences in the southern part of the field area.
EAST REGION

Two main Areas comprise thirty-five square miles in the East Region of the Jefferson Basin (Figs. 3 and 4). Both areas contain Tertiary sediments ranging from early Oligocene to early or middle Pliocene age (Kuenzi, 1966; Kuenzi and Fields, 1971). The Tobacco Root Fault separates most of this East Region with north-northeast trending folded and faulted sediments from little or non-deformed Tertiary sequences in the Central and West Regions west of the Tobacco Root Fault (see structure section—page 43, and Figs. 9 and 10—pages 44 and 47). Structural discontinuities cloud total sediment thickness estimates which range from 900 to 1200m.

Bull Mountain Area - Description

Tertiary rock exposures in the Bull Mountain Area (Fig. 4) occur within a five to six square mile enclosure along the south and southwest flanks of the Bull Mountain uplift (Fig. 2). Early Oligocene and late Miocene to early or middle Pliocene age sediments (Kuenzi, 1966; Kuenzi and Fields, 1971) occur in small isolated or stringy discontinuous outcrops in small gulches carved in pre-basin, basement rock exposures. Older Oligocene age sediments are separated from younger Miocene-Pliocene age sediments by an angular, erosional unconformity. Pre-basin rocks consist of late Cretaceous or early Tertiary age latite intrusives (Kuenzi, 1966), and Precambrian Belt rocks of the Lahood Fm. Fault contacts and/or an angular-erosional unconformity separate both younger and older Tertiary sequences from underlying pre-basin rock lithologies (Plate 1).
Oligocene deposits comprise mostly mud, ash, and sand. Total thickness estimates are tenuous in a range of 75 to 120m. Folded, faulted, and otherwise discontinuous exposures hinder the deciphering of vertical or lateral facies relations in time and/or space. Sediment composition and texture characteristics are remarkably similar to deposits found in lower sequences of the Little and Big Pipestone areas (see West Region-page 11). Fine-grained units are typically mud-rich and may contain floating sand or granule granitic-lithic clasts. Ash occurs in complete gradation from small admixtures with mud to relatively pure, sometimes fragmental pumiceous deposits and accretionary lapilli. Unaltered glass shards contribute significantly.

Interbedded with finer-grained deposits are occasional thin (0.5m) to thick (2m+) bedded, coarse sand packages. Coarse-grained units scour into underlying finer sediments and consist internally of multistory trough and low-angle tangential cross-bedded sands. Sand compositions are dominated by granitic-lithic clasts with lesser Elkhorn Mountain Volcanic rock fragments and rare metasedimentary clasts. Paleocurrent data (Fig.5) suggest predominant south-southeast flow direction.

Two principal lithologic units describe Miocene-Pliocene age deposits adjacent to Bull Mountain. Limited exposures of similar age deposits one and one-half miles west of the main Bull Mountain front (Fig.2), distinguish a more varied sedimentary facies (Plate 1, sec 27 T2N R4W).
Sandy pebble to cobble breccia, and sand with cobble conglomerate characterize the deposits along the flanks of Bull Mountain. Very angular pebble, cobble, and local boulder size Precambrian Belt rock clasts distinguish sediments of the breccia facies. Intermixed and interbedded sands contain similar smaller Belt rock fragments along with abundant volcanic-lithic clasts. Very low-angle or horizontal cross-bedded sands and pebbly sands, locally imbricate, interbed with chaotic matrix supported pebble-boulder size breccia. Scour surfaces, some with basal lag deposits, distinguish most bedding. These sandy breccia deposits fine basinward and locally interbed with sands and well rounded cobble conglomerates immediately south of Bull Mountain.

Conglomeratic units consist of well rounded cobbles, some pebbles, and interbedded sand layers. Conglomerate layers exhibit crude horizontal or low-angle cross-bedding in packages 30 cm to several meters thick. Quartzite compositions dominate. Elkhorn Mountain Volcanic rock clasts contribute with other metasedimentary lithic materials. Granitic-lithic clasts are much less abundant.

Sandy units vary from somewhat lensoidal to more tabular bodies interbedded with and filling interstices of the clast-supported conglomeratic units. Typical sand unit thicknesses range from 0.1-0.5m and consist internally of planar to very low-angle tangential or steeper planar tabular to trough cross-bedded sands. Sand compositions comprise feldspar, quartz, and abundant volcanic and lesser metasedimentary-lithic clasts, granitic-lithic clasts are much less common. Paleocurrent data (Fig.7) suggest dominant easterly sediment transport.
A physically separate group of late Miocene to early Pliocene age sediments are exposed one and one-half miles west of the main Bull Mountain front (Plate 1, sec 27 T2N R4W). Silt, sand, pebbly sand or sandy pebble conglomerate, ash, and lesser marl distinguish a different, more varied sedimentary facies to sediments described closer to Bull Mountain. Coarse sandy units occur in thin (0.5m) to thick (5m max.) relatively continuous sand packages internally built of multistory planar to low-angle tangential and trough cross-bedded sands. Scours, some with basal pebble lags, and truncations are common within and along basal sand packages. Pebbles may alternate with granule or sand in some cross-bedded laminae. Sand compositions exhibit abundant volcanic-lithic clasts with lesser Precambrian Belt and other probable Paleozoic sedimentary rock fragments. Pebble size materials consist of volcanic-lithic clasts with lesser Precambrian Belt rock fragments and rare granitic-lithic clasts. Paleocurrent data (Fig.7) suggest dominant southerly flow directions.

Finer, "dirty" appearing silts and sands are interbedded with the sand packages described above. These deposits are more poorly sorted and massive, or better sorted and laminated exhibiting frequent muddy drapes. Sediments above the thickest (5m) sand package show an increase in ash component associated with thin-bedded, interbedded, sand and marl.
Parrot Bench Area - Description

Eleven square miles encompass Tertiary rock exposures in the Parrot Bench Area (Fig.4). Sediment age ranges from early Oligocene to middle (Whitneyan), and probably late (Arikareean) Oligocene, and, from early-middle (Barstovian) Miocene to middle Pliocene (Kuenzi, 1966; Kuenzi and Fields, 1971). An erosional and local angular-erosional unconformity separates these older and younger age sediments into two general depositional sequences contrasted in sediment composition, and inferred sedimentary processes and depositional environment. Fault contacts separate the Miocene-Pliocene age sediments from pre-basin rocks along the south and east margins of the Area. Older Oligocene age deposits are either in fault contact or separated by an angular-erosional unconformity from pre-basin rocks along the south and southwest boundaries. Both depositional sequences exhibit dips variably north and east. Numerous north-northeast trending folds and similar trending faults deform these sequences further limiting understanding of vertical and lateral facies relations (Plate 1).

Abundant calcareous sediment distinguishes Oligocene age deposits of the Parrot Bench Area from all other exposures in the Jefferson Basin. Calcareous units show great variation from relatively pure fossiliferous limestone to terrigenous-limestone admixtures (marl) and chert. Granitic-lithic based sand or pebbly sand, ash, and ash-rich sand and silt interbed with calcareous units to embrace the bulk of Oligocene age sediment types.
Calcareous units exhibit great variation in both composition and texture. Bedding features vary in outcrop scale from lensoidal and discontinuous to laterally continuous units with internal textural variation. Laterally continuous units may span 20-80m through periodic sediment covered intervals. Limestone units often exhibit lateral and vertical texture variation marked by a coarser, detrital carbonate, terrigenous, or mixed carbonate-terrigenous basal or marginal facies changing upward and/or laterally into micritic and fossiliferous limestone. Irregular, often scoured upper and lower contacts are typical. Bedding thickness shows marked variation from millimeter scale shaley fissile beds to one 2m indistinctly bedded micritic and fossiliferous layer.

Algae, ostracodes, and gastropods comprise most fossiliferous materials. Algal contribution varies from occasional filamentous strands to stromatolitic mats and mixed stromatolite-detrital layers to relatively pure diatomaceous earth. Stromatolite mats may be several centimeters thick in wavy or undulatory layers with very irregular, hummocky upper surfaces. Collapsed, eroded, or otherwise discontinuous laminae may disrupt mat development. Ostracodes are most common in thin (mm to 1cm) fissley units where whole and fragmental forms occur together in a very fine-grained, detrital, laminated rock friable along bedding planes. Scoured surfaces, small channels, and local ripple cross-bedded layers distinguish some bedding. Possible interference ripples(?) exist on few upper bed surfaces. Local oolitic limestones occur with other fine-grained, detrital carbonate or terrigenous sand associated with these thin-bedded limestone units. Local gastropod
accumulations are somewhat restricted to thicker (several to ten's of cm) bedded usually micritic limestone layers. Whole and fragmental gastropod shells occur in clumps and somewhat continuous horizons with micritic limestone and minor terrigenous detritus, or locally as more fragmental hash deposits mixed with greater terrigenous detrital proportions.

Ash admixing with calcareous sediment provide significant additional variety to this texturally diverse sediment group. More pure ash layers are often cross-bedded and may contain root casts. Cloudy, massive, micritic or marly layers form where ash contributes to some carbonate or mixed carbonate-terrigenous sediment.

Calcareous chert and siliceous-calcareous sediment occur within a compositional spectrum between chert and limestone end members. Chert occurs in thin discontinuous "whispy" bands and lensoidal pods to relatively continuous layers several centimeters thick. Some chert is white though most varieties are very dark shades of brown, brown-black, or greenish-black.

A few granitic-lithic based sandstone packages and thinner (0.5 to 1m+) sand layers interbed with the finer-grained carbonate or mixed calcareous-siliceous deposits described above. Bedding varies from several centimeters to 0.5m in sand packages ranging from 1m to 10m or more. Most contacts with surrounding finer-grained sediment are covered or obscure. Where observed, basal contacts are sharp with erosional surfaces. Few upper contacts grade vertically from sand to silt, some with root casts, into overlying finer-grained calcareous sediment.
Primary sand intervals within the lower half or third of the section occur mostly within two thick (several m+), multistory sand packages. Sands further up in the section occur as thinner (0.5 to 1 m+), individual bed sets sporadically interbedded with finer-grained calcareous units. Partly continuous exposures along strike within units near the top of the section define a north-northwest directed lateral fining sequence where ash rich silts, sands, and occasional conglomerate grade laterally to fine-grained diatomaceous and calcareous sediment and sand.

Pebbley sand or sandy pebble conglomerate occur above some basal scour surfaces and contribute to some sand interbeds and channel-fill sequences within larger sand packages. Horizontal, low-angle tangential, trough, and planar tabular cross-bedded sands contribute to these sand packages. Some sands are ash dominated, most consist of abundant granitic-lithic clasts, feldspar, quartz, and lesser metamorphic and metasedimentary rock materials. Pebble compositions comprise metamorphic and metasedimentary clasts with lesser granitic-lithic rock fragments.

The north trending contact separating late-middle Oligocene (Whitneyan) sediments from overlying early-middle Miocene deposits changes character laterally along very few exposures. Scouring with some unquestionable relief separates coarser, angular, more locally derived sands, breccia, and minor conglomerate from underlying finer-grained units along southernmost exposures. Minor angular discordance may separate these units along this southernmost section. However, limited northernmost contact exposures reveal a dissimilar
geologic setting. Here, angular discordance is not evident and sediment types, though different, are much less disparate. Northernmost Oligocene deposits comprise very fine-grained diatomaceous sediment grading upward into fine-grained tuffaceous sand. Coarser, more lithic-rich, tuffaceous sand distinguish the oldest Miocene age sediment observed. Associated with this contact at all exposures is a distinct sediment color change from pale whitish greys in Oligocene age sediment, to dirty yellow orange tan within Miocene age units. This middle Tertiary contact placement along northernmost exposures is founded primarily on biostratigraphic evidence of Kuenzi(1966), and Kuenzi and Fields(1971).

Siltstone, sandstone, ash, and pebble or sandy pebble conglomerate encompass most sediment in the Miocene-Pliocene age sequence. One notable exception defines a pronounced coarsening facies southward in the southeast portion of the Parrot Bench Area (Plate 1). Sand, cobble conglomerate, and cobble breccia comprise this coarse facies that fines and interbeds with more central basin facies to the north.

Horizontal, low-angle tangential, planar tabular, and trough cross-bedded sands, locally pebbly, interbed with low-angle or horizontal cross-bedded sandy pebble conglomerate through much of the lower and middle upper parts of this younger sequence. Most beds are laterally discontinuous with common scours and small channels filled with silt, cross-bedded sand, pebbly sand, or pebble conglomerate. Sand compositions are more angular and granitic-lithic rich than the rounded to well-rounded metasedimentary and volcanic-lithic pebbles frequently associated. Angular to subrounded metasedimentary,
sedimentary, and volcanic-lithic clasts also contribute to these sands. Lesser marl and abundant fine-grained, interbedded or admixed ash also occur with these sand and conglomeratic units. Paleocurrent data (Fig. 7) indicate easterly sediment transport directions.

In addition to its nearly ubiquitous contribution to other lithologies, ash may comprise significant individual rock units, particularly within exposures higher in the section. Good sorting and complex cross-bedding are usually associated with these ash-dominated units. Planar tabular and tangential cross-bedding are most common, trough cross-bedding is locally abundant. Mixed ash with other lithic and feldspathic sand may grade upward into ash-dominated layers. Ash compositions comprise mostly fresh, fragmental, glass bubble shards with lesser crystals and pumice. Glass contributions exhibit a spectrum of shapes and are remarkably fresh. Pumice shapes vary from regular and undeformed to fragmental or highly stretched varieties. Most pumice is fresh or only slightly altered. One notable outcrop exhibits fine to medium-grained glass mixed with coarse-grained sand to granule size white, well-rounded pumice balls (few mm to 2 cm) in medium to thick bedded, low-angle, planar tabular, or trough cross-bedded sets. Glass or feldspar crystals, volcanic-lithic fragments, and assorted detritus from local pre-basin rock exposures contribute variably to these otherwise relatively homogeneous, blue-gray, ash-dominated units.

A coarser sedimentary facies distinguishes southernmost exposures of the younger Tertiary section (Plate 1, @El/2 sec 25 T1N R4W, and sec 30 T1N R3W). Lithic sands interbed with cobble conglomerate and cobble and local boulder breccia in an intertonguing, northward fining facies.
Figure 7. Rose diagrams from Miocene-Pliocene age sands of the Jefferson Basin. Shaded areas represent trough and planar tabular cross-bed measurements. Striped arcs designate ranges of paleochannels and the direction of flow which created the channels. Roses are centered over outcrop localities.
Lithic components consist mostly of Elkhorn Mountain Volcanic rock detritus in addition to other sedimentary, metasedimentary, metamorphic, and lesser granitic-lithic clasts. Abundant fresh volcanic glass contributes to these angular, lithic rich sands. Sands exhibit mostly horizontal or low-angle cross-bedding. Minor trough cross-beds occur within small, channel-fill sequences. Sands are often accompanied by granules or pebbles in lensoidal to somewhat tabular sheets between coarser, conglomeratic units. Cobble conglomerate occurs in lensoidal to tabular bodies built internally of clast-supported, horizontal or very low-angle cross-bedded layers.

Abundant scour surfaces differentiate most layering. Variably sized channels occur within and along the base of both sand and conglomeratic units. Channels may contain sand, conglomerate lag with sand, or fill with chaotic, poorly sorted, matrix-supported, angular pebble to boulder size breccia. Paleocurrent data (Fig.7) suggest dominant north-northeast sediment transport in agreement with northward fining texture trends.

Interpretation - East Region

Basal terrigenous sand and limestone facies record periodic and fluctuating lake development in the southeast corner of the basin. Contemporaneous low-relief floodplain environments received fine-grained mud and ash rich sediment repeatedly scoured by through-flowing, sandy fluvial channel systems. Slight marginal uplift and erosion removed a variable and unknown quantity of sediment in late Oligocene or early Miocene time. Renewed Miocene-Pliocene sedimentation occurred in...
Figure 8. Schematic sediment facies correlation, East Region. Note the coarse marginal facies in the Miocene-Pliocene age deposits. Lateral extent of the limestone-rich facies outward from the Parrot Bench Area is unknown.
braided fluvial, alluvial, and aeolian depositional environments. Figure 8 schematically illustrates gross sediment facies relations in a north-south profile between the Bull Mountain and Parrot Bench areas.

Fine-grained Oligocene age facies in the Bull Mountain Area formed under similar processes responsible for analogous facies accumulations in the Little and Big Pipestone areas (see West Region, interpretation section-page 16). Some of these deposits may actually be eastward lateral extensions of those units or reflect similar processes sourced in higher elevations around the Bull Mountain uplift. Associated sand packages formed in through-flowing braided and meandering fluvial channels draining south or southeast.

Composition and texture variation amongst calcareous and mixed calcareous-siliceous facies suggest both ephemeral and perennial lake development and periodic influx of terrigenous sediment (Picard and High, 1972; Monroe, 1981). Abundant scours and channels between and within calcareous units indicate frequent shallow water (above wave base) conditions and local marginal lake sediment reworking (Picard and High, 1972). Thin oolitic sands, ripple and probable interference ripple cross-bedding suggest agitation and the development of extensive lake margin flats. Stromatolitic mats formed in slightly deeper water, perhaps analogous to similar "Lagoonal Facies" deposits described by Picard and High (1972), or "Offshore to Nearshore Lacustrine Facies" recognized by Monroe (1981). Storm activity probably influenced some algal disruption. Periodic and variable marginal facies development reflect fluctuating lake levels responding to climatic and/or sedimentation rate changes. Interpretations for deposition of
contemporaneous fine-grained facies elsewhere in the basin (see West Region, interpretation section-page 16) suggest mass-flow sedimentation processes were probably an important influence in lake development and/or lake level fluctuation in space and/or time.

Volcanic ash materials indicate contribution from both primary airfall and transported reworked ash deposits from other sources within the basin. Primary airfall contributions were locally reworked into aeolian dunes. Airfall and other detrital ash mixed with sand, mud, and other calcareous sediment to form an intermediate suite of siliceous-calcareous deposits. Volcanic ash most likely provided the source of silica necessary to produce the cherts. If chert formed as a primary precipitate, lake waters may have experienced highly fluctuating pH (Eugster, 1969) and salinity (O'neill and Hay, 1973), as interpreted for other non-marine basins in Oregon and east Africa. However, paucity in evaporite minerals or other features indicating this lake to be very saline suggest most of the chert quite likely formed from subsurface diagenetic processes (Blatt, 1980).

Abundant tabular and wedge shaped beds in the coarse-grained sand units formed from small bar migration and channel-fill processes in a braided fluvial system. Thinner sand units upward in the section may be similar to channeled sands described by Monroe (1981) for Oligocene "fluvial-lacustrine" facies in the Ruby Basin. Thicker sand packages lower in the section may record migration of large through-flowing braided fluvial systems or possibly a coarse braided marginal lacustrine facies contributing to a complex deltaic system(s) (Picard and High, 1971; Monroe, 1981).
Kuenzi (1966), and Kuenzi and Fields (1971), describe the contact separating Oligocene (Whitneyan) deposits from Miocene (Barstovian) age sediments as an angular, erosional unconformity. In the Parrot Bench Area, Whitneyan age fossils are separated from younger Barstovian age fossils by approximately 38m of section. A one million year absolute minimum age gap may separate these units (Fields, 1983 pers.comm.). Field observations (this study) indicate that while basin margin exposures (Bull Mountain and southern margin of the Parrot Bench Area) may exhibit angular unconformable relations, more central basin exposures may exhibit little or no such structural discontinuity. Observations (this study) of changes in both sediment facies distribution and structural style basinward along the unconformity, necessitates re-interpretation of the mode and timing of Tertiary structure in the evolution of the Jefferson Basin (see structure section-pages 51-52). The amount and age of sediment missing along this unconformity is not well known and probably varies significantly.

Facies patterns for the younger sediment sequence emphasize the importance of local source contributions to a primary, east-flowing braided fluvial system. Coarse, angular breccias shed basinward from Bull Mountain formed by sheetwash, debris-flow, and complex channeling processes in small alluvial fans (Allen, 1964; Bull, 1972 and 1977; Walker, 1975 and 1980). Fining basinward, these sediments intertongue with and contribute to other sands and coarse cobble conglomerate of this east-flowing braided fluvial system. Conglomerates were deposited in migrating bars and contributed to channel-fill sequences. Interbedded sands filled cross-bar channels, contributed to
larger channel-fill sequences, or were deposited in smaller migrating bars or bedforms within channels or on the backs of migrating gravel bars. Alluvial fan and alluvial plain sequences in the Parrot Bench Area contribute to this eastward-flowing system but are buried or removed along the present Jefferson River floodplain (Plate 1).

Another coarse facies distinguishes an alluvial fan environment along the southeast margin of the Parrot Bench Area. Sand, conglomerate and lesser breccia formed in braided channel and bar complexes that fine and intertongue with alluvial plain sequences northward. Compositions reflect rock types exposed in immediate adjacent highlands, analogous to similar marginal deposits elsewhere in the basin. Some breccia deposits in this sequence formed as sheetwash, most formed as debris or mudflow deposited in pre-existing stream-cut channels.

Most of the younger sedimentary sequence was deposited in an alluvial plain environment. The northern Highland Range and Boulder Batholith served as major sediment source areas. Previously mentioned coarse-grained marginal facies contributed variably to this alluvial plain system. Relatively small, mostly ephemeral braided streams traversed a silt-sand dominated floodplain eastward. Small playas or other ephemeral ponds occasionally developed on the floodplain. Airfall deposits of volcanic ash frequently inundated the basin. Small aeolian dunes advanced and locally contributed to other fluvial channel deposits in this East Region of the Jefferson Basin.
WEST PROVINCE

The West structure province includes all areas west of the Tobacco Root Fault (Fig. 9). Tertiary basin fill dip into this fault in one large, relatively simple north-striking, gently east-dipping homoclinal. At the west margin of the basin, Tertiary sediments onlap both Elkhorn Mountain Volcanic rocks and granitic rocks of the Boulder Batholith along an irregular disconformable contact. Basin fill attitudes vary along this pre-basin rock contact. Very few minor faults are exposed or recognized within the sediment package. Simple basin fill structures of this West province markedly contrasts the folded and faulted basin-fill sequences east of the Tobacco Root Fault.

The north-trending Tobacco Root Fault occurs along the western flanks of the Bull Mountain and Tobacco Root Mountain uplifts (Figs. 2 and 9, Plate 1). No surface exposure of this fault exists in the field area. First recognized on morphological evidence (Pardee, 1950), the inferred placement and location of the Tobacco Root Fault is further supported in gravity (Burfiend, 1967), paleontology (Kuenzi, 1966; Kuenzi and Fields, 1971), and structural-stratigraphic observations (this Study).

Precambrian Belt and Paleozoic sedimentary rocks are juxtaposed against late Tertiary or Quaternary sediments in a dramatic scarp along the northwest flank of the Tobacco Root Mountains just south of the field area. Immediately northward, westernmost lower Oligocene age strata of the Parrot Bench Area (Fig. 4) occur at the same elevation as
Figure 9. Subdivision of study area into a structural framework of two provinces west and east of the Tobacco Root Fault. Line A-A" designates the cross-section location of figure 10. Dotted pattern identifies pre-Tertiary basement rock exposures. The large unpatterned area includes undifferentiated Tertiary and Quaternary sediments.
Pliocene age sediments exposed immediately westward in the easternmost Central Basin Area (Fig. 4, and Plate 1). The inferred trace of the Tobacco Root Fault north from the western part of the Parrot Bench Area is less certain. Kuenzi and Fields (1971) extend the main fault trace northward to explain the higher elevation of Oligocene and Miocene age strata adjacent to Bull Mountain relative to lower Miocene–Pliocene age units exposed closer to Whitetail Creek on the west (Fig. 2). Separating these exposures are thin surficial Quaternary sediments which cover the inferred fault trace. However, Structural mapping (this study) identifies these relatively un-deformed Pliocene age strata westward from considerably folded and faulted Oligocene and Miocene age sediments eastward, in support of at least one substantial trace of the Tobacco Root Fault northward through this area.

A precise attitude and displacement for the Tobacco Root Fault is unknown. Map data suggests a relatively high-angle western dip at the surface. Using physiographic evidence, Pardee (1950) estimated 5,000–6,000 feet of late Pliocene or early Pleistocene displacement. Based on structural–stratigraphic relations, Kuenzi and Fields (1971) suggest a "stratigraphic throw" of 6,000 feet.

Tertiary sediment attitudes along the westernmost contact with pre-basin rocks deviate markedly from general north-striking, east-dipping trends elsewhere in the province (Plate 1). Along this western margin, strikes always parallel the pre-basin rock contact and dips may steepen to 35 degrees. In a very short distance basinward however, attitudes flatten and merge in a general north-striking, very gently east-dipping and eastward-thickening homoclinal sediment package.
Four minor faults were mapped within the Tertiary sediments of the west province (Plate 1). Three faults near the western basin margin sub-parallel the nonconformable pre-basin rock contact, offset early Oligocene age sediment, and are downdropped eastward along vertical or steeply east dipping surfaces. One fault in the south-central map area offsets probable Pliocene age sediments along a vertical or very steep west dipping fault plane questionably downdropped on the west. Fault offsets are minor and range from few to probably several meters at most.

Interpretation - West Province

Remarkably uniform sediment sequence attitudes suggest that during Tertiary basin subsidence, the West province structurally behaved as one relatively large contiguous unit. The north-south trending, east-west varying sediment facies patterns, the north-south trending eastward younging sediment age distribution, and the regionally consistent north trending, east dipping sediment sequence attitudes identify a regional east-tilted structural block eroded to deeper levels westward. Boulder Batholith uplift on the west coupled with basin downdropping along the Tobacco Root Fault on the east, are interpreted to accomodate basin structure of the West province (Fig.10).

Variable bedding attitudes along the western basin margin result from Oligocene age sediment onlapping an irregular, eroded, basement rock surface. Steepened dips along this margin may partly reflect steeper initial sedimentation angles, but mostly result in response to compaction and the proximity of these sediments to the irregular, uplifting basement. Minor faults offset Tertiary sediments in response
Figure 10. Schematic cross-section illustrating probable pre-Tertiary basement rock configuration and its relation to the overlying Tertiary cover. Note the drape fold response of Tertiary sediments over fragmented basement blocks of the East Province in contrast to the relatively undeformed homoclinal sediments of the West Province. Cross-section location is shown on figure 9.
to basin fill adjustment of the exhuming Jefferson Basin.

The West Province is thus viewed as a hinged, one-sided basin, structurally downdropped on the east along the Tobacco Root normal fault. Lack of structural deformation within the Tertiary sediments probably reflects the relative homogeneity of basement rock subsidence in marked contrast to the more fragmented, block-faulted basement interpreted east of the Tobacco Root Fault (see East Province structure section—below, and Fig. 10).

EAST PROVINCE

The East Province (Fig. 9) encompasses all Tertiary basin area east of the Tobacco Root Fault and includes the east embayment of the Jefferson Basin between Bull Mountain and the Tobacco Root Mountain uplifts (Fig. 2). North-northeast trending folds and faults delineate the structural grain. West-northwest and east-northeast fault trends locally influence basin fill structure along the Bull Mountain and Tobacco Root Mountains basin margin fronts respectively (Plate 1). Fault and/or angular-erosional unconformable contacts characterize Tertiary sediment relations to all pre-basin (basement) rock exposures. Common east and north dipping Tertiary basin fill trends deviate with proximity to folds, faults, and pre-basin rock contacts. Marked Tertiary sediment deformation contrasts this province east of the Tobacco Root Fault from the more simple, relatively homogeneous, homoclinal structure west of the Tobacco Root Fault.
The Tobacco Root Fault defines the western boundary of the East province (Fig. 9). Evidence and significance of this fault is outlined in the previous West province section and further discussed in the following interpretation section (page 51). Similar trending faults of varying magnitude offset Tertiary sedimentary sequences east of this inferred Tobacco Root Fault trace (Plate 1). Similar folded Pliocene age sediments exhibit up to 40 degree dips into some of these faults separating Tertiary sediments from pre-basin rocks along the west and southwest flanks of Bull Mountain. Further south in the western portion of the Parrot Bench Area (Fig. 4), these faults exhibit shorter more poorly exposed surface traces along similar trending folds within the Tertiary basin fill (Plate 1).

The Mayflower Mine Fault (Kuenzi and Fields, 1971; Schmidt and Hendrix, 1981; Schmidt, 1983) and an inferred north-northeast trending splay along the east side of Mayflower Gulch (Kuenzi and Fields, 1971) define the east and southeast margins of the Jefferson Basin exposed within the East Province (Fig. 9). Schmidt (1983) interprets this fault as one in a system of right-lateral, oblique-slip faults associated with the "Transverse Zone" of the Laramide fold and thrust belt. The north-northeast trending fault splay separating Pliocene age sediments from Precambrian Belt rocks along the eastern basin margin may have originated as a reverse-slip fault where impinging thrust plates met foreland uplifts as described for similar structural relations elsewhere in the "Transverse Zone" (Schmidt, 1983). I interpret later Cenozoic normal faulting along this eastern margin of the basin to occur along this earlier Laramide structural weakness. Pliocene age sediments dip
into this inferred fault splay at 30 degrees or more.

Few exposures of west-northwest trending faults offset both basement rocks and Pliocene age cover along the southern margin of Bull Mountain. Similar relations exist along the southwest margin of the Parrot Bench Area where small pockets of Oligocene age sediment are involved in east-northeast trending basement faults.

All Tertiary basin fill sediments in the East Province are folded or tilted to some degree. Folds, almost without exception, trend north-northeast with slight northerly plunges. Axial fold traces near the fault bounded southeast margin may curve away from the fault trace and extend into the basin (Plate 1). Here as with other basin margin faults along the west and southwest flanks of Bull Mountain, Tertiary strata dip into the fault from 16-40 degrees.

Numerous small, high-angle, similar trending normal faults offset fold limbs throughout the province. Total offsets are difficult to estimate, but probably range from few to several and possibly tens of meters or more. Sediments are downdropped on the west or basinward for most of these and other faults mapped within the province. Apparent offsets and stratal disruptions around the Tertiary faults may decrease along strike in a basinward direction.
Interpretation - East Province

Significant Tertiary sediment deformation east of the Tobacco Root Fault most likely reflects the degree of underlying basement inhomogeneity in response to late Cenozoic extension. In marked contrast to the West Province, basement within the East Province fragmented and differentially subsided in individual structural blocks (Fig. 10). Tertiary sediment deformation is thus viewed as a drape fold and fault response to accommodate adjustment of the underlying basement.

Similarity in orientation between the Jefferson Basin, the Tobacco Root Fault, and other lesser faults throughout the east embayment of the basin suggest an overall common genetic origin. Furthermore, similar character between the Tobacco Root Fault and faults throughout the embayment suggest much of the embayments structural development formed as the subsiding Jefferson Basin successively attempted to step out (eastward) to weaknesses associated with the main trace and splay of the Mayflower Mine Fault. Tertiary strata rotated into bounding faults are analogous to one-sided basin and range structures described by Anderson et al. (1983), and best interpreted geometrically with a listric normal fault model (Hamblin, 1965; Stewart, 1980; Anderson et al, 1983).

Kuenzi (1966), and Kuenzi and Fields (1971), interpret a pre-late Miocene structural event (folding of Oligocene sediments) to explain 1) their sediment thickness correlations, 2) presence of the middle Tertiary unconformity, and 3) the apparent greater structural deformation of Oligocene age strata than Miocene-Pliocene age strata in the Parrot Bench Area. Map and field observations (this Study) require
a different interpretation with significant implications regarding the structural evolution of the Jefferson Basin.

I interpret the apparent greater structural deformation of Oligocene sediments in the western Parrot Bench Area to result from a deeper level exposure where a thinner sediment accumulation overlies the faulted pre-Tertiary basement. Thus, greater structural development is related with proximity to the underlying faulted basement. An analogous situation is demonstrated in comparing Miocene-Pliocene age strata between the Bull Mountain and Parrot Bench areas. Thinner, marginal sediment facies in the Bull Mountain Area exhibit significantly greater structural deformation than similar age deposits in the Parrot Bench Area. These deposits in the Parrot Bench Area overlie a notably thickened Tertiary sediment accumulation. However, both Areas were deformed by the same significant late Pliocene or early Pleistocene structural event. Basement controlled deformation is manifested in more tightly folded deeper level strata and more gently folded shallow level strata. Similarly, decreases in apparent structural deformation are usually observed basinward within the same facies or lateral facies equivalent.

Further support of this structural interpretation comes from observations along strike of the middle Tertiary unconformity in the Parrot Bench Area. Near the basin margin contact, less similar sediment facies are separated by a slight angular-erosional unconformity. However, sediment facies along northernmost exposures of this unconformity are less dissimilar and little or no angular relationship is detected. In addition, I have mapped near the basin margin contact
(Plate 1, @N1/2 sec 2 T1S R4W), similar coarse, Miocene age sediment facies one-half mile southwest of the previously interpreted (Kuenzi, 1966; Kuenzi and Fields, 1971), non-folded middle Tertiary unconformity. Though observations are limited, evidence suggest that the unconformity is folded near the pre-basin rock contact.

These observations coupled with sediment facies patterns indicating this part of the basin to be the general depocenter since at least early Oligocene time, are interpreted as evidence for relatively continuous basin growth development through time. The Jefferson Basin structural evolution is thus not constrained to discrete structural episodes, but rather probably reflects incremental deformation growth since late Eocene or early Oligocene time which culminated in a significant late Pliocene or early Pleistocene structural event.

Kuenzi and Fields (1971) interpret an east-west trending Jefferson Fault separating the Bull Mountain and Tobacco Root Mountain uplifts to explain the lack of eastward tilt in the unconformity in the former and the presence of an east tilted unconformity in the latter. Few west-northwest trending faults mapped (this study) along the southern margin of Bull Mountain may be associated with some larger marginal fault(s) just south of these exposures. If present, the fault(s) would trend roughly east-west though I would probably place the fault trace closer to the Bull Mountain front than did Kuenzi and Fields (1971). Thin, deformed Tertiary sediments along immediate flanks of Bull Mountain are here viewed as remnants caught along the margin of this uplift somewhat detached from downdropped listric normal block-faulted sequences interpreted immediately southward toward the Parrot Bench.
General structural and morphological observations suggest displacement on the Tobacco Root Fault may decrease northward through the field area. If so, the Tobacco Root Fault may be viewed as a scissors fault opening to the south along the western flank of the Tobacco Root Mountains south of the field area (Fig. 11).

The Tobacco Root Fault, the Mayflower Mine Fault and its northern splay, and the inferred subsurface basement faults between these two main fault traces are interpreted as listric normal faults. Basement block rotation accompanied subsidence along these faults. Drape folding and faulting occurred in the Tertiary sediment cover as basement subsidence ensued. Continued uplift of the Tobacco Root Mountains along the Tobacco Root Fault tended to continually "hang up" structural blocks where the northwest corner of the range encountered the east embayment of the Jefferson Basin, thus eventually exposing deeper level Oligocene age strata in the western portion of the Parrot Bench Area. Basin development in both provinces (West and East) is interpreted utilizing one mechanism and stress regime. The fundamental structural characteristics distinguishing each province result from the mode of basement rock response to Cenozoic extensional stresses. These modes probably reflect differences in basement rock composition and/or previous structural history.
Figure 11. Schematic block diagram. View is toward the southeast across the Parrot Bench Area and along the western flank of the Tobacco Root Mountains. A hypothetical marker bed (xxxx) demonstrates the probable greater displacement on the Tobacco Root Fault south of the field area.
CONCLUSIONS

Early Tertiary foreland breakup established the framework for intermontane basin growth in eastern Idaho and southwest Montana (Suttner et al., 1981). Structural adjustment of the recently dissected foreland coupled with a climatic setting favorable to erosion contributed to the late Eocene development of the Jefferson Basin. Facies patterns recognized for Tertiary deposits indicate some relation to a paleo-depositional basin of remarkable similarity to the morphology of the present Jefferson Basin. Thus, I interpret the general trend and shape of the present basin to be an intrinsic feature inherited since at least late Eocene time.

By early Oligocene time, primary ash and significant other volcaniclastic materials were being reworked into the basin from previous surrounding sediment accumulations. Abundant mass-flow and increasing fluvial sedimentation was largely directed southeast over a generally low-relief depositional plain. Some individual sediment flows may have spanned several miles across the width of the Jefferson Basin. At the same time, one or more lakes developed in the southeast corner of the area structurally bound by marginal highlands of the Tobacco Root Mountains. Through time, episodic lake development caused frequent lake level fluctuations controlled by sediment input, sediment damming, and regional climatic changes. Some fluvial drainages probably re-distributed their sediment loads in deltaic systems formed along margins of the lake(s).
By early-middle Oligocene time, a maturing fluvial drainage was transporting coarse clastics eastward from newly uplifted granitic and metamorphic rocks of the southern Boulder Batholith and the northern Highland Range, respectively. Granitic, sedimentary, and metamorphic rocks within the Tobacco Root Mountains were also contributing to this expanding fluvial system. By late-middle or late Oligocene time, sandy and conglomeratic braided and meandering fluvial systems covered much of the western and central basin regions. Lateral migration of this fluvial system replaced or contributed to fluctuations in the lake(s) in the southeast corner of the basin.

By middle to late Miocene or early Pliocene time, the Bull Mountain and Tobacco Root Mountain uplifts began shedding detritus in alluvial fans to an earlier developed (Miocene) alluvial plain draining eastward. Abundant fresh volcanic ash and lesser terrigenous debris accumulated in small aeolian dunes. Migrating dunes locally contributed to ephemeral and small perennial streams draining the alluvial plain.

Sometime in late Pliocene or early Pleistocene time, significant extensional stresses resulted in major block-fault rejuvenation as surrounding massifs rose and the Jefferson Basin subsided. Listric normal faults accommodated major basement block subsidence. Relatively brittle, fragmented basement blocks north of the Tobacco Root Mountains rotated as they subsided, resulting in folding and faulting of the overlying Tertiary sediments. To the west, granitic basement block subsidence just west of the Tobacco Root Fault was more homogeneous, less brittle, and comparatively little deformation of the basin-fill occurred.
Approximately 900 to 1500m of Tertiary sediment fill the Jefferson Basin. Sometime in early Miocene time, an erosional episode removed an unknown quantity of late Oligocene and possibly early Miocene age sediment from the basin. Sedimentation in central-basin areas was interrupted for a much shorter period than were basin margin areas. Because this middle Tertiary unconformity is almost un-recognizable within certain central-basin deposits, re-thinking of previous interpretations of a major regional unconformity for all intermontane basins of the northern cordillera is necessary.

Previous interpretations which distinguish older from younger Tertiary deposits on the basis of grain size are oversimplified. Coarse-grained deposits (coarse sand and larger) are not restricted to the younger sedimentary sequence. A better understanding of the distribution of Tertiary sediments is achieved by establishing a spatial, as opposed to a temporal, stratigraphic framework.

Paleocurrent data and the distribution of both basement rock lithologies and Tertiary sedimentary facies indicate 1) internal drainage occurred in both the Oligocene and Miocene-Pliocene age depositional sequences, and 2) the depocenter of the basin today is the same as it was in late Eocene or early Oligocene time. These observations identify structure and tectonics as major controlling influences in the evolution of the Jefferson Basin.

Chadwick (1978) recognizes the arrival of bi-modal vulcanism in southwest Montana at about 40 m.y. ago. He interprets this bi-modal character as a fundamental shift from compressional to extensional
tectonism. Citing clay mineralogical evidence, and correlation with sedimentation rates of deep sea drilling data (Davies, 1977), Thompson et al (1982) argue for regional synchronous climatic events as the significant factor controlling the sedimentation history of all intermontane basins of the northern Rocky Mountains. While I recognize the important climatic influence, I cannot exclude the important role of tectonics in the evolution of the Jefferson Basin. Until we achieve a better understanding of the complex stratigraphic frameworks within individual basins, I suggest caution in the application of such independent processes to account for Tertiary basin evolution in this northern Rocky Mountain region.

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