[PS]Implications for Tectonic Control on Paleogeography and Sediment Dispersal Pathway: Integrated U-Pb Detrital Zircon Age-Analysis of the Paleogene Missouri River Headwater System, SW Montana*

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Abstract

Cenozoic intermontane basins in southwest Montana lie within the Sevier-Laramide orogenic belt and constitute many of the basins within the Northern Basin and Range (B&R) province. Paleogene fluvial deposits within the intermontane basins record basin evolution and sediment dispersal pathways across the post-contractile Cordilleran fold-thrust belt. Recent work has demonstrated that structurally controlled fluvial incision served to establish an interconnected drainage system and develop intermontane-scale paleovalleys prior to B&R extension. In adjacent regions to the south and west of the uppermost modern Missouri River, paleotributaries to the paleo-Missouri River were essentially identical to those of the modern system. The sediment dispersal pattern is similar to that which is typical of modern fold-thrust belts. Resultant outflow was northward into the upper paleo-Missouri River and beyond, into the northeastern continental basin region.

A newly documented large-scale Eocene fluvial conglomerate (cobble to boulder) in the Beaverhead Basin demonstrates northward paleoflow and serves as evidence for a major influx of detritus to the paleo-Missouri River system from previously undocumented tributaries in the far southwest, near the Montana-Idaho border. Paleocurrent data document that the Grasshopper and Medicine Lodge basins were contiguous with the Horse Prairie Basin, similar to the modern, with net outflow eastward toward the modern Beaverhead Canyon. That paleodrainage configuration is further supported by using detrital zircon U-Pb ages and conglomerate clasts as provenance indicators and tracers. Composition of conglomerate constituents and detrital zircon ages from trunk fluvial outcrops suggest a paleodrainage link between the paleo-Beaverhead Basin and the southwestward Horse Prairie and Medicine Lodge paleobasins. Furthermore, these data indicate erosion of Meso-Proterozoic Belt Formation strata as a primary sediment source, with a minor to moderate supply of sediment from Archean basement, Cretaceous plutons, and early Paleogene volcanics. In addition, detrital zircon ages serve as an effective tracer of sediment derived from Cretaceous plutons in the southern Pioneer Mountains that was routed through separate drainages in the Grasshopper and Frying Pan basins.

The Frying Pan Basin discharge was eastward, directly into the Beaverhead Basin, whereas discharge from the southern basin system was most likely northward through the paleo-Clark River Canyon.

Implications for tectonic control on paleogeography and sediment dispersal pathway: Integrated U-Pb detrital zircon age-analysis of the Paleogene Missouri River headwater system, SW Montana

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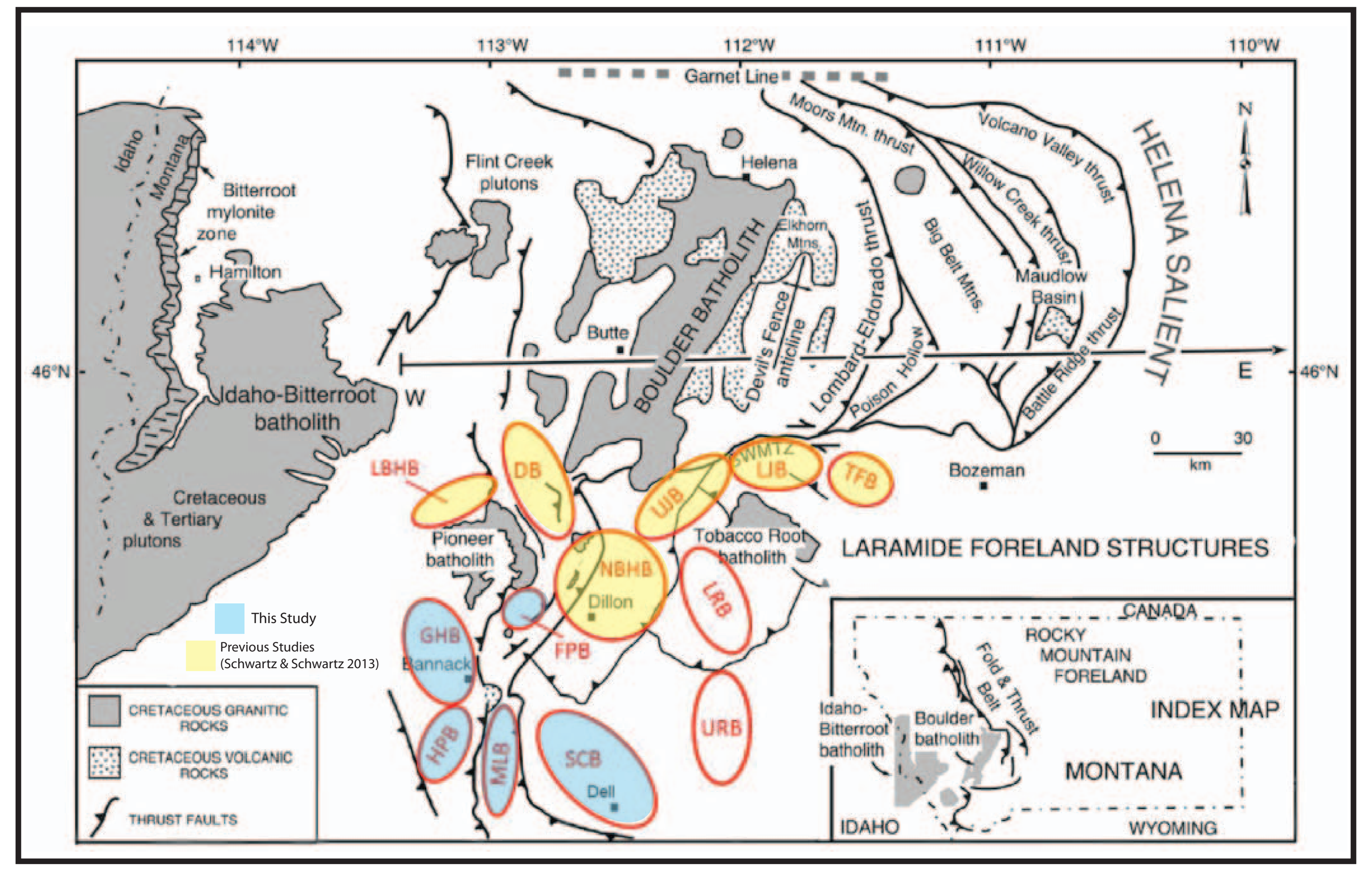
A newly documented large-scale Eocene fluvial conglomerate (cobble to boulder) in the Beaverhead Basin demonstrates northward paleoflow and serves as evidence for a major influx of detritus to the paleoMissouri River system from previously undocumented tributaries in the far southwest, near the Montana-Idaho border. Paleocurrent data document that the Grasshopper and Medicine Lodge Basins were contiguous with the Horse Prairie Basin, similar to the modern, with net outflow eastward toward the modern Beaverhead canyon. That paleodrainage configuration is further supported by using detrital zircon U-Pb ages and conglomerate clasts as provenance indicators and tracers. Composition of conglomerate constituents and detrital zircon ages from trunk fluvial outcrops suggest a paleodrainage link between the paleoBeaverhead Basin and the southwestward Horse Prairie and Medicine Lodge paleobasins. Furthermore, these data indicate erosion of Mesoproterozoic Belt Formation strata as a primary sediment source, with a minor to moderate supply of sediment from Archean basement, Cretaceous plutons, and early Paleogene volcanics. In addition, detrital zircon ages serve as an effective tracer of sediment derived from Cretaceous plutons in the southern Pioneer Mountains that was routed through separate drainages in the Grasshopper and Frying Pan Basins. The Frying Pan Basin discharge was eastward, directly into the Beaverhead Basin, whereas discharge from the southern basin system was most likely northward through the paleo-Clark River canyon.



Structural overview map of the Northern Rockey Mountains from the Idaho Batholith to the Helena Salient in southwestern Montana. Intermontane bains of intrest to this investigation are outlined in red ovals. Key: HPB=Horse Prairie Basin, MLB=Medicine Lodge Basin, SCB=Sage Creek Basin, GHB= Grasshopper Basin, URB= Upper Ruby Basin, LRB= Lower Ruby Basin, FPB= Frying Pan Basin, NBHB=Northern Beaverhead Basin, LBHB=Lower Big Hole Basin, DB= Divide Basin, UJB=Upper Jefferson Basin, LJB=Lower Jefferson Basin, TFB=Three Forks Basin (Modified from Lageson et al., 2001).

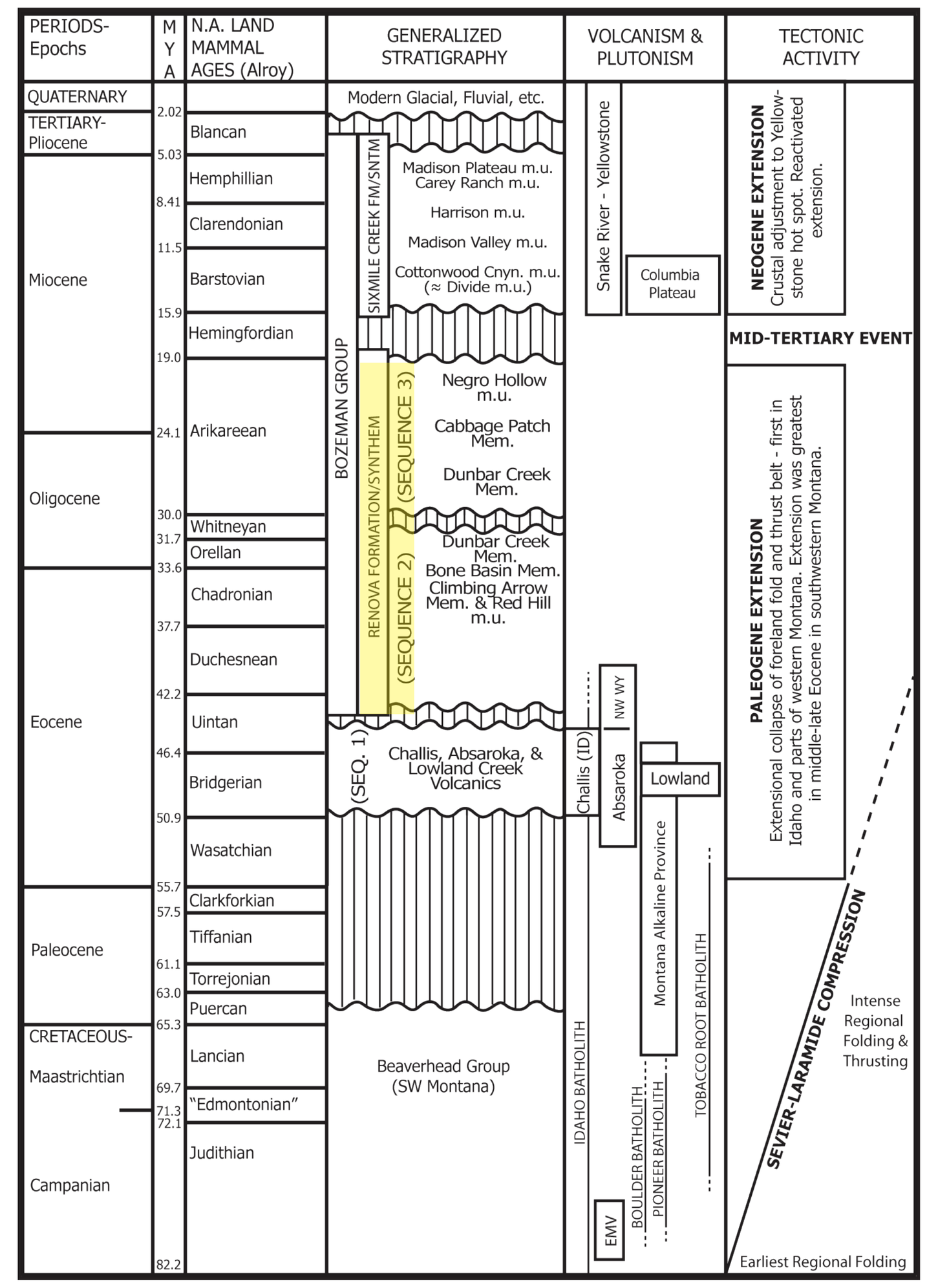
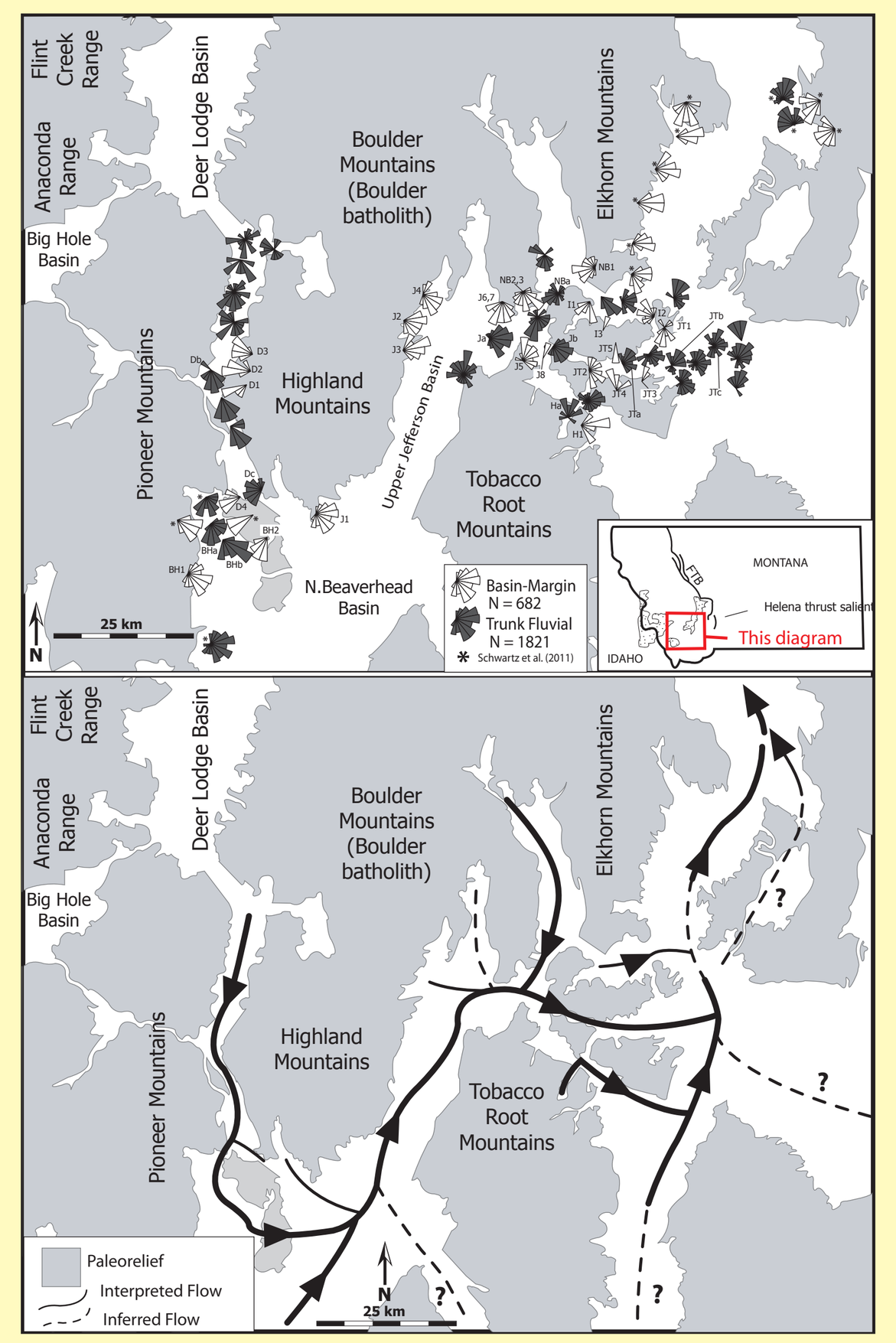


Chart correlating latest Cretaceous through modern stratigraphy with volcanic, plutonic and tectonic events. The time period of the Renova Formation is highlighted in yellow.

Background



Paleogene trunk-fluvial drainage systems north of the study area have been defined based upon fluvial and alluvial facies and paleocurrent data from Schwartz and Schwartz (2013). All of the highland areas in this region are documented to have been present during the Paleogene. This study intends to further define the regional paleogeography and paleodrainage by studying the the adjacent southern and western basins.

Basin Interior: Trunk Fluvial Facies

(1) Gravel-Bed Braided River :

- Framework supported polymictic conglomerate
- Moderately to well sorted, imbricated
- Sub- to well-rounded clasts, up to 50cm diameter
- Vertically and laterally stacked channel bodies
- Architecture comprised of 2 main components:
  1. **Channel fill bodies** - trough cross-stratified upward fining channels chaped units
  2. **Bar-top beds** - low angle to sub horizontal planar strata in tabular to lensoidal units
- Max channel thickness = 20m; max width >400m

Imbricated clasts within the channel body indicate paleoflow directions.

Stacked trough cross-stratified channel units. Ren11-01.

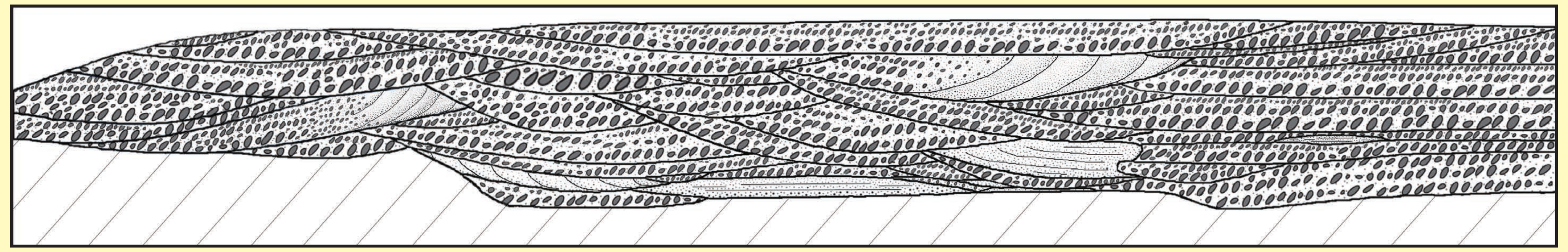


Illustration of Ren11-01 outcrop demonstrating the architecture and internal fabric of the braided fluvial system. Note stacked upward fining successions and diverse architecture composed of tabular bar-top beds and scoop-shaped channel fill bodies. Cobbles are not drawn to scale; verticle exaggeration is ~1.5X.

(2) Sand-bed River: (Anastomosing?)

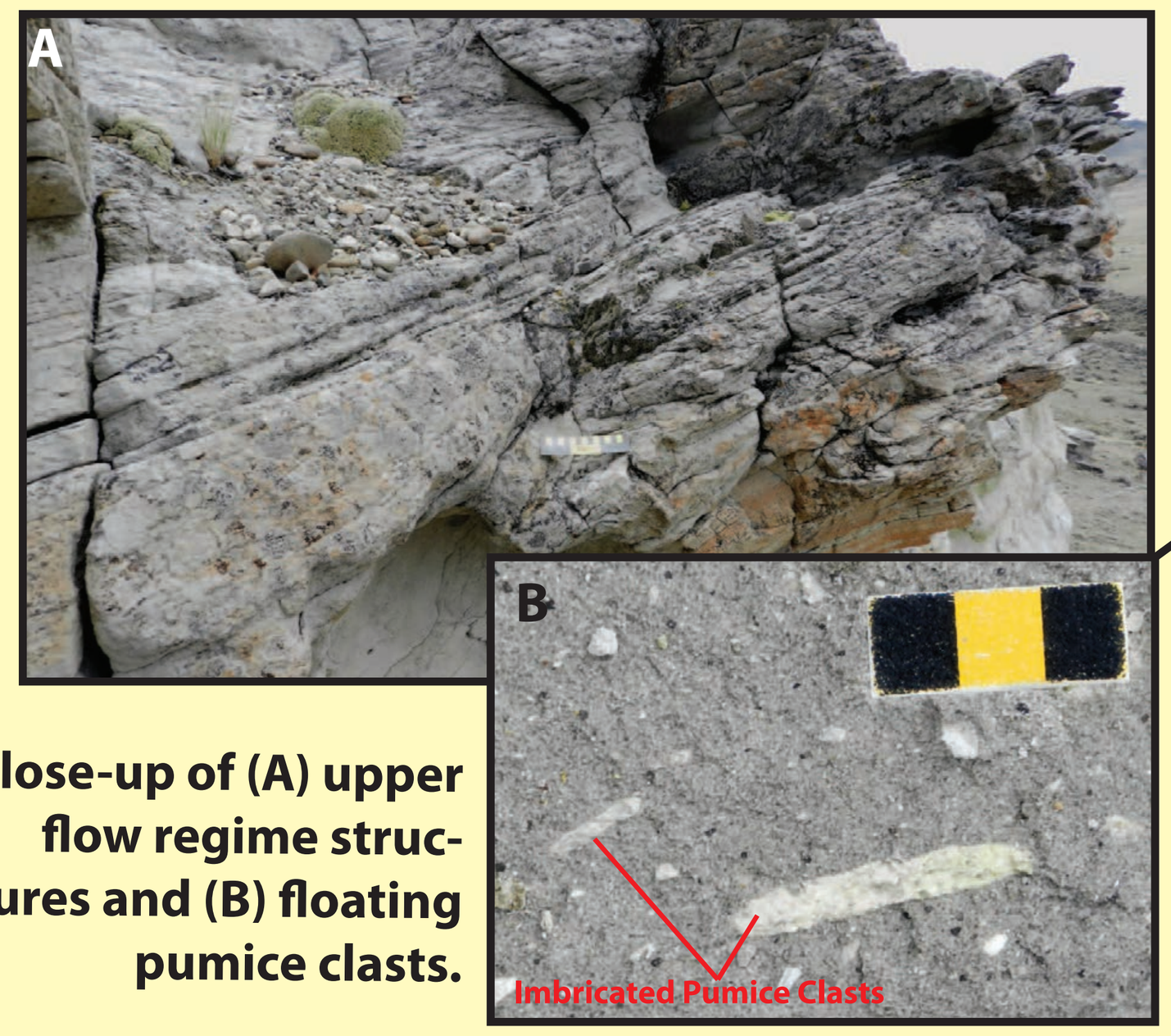
- Isolated channel bodies and splay sandstones encased within thick, abundant overbank mudstone deposits.
- Channel bodies consist of cyclical, upward fining and thinning units.
- Fine to coarse sandstone
- Abundant small to large scale trough cross-stratification.
- Max thickness = 3m
- Channel width = +8m

Anastomosing fluvial sandstone body in scour contact with Renova-age overbank mudstones; Grasshopper Basin.

Upward fining and thinning bed units with abundant small- to medium-scale trough cross-bedding.

(3) Flashy, sheetflood volcaniclastic river:

- Widespread volcaniclastic sandstones; tabular, sheet-like geometry
- Abundant upper flow-regime bedforms, soft-sediment deformation; hyperconcentrated
- Cyclical bedsets: upward thinning beds with an upward transition from upper to lower flow regime structures
- Imbricated floating platy pumice clasts, up to 3cm in diameter



Close-up of (A) upper flow regime structures and (B) floating pumice clasts.

Overview of flashy, sheetflood volcaniclastic river facies. Note widespread, tabular configuration; 1.9 m man in orange hat for scale.

Basin Margin: Alluvial Fan Facies

(1) Proximal alluvial fan deposits:

- Alluvial fan system, widespread and continuous (thickness = +250m)
- Tabular bedding, locally channelized
- Heterogeneous makeup, polymictic composition
- Consists of three distinguishable facies: (A) *Clast supported breccia sheet flow*, (B) *Channelized breccia/conglomerate sheet flow* (C) *Matrix Supported Debris Flow*
- Poorly to moderately well-imbricated
- Clasts are angular to sub-round, 6-8 cm in diameter on average. Max clast size is 45 cm diameter (angular limestone block)
- Fine to medium grained volcaniclastic sand matrix with abundent mud and pebbles

Limestone block at FP-12-04

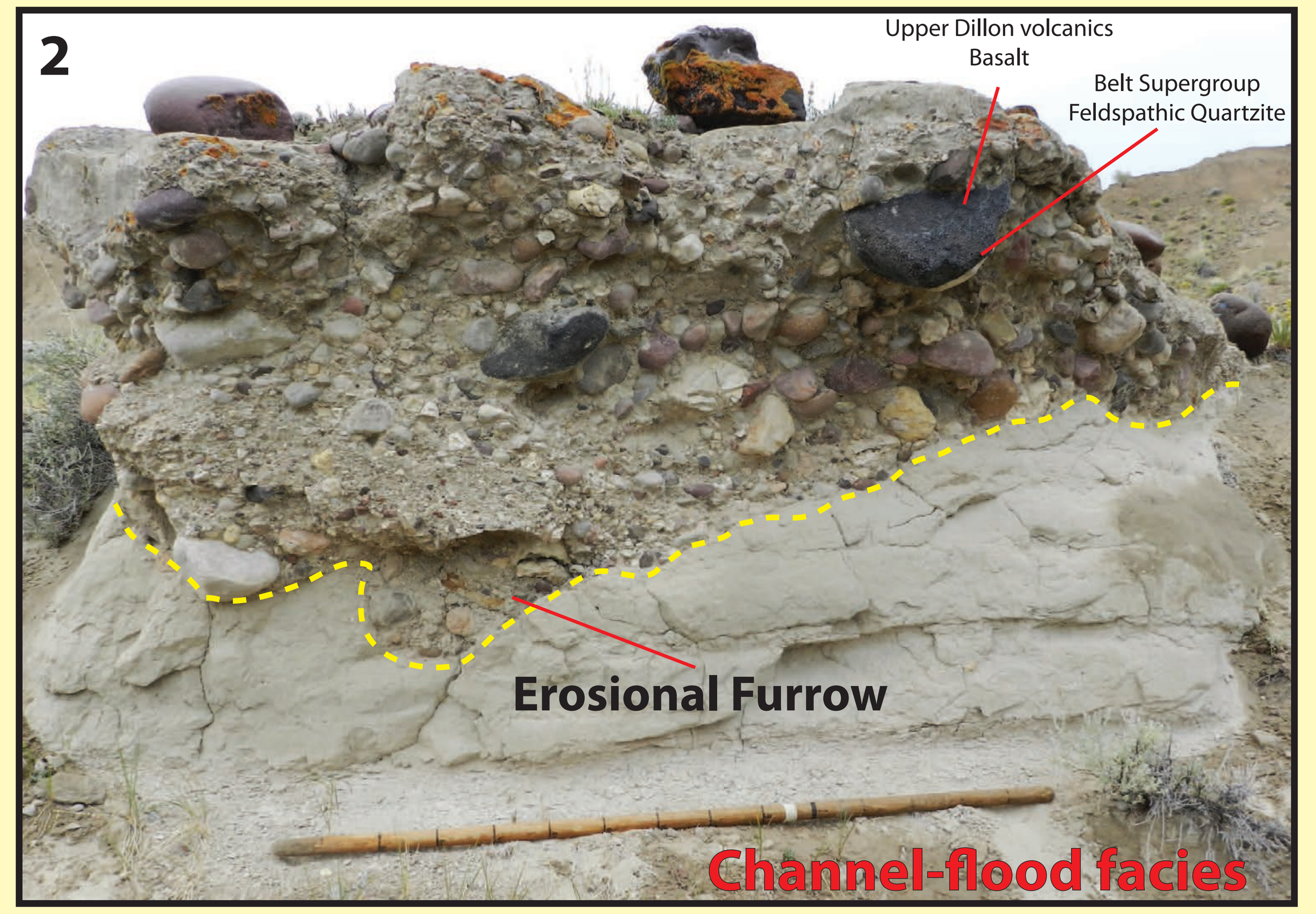
C) Debris Flow Breccia:
- Matrix supported breccia
- Rare imbrication, crude where present
- Crude normal to inverse bedding
- Very poorly sorted
- Angular to sub-angular clasts
- Muddy matrix

A) Sheet Flow Breccia:
- Clast supported breccia
- Angular to sub-angular clasts, up to 35cm in diameter
- Poorly imbricated
- Moderately- to well-defined clinoformal tabular beds (25-30 cm thickness on average)

B) Channelized Sheet-Flow:
- Tabular bedding with coarse channel lenses
- Channel-form bedding
- Clast supported
- Mostly normal graded beds, poor-moderate sorting
- Some clast imbrication
- Sub-rounded to sub-angular clasts

(2) Medial to distal alluvial fan deposits:

- Isolated sandstone and breccia/conglomerate bodies encased within thick mudstones
- Coarse grained facies include (1) localized sheet flood and (2) channel-flood deposits.
- Pedogenic alteration of mudstones indicates prolonged subaerial exposure between depositional events



Paleodrainage & Detrital Zircon Provenance

TRUNK FLUVIAL FACIES

Jefferson - Three Forks Basin

NE

@ CLA-11-01: Davis Ranch, Renova Fm. Indianola Group. Oligocene. Interbedded, fine- to boulder-cobble conglomerate, trunk fluvial (late Eocene)

@ CLA-11-02: Davis Ranch, Renova Fm. Highwood Mtns. Indianola Group. Oligocene. Interbedded, fine- to boulder-cobble conglomerate, trunk fluvial (late Eocene)

Northern Beaverhead Basin

@ REN-11-01: Silver Bow Rd. Polymictic cobble-boulder conglomerate, trunk fluvial (late Eocene)

"Southern Basins"

ML-12-03: Bannack Rd.; two-mica GF granite (Oligocene to early Miocene?) (Stevenson et al., 2008)

ML-12-05: Red Butte, sublithare- nite to two-mica GF granite (Oligocene to early Miocene?) (Stevenson et al., 2008)

ML-12-07: Hansen Ranch; fluvial quartz sandstone (Oligocene to early Miocene?)

SW

Sage Creek Basin

@ Sage Creek Ranch; Sage and Fickes; Two Eocene-Oligocene sites (15DCI1 & 16CRI1); sandstone interbed from Bathtub et al. (2012)

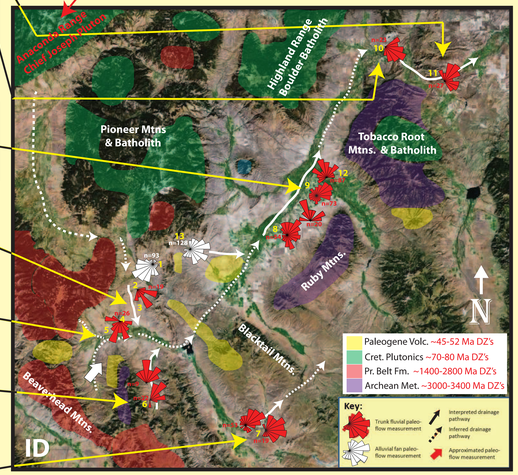
Number

Relative probability

Age (Ma)

Chief Joseph Pluton Alluvium

@ MC: Mussigbrod Creek, Chief Joseph Pluton; two-mica granitic porphyry (modern) (Stevenson et al., 2008)



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Overview of study area in SW Montana depicting paleocurrent measurements, select outcrop/sample site locations, and distribution of major ancient sources of Paleogene sediments. (Google Earth, 2013)

BASIN-MARGIN FACIES

Frying Pan Basin

@ FP-12-01: Frying Pan Basin trunk fluvial (late Eocene) (Rothfus et al., 2012)

Grasshopper Basin

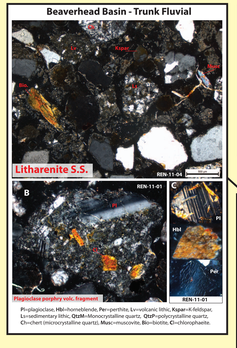
@ML-12-01: Taylor Creek Quarry; volcanics; Grasshopper Valley (Stroup et al., 2008)

Potential Paleogene Source Rocks - Summary

Source Rock	Outcrop Locations	Depositional/ Emplacement Age	General Lithologies	Zircon Age Population (Ma)	Reference
Lower and Middle Dillon Volcanics	Locally abundant; Upper: Sage Creek, Frying Pan, Melrose. Middle: Virginia City	Eocene to Oligocene	Alkaline and transitional basaltic and rhyolitic volcanics	40-53; 27-39	Fritz et al., 2007
Lowland Creek Volcanics	Between the Anaconda and Boulder batholith-Highland Ranges	Eocene	Quartz latitic volcanics	48-53	Dudas et al., 2010
Chief Joseph Pluton	Anaconda Range; eastern part of Bitterroot Lobe, Idaho Batholith	Eocene	2-mica granodiorite, monazite	~50-53 (807)	Foster et al., 2007
Clifford Creek Granite	Eastern Pioneer Mountains	Late Cretaceous	2-mica granite (macroscopic muscovite)	~69-73	Roe, 2010
Frontier Formation	Eastern Pioneer Mountains	Late Cretaceous	Grey sandstone, siltstone, porcellanite	205; 270	Zartman et al., 1995
Pioneer Batholith	Pioneer Mountains	Late Cretaceous	Granite, granodiorite, diorite	70-78	Foster et al., 2012
Tobacco Root Batholith	Tobacco Root Mountains	Late Cretaceous	Granite, granodiorite, diorite	71-77	Arth et al., 1986
McCarty Mountain pluton	McCarty Mountain	Late Cretaceous	Granite, granodiorite, diorite	~74	Brumbaugh and Hendrix, 1981
Idaho Batholith (Atlanta Lobe)	Central Idaho	Cretaceous	Metaluminus to peraluminus granitic	69-80; 88-98	Gaschnig, 2009
Boulder Batholith	Boulder Batholith	Late Cretaceous	Granite, granodiorite, diorite	61-64; 73-81	Lund et al., 2002; Wooden,
Elkhorn Mountain volcanics	Highland Range, Bull Mtn, Tobacco Root Mtns.	Late Cretaceous	Rhyolitic to andesitic extrusives	80-83	Tilling, 1974
Blacktail Formation (Vaughn Member)	Pioneer Mountains, Highland Range, McCarty Mtn.	Late Cretaceous	Volcaniclastics; Chert and quartz rich sandstones, siltstones, shale	90-110; 1700-1900; 2500	Zartman et al., 1995
McCarty Mountain sedimentary rocks	McCarty Mountain; Pioneer Mountains	Cretaceous (?)	Clastic sedimentary rocks	422-471; 900-1400	Rothfuss et al., 2012
Flathead Formation	Tobacco Root, Pioneer, Ruby, Highland Mountains	Cambrian	Quartz arenites and quartzites	471-422; 900-1400	2008; Belgord et al., 2009
Neoproterozoic to Eacliest Paleozoic Quartzites	Beaverhead Mtns., Horse Prairie and Bloddy Dick Creek area	Neoproterozoic to Cambrian	White quartzites	1000-1250; 1400; sparse 1800-2600	Sherwin et al., 2011
Belt Supergroup	Beaverhead, Tendoy, Tobacco Root, Ruby, Pioneer, Highland, Tobacco Root Mountains	Mesoproterozoic	Quartzites (+/- feldspathic), siltites and argilites	1450-1600; 1700-1900; 2300-2750	Belgord et al., 2009; Sherwin et al., 2011
Paleoproterozoic Metamorphic Rocks	Highland Range, Pioneer Mtns, Tobacco Root Mtns, Tendoy Mtns	Proterozoic	QF gneiss and amphibolites, schists	1600-1900; 2450	O'Neill et al., 1987; Brady et al., 2004
Archean Meatamorphic (WY province?)	Tobacco Root, Ruby, Highland Mountains	Archean	QF gneiss and amphibolites, schists	2500-3300	Mueller et al., 1996

Conglomerate Clast-Count Data & Sandstone Petrography

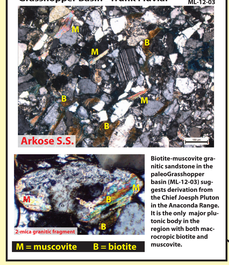
Beaverhead Basin - Trunk Fluvial



Pl=plagioclase, Hbl=hornblende, Per=perthite, Lv=volcanic lithic, Kpar=K-feldspar, Ls=sedimentary lithic, QtzM=Monocrystalline quartz, QtzP=polycrystaline quartz, Ch=chert (microcrystalline quartz), Musc=muscovite, Bio=biotite, Ch=chlorophaeite.

Grasshopper Basin - Trunk Fluvial

ML-12-03



Biotite-muscovite granitic sandstone in the paleoGrasshopper basin (ML-12-03) suggests derivation from the Chief Joseph Pluton in the Anaconda Range. It is the only major plutonic body in the region with both macroscopic biotite and muscovite.

Northern Jefferson Basin

Cla11-01

Three-Forks Basin

Cla11-02

E flow

Clast Type

NE flow

Beaverhead Basin

Ren11-08

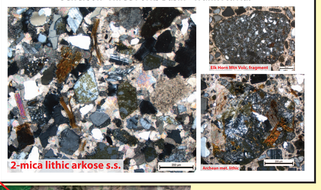
Ren11-01

Ren11-04

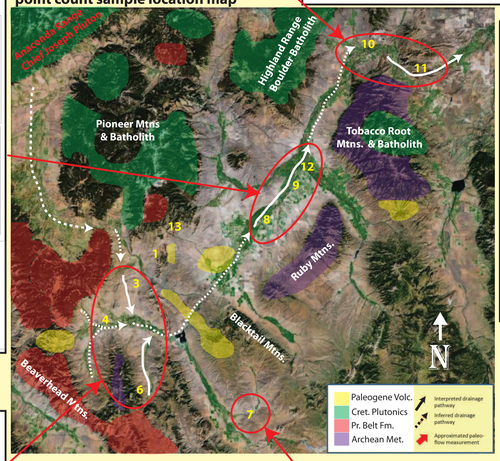
NE flow

"Southern Basins"

Jefferson- Three Forks Basin - Trunk Fluvial



Conglomerate clast-count & point count sample location map



BASIN-MARGIN FACIES

Frying Pan Basin

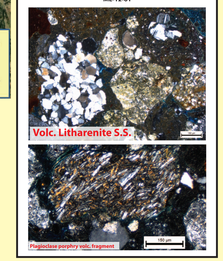
FP12-05

Grasshopper Basin

ML12-01

Grasshopper Basin - Basin Margin

ML-12-01



3 Grasshopper Basin (no conglomerates)

Medicine Lodge Basin

ML12-06

Horse Prairie Basin

ML12-04

Sage Creek Basin

SC12-04

Paleodrainage divide?

Conglomerate clast-count histograms from trunk fluvial facies demonstrating paleo-downstream compositional evolution of the "paleo-Missouri River headwaters" system (this study). These progressive changes are attributed mostly to channel mixing and alluvial input from adjacent paleo-uplifts. Note progresseive downstream dilution trend of "Pr Belt Fm" as new clast types are added to the system.

Medicine Lodge Basin - Trunk Fluvial

ML-12-07

Sublitharenite S.S.
Recycled Belt Fm. Feld Quartzite

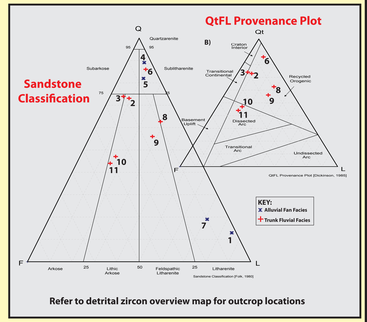
Sage Creek Basin - Trunk Fluvial

SC-12-04

Volc. Litharenite S.S.

Basin	No.	Site	Q%	%F	Plag (%)	Kspar (%)	%L	%Ls	%Lm	%Li	Plut (%)	Volc (%)	2-Mica?
Grasshopper	1	ML-12-01	13	2	71	29	85	7	0	93	0	100	No
	2	ML-12-02	73	18	36	64	9	66	3	25	20	80	Yes (abundant biotite & muscovite)
	3	ML-12-03	74	20	34	66	6	35	0	65	0	100	Yes (very abundant biotite & muscovite)
Horse Prairie	4	ML-12-04	89	3	0	100	8	100	0	0	0	0	No
	5	ML-12-05	68	10	15	85	23	84	0	16	6	94	Yes (semi-minor biotite & muscovite)
Medicine Lodge	6	ML-12-07	82	7	0	100	11	83	2	15	0	100	No
Sage Creek	7	SC-12-01	19	10	62	38	71	3	0	97	0	100	No
Beaverhead	8	REN-11-04	62	9	0	37	28	50	2	48	0	100	Yes (semi-minor muscovite and biotite)
	9	REN-11-01	56	16	28	72	28	62	0	38	0	100	Yes (semi-minor biotite; minor musc.)
Jefferson	10	CLA-11-01	40	31	56	44	28	50	1	49	67	33	Yes (abundant biotite; minor muscovite)
Three-Forks	11	CLA-11-02	44	41	57	43	15	67	7	35	49	51	Yes (very abundant biotite; semi-abundant muscovite)

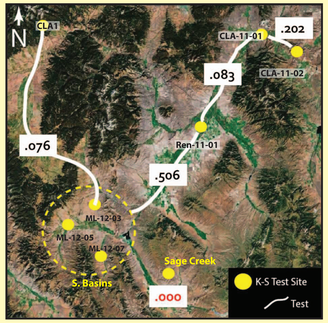
Point-Count Ternary Plots



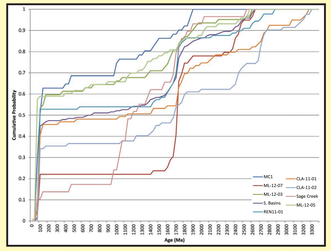
Refer to detrital zircon overview map for outcrop locations

Kolmogorov-Smirnov (K-S) Testing

K-S test P-values



Detrital Zircon CDF



Detrital zircon U-Pb age cumulative distribution functions (CDF). K-S test results (P-values) are generated from maximum distance (D) between two given functions.

Statistical comparisson of detrital zircon U-Pb age distributions

Reject similarity when P-value <0.050

K-S P-values using error in the CDF

	MC1	ML-12-07	ML-12-03	MI-12-05	S. Basins	REN11-01	CLA-11-01	CLA-11-02	Sage Creek
MC1		0.000	**0.076**	0.022	0.005	0.011	0.002	0.000	0.000
ML-12-07	0.000		0.000	0.000	0.000	0.000	0.005	0.027	0.000
ML-12-03	**0.076**	0.000		**0.956**	**0.249**	**0.265**	0.021	0.001	0.000
MI-12-05	0.022	0.000	**0.956**		0.044	**0.051**	0.012	0.000	0.000
S. Basins	0.005	0.000	**0.249**	0.044		**0.506**	**0.081**	0.000	0.000
REN11-01	0.011	0.000	**0.265**	**0.051**	**0.506**		**0.083**	0.004	0.000
CLA-11-01	0.002	0.005	0.021	0.012	**0.081**	**0.083**		**0.202**	0.001
CLA-11-02	0.000	0.027	0.001	0.000	0.000	0.004	**0.202**		0.001
Sage Creek	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	

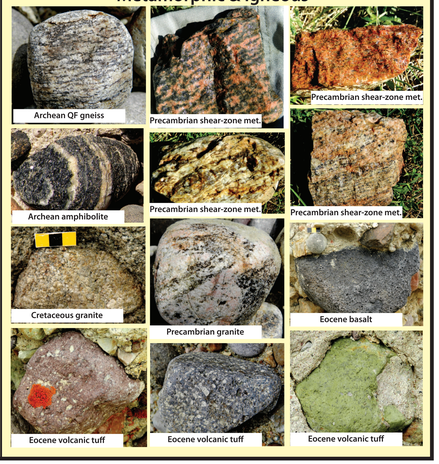
- K-S testing does not reject paleodrainage network (paleo-Missouri River headwater system) that connected headwaters near the Montana-Idaho boarder with paleobasins in the Beaverhead, Jefferson, and Three-Forks intermontane valleys to the northeast.

-K-S tests support that the paleoSage Creek drainage system was seperate from Paleo-Missouri Headwaters system

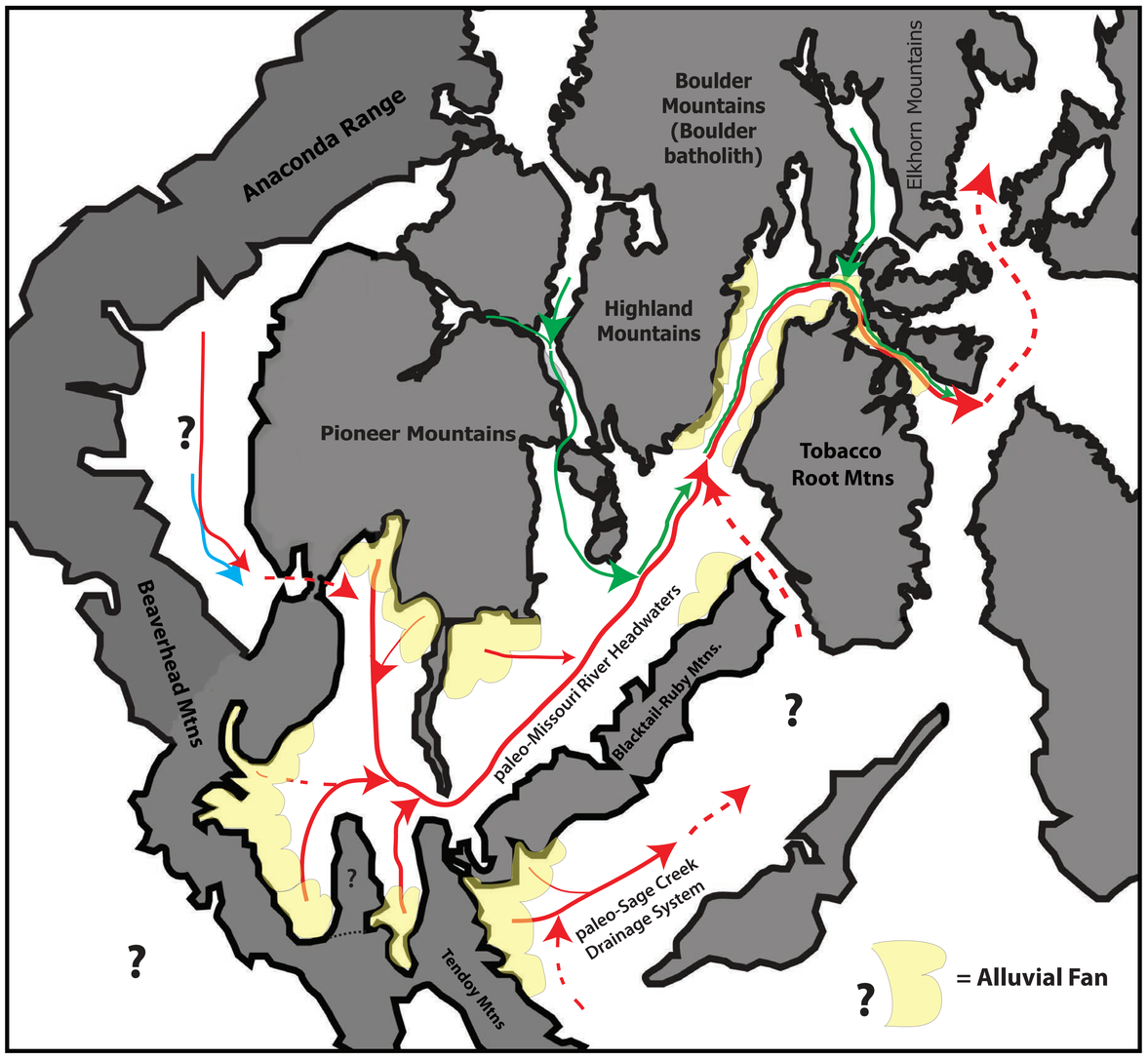
ALLOCHTONIOUS CONGLOMERATE CLASTS FOUND WITHIN CHANNEL SYSTEM

Sedimentary & Metasedimentary

Metamorphic & Igneous



Eocene-Oligocene Geography and Drainage



Southwestern Montana, Summer 2012

Summary & Conclusions

1) Stratigraphy: Detrital zircon ages and stratigraphic position indicate Eocene to Early Miocene deposition.
2) Axial Depositional System: through-going, high energy braided streams (gravel and sand-bed).
3) Paleodrainage: Mostly similar to the modern Missouri headwater system. Net outflow eastward from Grasshopper Basin into the modern Beaverhead canyon, interconnected with the paleo-Beaverhead-Jefferson river system.
- Paleodrainage divide between the paleo-Upper Beaverhead and Sage Creek Basins.
- The modern upper Missouri River headwater system has a >34 m.y. history.

4) Provenance:
a. **Southern basins source areas:**
- Proterozoic Belt feldspathic quartzites; ~1.6, 2.5Ga detrital zircons --> Beaverhead and Tendoy Mtns.
- Cretaceous granitic sand; ~70-75 Ma zircons --> Plutons in Pioneer Mountains
- Lowland Creek & Dillon Volcanics; ~40-52Ma zircons --> Eastern Pioneers Mtns; locally abundant.

b. **Downstream changes in composition:**
- *Sandstone:*
  - Quartz rich (Upper Horse Prairie and Medicine Lodge Basins) to lithic-volcanic (Beaverhead Basin) due to alluvial input of early Paleogene volcanics from the Eastern Pioneer Mountains.
- *Conglomerate:*
  - Progressive decrease in feldspathic Proterozoic quartzite clasts - due to dilution.
  - Increase in Archean, Paleozoic, & Mesozoic clasts – due to added presence of corresponding source rocks in stream-adjacent uplifts, and from material transported by adjoined channel systems

5) Paleogeography: Similar to adjacent northern basins (Schwartz & Schwatz, 2013), southwesternmost MT has mountainous terrain with ancient uplifts mostly coincident with the modern highlands (Beaverhead, Tendoy, Pioneer Mountains).
- Development of the early Paleogene basins was result of Late K to early Eocene fluvial systems that carved intermontane-scale paleovalleys with reliefs of the 100-1000 m scale into the Sevier orogenic wedge.
- The Paleogene terrain was likely modified and overprinted to some degree by Basin-and-Range (~16Ma) and Yellowstone hotspot trackway (~6Ma) uplift and extension.
- Unlike modern configuration, ancient highlands existed along the western margin of the Sage Creek Basin.

1) Data in this study are most consistent with incisional model of basin origin with respect to the expected through-going drainage patterns and three-dimensional geography.
2) Supports a passive control on Paleogene dispersal pathways; preexisting Sevier-Laramide structural fabric
3) Integrated provenance data sets are imperative for provenance & paleodrainage assessments in geologically complex terrains

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