# KECK GEOLOGY CONSORTIUM

# PROCEEDINGS OF THE TWENTY-FIFTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

April 2012
Amherst College, Amherst, MA

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**TECTONIC EVOLUTION OF THE CHUGACH-PRINCE WILLIAM TERRANE, SOUTH-CENTRAL ALASKA**
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**ORIGINS OF SINUOUS AND BRAIDED CHANNELS ON ASCRAEUS MONS, MARS**
Faculty: *ANDREW DE WET*, Franklin & Marshall College, *JAKE BLEACHER*, NASA-GSFC, *BRENT GARRY*, Smithsonian
Students: *JULIA SIGNORELLA*, Franklin & Marshall College, *ANDREW COLLINS*, The College of Wooster, *ZACHARY SCHIERL*, Whitman College.

**TROPICAL HOLOCENE CLIMATIC INSIGHTS FROM RECORDS OF VARIABILITY IN ANDEAN PALEOGLACIERS**
Faculty: *DONALD RODBELL*, Union College, *NATHAN STANSELL*, Byrd Polar Research Center
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**EOCENE TECTONIC EVOLUTION OF THE TETON-ABSAROKA RANGES, WYOMING**
Faculty: *JOHN CRADDOCK*. Macalester College, *DAVE MALONE*. Illinois State University
Students: *ANDREW KELLY*, Amherst College, *KATHRYN SCHROEDER*, Illinois State University, *MAREN MATHISEN*, Augustana College, *ALISON MACNAMEE*, Colgate University, *STUART KENDERES*, Western Kentucky University, *BEN KRASUSHAAR*

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Faculty: *DAVID DETHIER*, Williams College
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**ANATOMY OF A MID-CRUSTAL SUTURE: PETROLOGY OF THE CENTRAL METASEDIMENTARY BELT BOUNDARY THRUST ZONE, GRENVILLE PROVINCE, ONTARIO**
Faculty: *WILLIAM PECK,* Colgate University, *STEVE DUNN,* Mount Holyoke College, *MICHELLE MARKLEY*, Mount Holyoke College
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**EOCENE TECTONIC EVOLUTION OF THE TETON-ABSAROKA RANGES, WYOMING**
Project Faculty: JOHN P. CRADDOCK, Macalester College & DAVE MALONE, Illinois State University

**DETRITAL ZIRCON PROVENANCE STUDY OF YELLOW SANDSTONES FROM THE WILLWOOD FORMATION IN THE BIGHORN BASIN, WYOMING, USA**
ANDREW L. KELLY, Amherst College
Research Advisors: Tekla A. Harms & Peter D. Crowley

**A MINERALOGICAL TEXTURAL AND CHEMICAL CHARACTERIZATION OF A HYPOTHESIZED KIMBERLITE AT WHITE MOUNTAIN, SUNLIGHT BASIN, WYOMING**
STUART KENDERES, Western Kentucky University
Research Advisor: Andrew Wulff

**THE DYNAMICS AND EMPLACEMENT OF THE HEART MOUNTAIN DETACHMENT: ANISOTROPY OF MAGNETIC SUCEPTIBILITY AND DETRITIAL ZIRCON ANALYSIS OF VERTICAL INJECTITES AT WHITE MOUNTAIN AND SILVERGATE, WYOMING**
BENJAMIN KRAUSHAAR, Fort Lewis College
Research Advisor: John P. Craddock

**STRUCTURAL EVOLUTION OF THE EOCENE SOUTH FORK DETACHMENT, PARK COUNTY, WYOMING**
ALISON MACNAMEE, Colgate University
Research Advisor: Martin Wong

**CALCITE TWINNING STRAIN ANALYSIS OF THE ALLOCHTHONOUS JURASSIC SUNDANCE, SOUTH FORK DETACHMENT, NORTHWEST WYOMING**
MAREN MATHISON, Augustana College
Research Advisor: Jeffrey Strasser & Michael Wolf

**PROVENANCE ANALYSIS OF THE WAPITI FORMATION (EOCENE) SANDSTONE IN THE ABSAROKA BASIN, WY USING DETRITAL ZIRCON GEOCHRONOLOGY**
KAT HRYN SCHROEDER, Illinois State University
Research Advisor: David H. Malone

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# DETRITAL ZIRCON PROVENANCE STUDY OF THE WILLWOOD FORMATION IN THE BIGHORN BASIN, WYOMING, USA

**ANDREW L. KELLY,** Amherst College
Research Advisors: Tekla A. Harms, and Peter D. Crowley

## INTRODUCTION

The goal of this study is to determine drainage flow patterns that occurred in the Bighorn Basin during the time of deposition of the Willwood Formation in order to better understand the history and processes that formed the basin as it is seen today. Work was conducted in the summer of 2011 in the Bighorn Basin of Wyoming and at Macalester College and in late January of 2012 at the University of Arizona by a group of Keck faculty and students. This work included dating detrital zircons found in the yellow sandstone members of the formation.

## REGIONAL CONTEXT

The Bighorn Basin, adjacent the Bighorn, Beartooth, and Owl Creek mountains with Precambrian crystalline rocks at their cores, is a deep, westwardly asymmetric basin formed by northeast-southwest horizontal compression and basin subsidence that resulted from loading by basin-margin uplifts (Kraus, 2001). The Willwood Formation is a 780 m thick (Davies-Vollum, 2001), lower Eocene, alluvial-fluvial unit formed in the intermontane Bighorn Basin (Kraus, 2001). The Willwood Formation is characterized by its bright red, purple, and brown-yellow colored beds with interlayered colorless intervals (Davies-Vollum, 2001). The main body of the formation contains major sandstone units, mudrock sequences with well-developed paleosols, and ribbon sandstones interbedded with mudrocks with less developed paleosols (Kraus, 2001). During Willwood time, there was a unidirectional drainage pattern towards the northwest, as interpreted from crossbeds (Fig. 2) (Kraus, 2001).

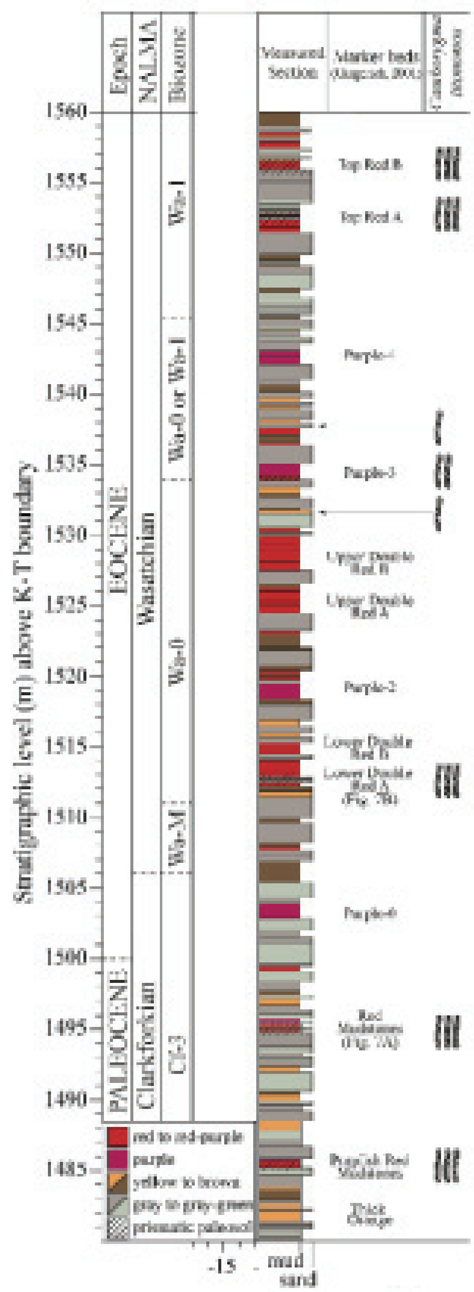


*Figure 1. Representative composite stratigraphic column of the Willwood Formation at Polecat Bench. Due to variation in the stratigraphy of the Willwood depending on location, this is a generalized column. Modified from Smith et al. (2008).*

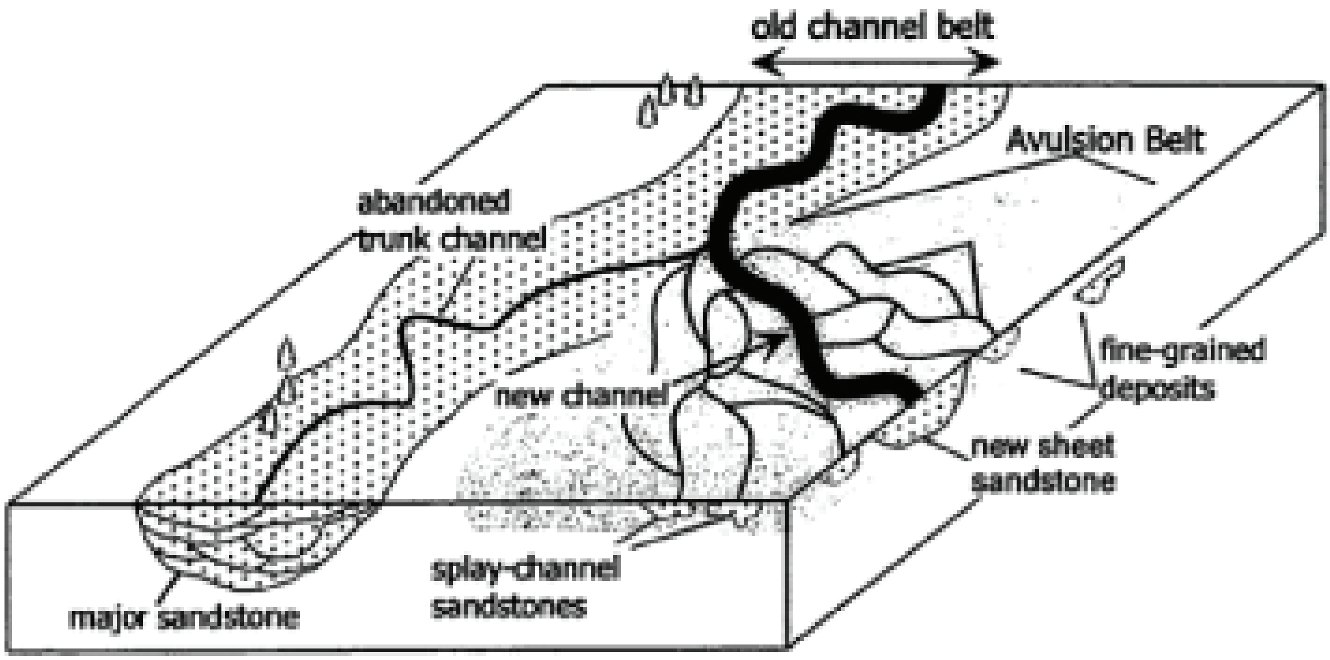


*Figure 2. Schematic diagram showing depositional environments present in the Willwood Formation. Taken from Kraus (2001).*

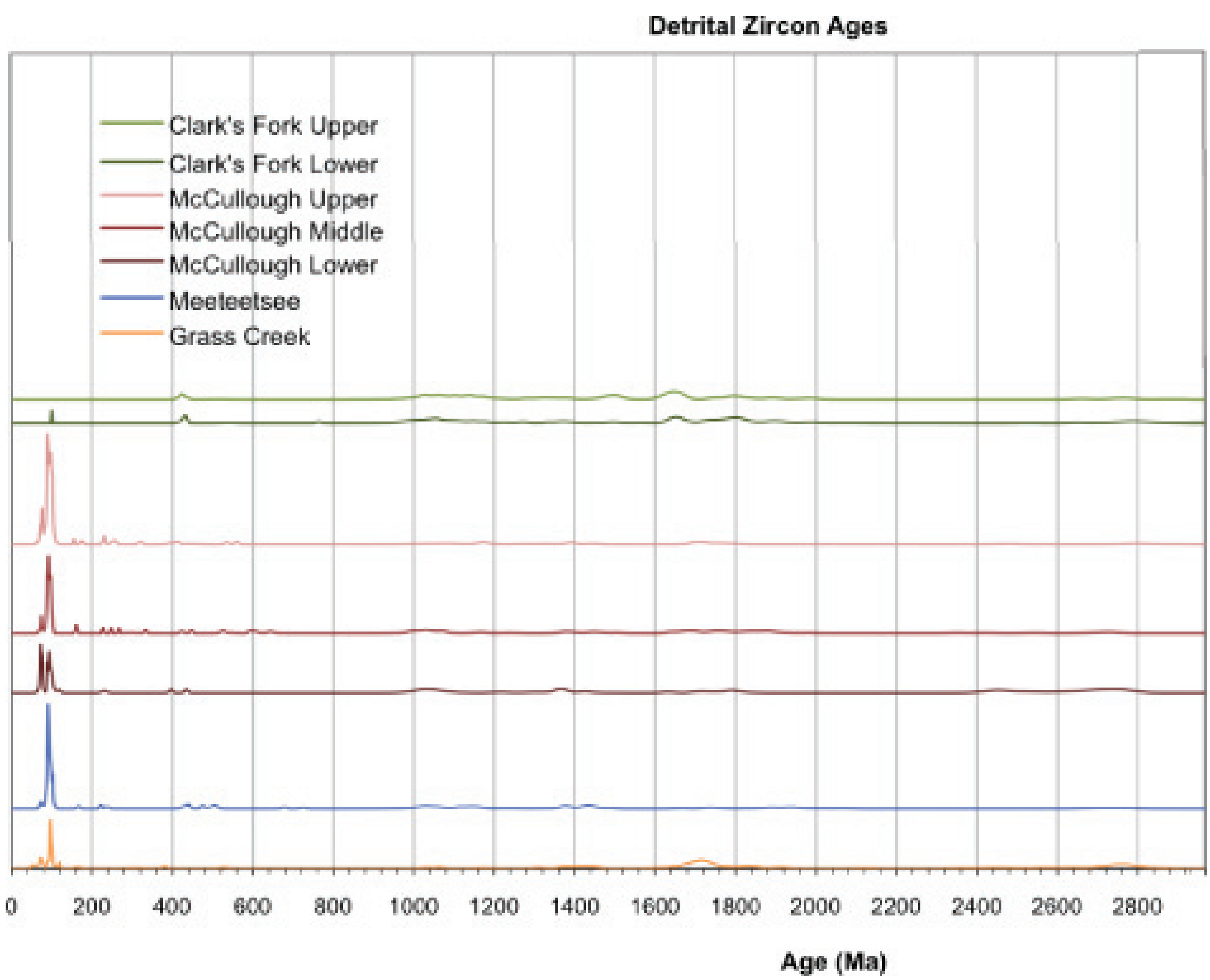


*Figure 3. Frequency plot of U-Th-Pb ages of detrital zircons from the seven samples used in this study.*

## METHODS

While on location in the Bighorn Basin, samples of yellow sandstone from the Willwood formation were collected from locations at Clarks Fork Canyon, Meeteetsee, Grass Creek, and the McCullough Peaks. Samples taken from different horizons were collected at Clarks Fork Canyon (two samples) and the McCullough Peaks (3 samples)S. The samples were then taken to Macalester College where they were crushed in chipmunk and disk mills, panned and sent through a Wilfley table, had a hand magnet separation performed on them, and went through a heavy liquid separation using methylene iodide with a density of 3.33g/cm3 to create heavy mineral splits containing at least one hundred grains of zircons. At the University of Arizona, isometric dates of the detrital zircon splits were collected using the Laser Ablation ICP Mass Spectrometer through the method described by Gehrels and others (2006).

## RESULTS

Frequency curves of the isometric dates obtained from the samples from Clarks Fork Canyon, McCullough Peaks, Meeteetsee, and Grass Creek are shown in Figure 3. The samples taken at Clarks Fork Canyon and McCullough Peaks show no variation between the different stratrigraphic horizons at each location. The samples from the lower and upper portions of the Clarks Fork Canyon contain the same peaks of zircon ages, including one peak at 428 to 435 Ma and another at 1635 to 1675 Ma. Similarly the lower, middle, and upper samples from the McCullough Peaks consist of the same zircon peak, at 71 to 100 Ma.

The results do show differences between the samples based on their geographic distribution. The samples from Clarks Fork Canyon, the northernmost sample location, have a different set of zircon peaks when compared to the rest of the samples from the McCullough Peaks, Meeteetsee, and Grass Creek areas. A young population of zircons dated at 71 to 100 Ma is found in every sample except for the two from Clarks Fork Canyon. The peak at 428 to 435 Ma found in the Clarks Fork samples is absent in the samples to the south. The southernmost sample taken at Grass Creek contains a Proterozoic peak at 1715 to 1750 Ma. Zircons that have Proterozoic ages are not present in any other sample except in the 1635 to 1675 Ma range found in the Clarks Fork Canyon samples, which means Proterozoic zircons are only present in the northernmost and southernmost sample sites and not in the geographically intermediate sites. No peaks of zircon ages that are found in the central basin samples, Meeteetsee and McCullough Peaks, that are not also found in the more marginal Grass Creek or Clarks Fork Canyon samples. The Archean zircons are found in the Grass Creek sample within the range 2650 to 2825 Ma.

## INTERPRETATIONS

The results from the McCullough Peaks and Clarks Fork Canyon samples point to little to no variation in the populations of detrital zircons due to stratigraphic position. This information gives us evidence to interpret that there were no major drainage variations over time and that the location of the sample is the dominant factor in determining what sources are feeding each area.

The disparity between the frequency curves of the samples from Clarks Fork Canyon and the rest of the samples (Fig 3) suggests a more complex drainage model, than single drainage in a northwesterly direction as previously described by Kraus (2001).
The 1635 to 1675 Ma and 1715 to 1750 Ma zircon peaks found in the Clarks Fork Canyon and Grass Creek samples respectively have a few potential sources in those areas. The Great Falls Tectonic Zone in southwest Montana, northwest of the Bighorn Basin, and the Yavapai-Mazatzal Province in Colorado, found to the south of the study area, contain metamorphic and plutonic rocks in the age range of 1600-1800 Ma (Link et al., 2005). Another potential source for zircons of this age is in the Paleozoic sedimentary rocks found in the region. Detrital zircon studies on these rocks have documented populations of zircons aged between 1.6 and 1.8 Ga (Gehrels et al., 1995).
A plutonic source for the 428 to 435 Ma zircons found in the Clarks Fork Canyon is not known to exist in the surrounding area, but Paleozoic sedimentary rocks that surround the Bighorn Basin have yielded 430 Ma aged zircons (Gehrels et al., 19995). The age could

be attributed to ash eruptions on the eastern coast of North America that may have carried zircons to the area where they were incorporated into older formations and have now been recycled into the Willwood (Kowallis et al., 2008).

The only Archean zircons are found in the sample from Grass Creek with an age of approximately 2650 to 2825 Ma. This result is unexpected due to the fact that the study area is surrounded by multiple exposures of Archean basement rock, including, among others, the Bighorn Mountains, the Owl Creek Mountains, and the Beartooth Mountains (Foster et al., 2006).

The southern samples, McCullough Peaks, Meeteetsee, and Grass Creek, all contain a relatively young population of zircons measured to be at about 71 to 100 Ma. There are many potential sources of this age found to the southwest of the Bighorn Basin. During

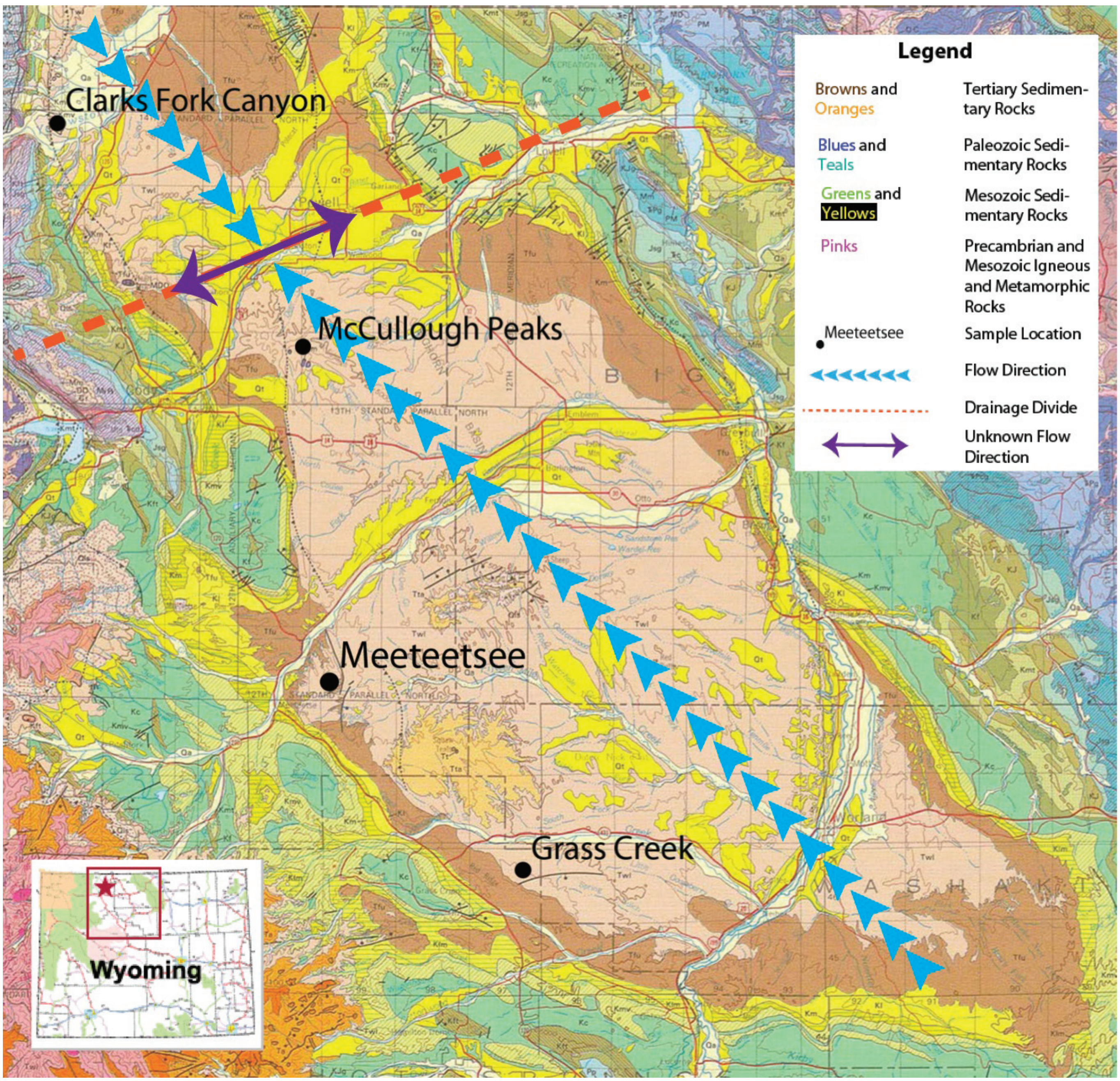


*Figure 4. Schematic diagram of proposed drainage pattern found in the Bighorn Basin at the time of the deposition of the Willwood Formation. Base map taken from Love and Christiansen (1985).*

this time period there was magmatic activity in California, the Great Basin in Eastern Nevada, Arizona, and Idaho (Barton, 1990; SLipman, 1992). In Idaho, the Atlanta lobe of the Idaho Batholith, to the northwest of the Bighorn basin, contains 80 to 100 Ma aged intrusions (Link et al., 2005).

One possible interpretation that can be made from these results is that the drainage system of the Bighorn Basin during the time of Willwood deposition contained two fluvial systems, one that drained from the northernmost part of the basin toward the south; a second that drained most of the basin from south to north. These two systems met at a divide somewhere between Clarks Fork Canyon and the McCullough Peaks. From there the water must have left the basin either to the northeast or southwest; the data does not presently constrain this direction. A schematic diagram for this system is shown in Figure 4. The evidence for this model is present in the detrital zircon populations of the Clarks Fork Canyon samples, because they contain sources not found in the samples to the south but do not contain populations that are abundant in southern populatoins, which should be present if Kraus's unidirectional flow system is accurate. The Clarks Fork samples also provide evidence that at the time of deposition, the Archean basement rocks that currently surround the Bighorn Basin were covered by sedimentary rocks that have since been eroded.

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