Volcanism and associated sedimentation in a retroarc foreland basin : the Upper Cretaceous Two Medicine formation of west-central Montana
by Angela Elaine Smith

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University


Abstract:
Deposits of the Campanian Two Medicine Formation near Wolf Creek, Montana, provide essential sedimentologic information necessary for interpretation of the response of alluvial systems to explosive and effusive intra-basinal volcanism. The Two Medicine Formation consists of approximately 1500 meters of interbedded sandstone, conglomerate, and mudstone, with lava flow and rhyolitic tuff. Lithofacies analysis implies deposition of the western facies was by sandy-gravelly braided systems within well-developed, fine-grained floodplains. In addition to normal fluid gravity flow processes, deposition also occurred via debris flow and hyperconcentrated flow. Channel response to volcaniclastic deposition was avulsion during high discharge events, reworking of choked braided systems, and incision into floodplain deposits.

Lithofacies analysis suggests deposition of the eastern facies was by braided distributary channels. Channels tunneled sediments to the marsh, tidal mudflat, and beach environments. Fluid gravity flow, hyperconcentrated flow, and debris flow processes influenced the depositional setting by overwhelming the coastal plain with sediment. Lacustrine deposits formed after high discharge events plugged channels, resulting in restricted ponded water. Syn-eruption events resulted in progradation of the braid-delta; inter-eruption periods were characterized by the reworking of volcanic debris, and the reestablishment of beach, tidal mudflat, and marsh settings.

Source areas for the primary volcanic rocks most likely were from the local Wolf Creek volcanic centers. The volcaniclastic sediments are compositionally similar to the primary volcanic rocks; thus, sedimentation in the Two Medicine basin was likely dependent on the erosion of local volcanic carapaces. In addition, the eastern facies was deposited by sediment transported by longshore currents, the westerly braid-plain, and from the Adel Mountain volcanic center.

Volcanism-produced detritus ultimately mantled topography sufficiently to disguise tectonic activity in the Wolf Creek area. Thrust faulting was likely active near the end of Two Medicine deposition, as thrust-belt-derived clasts of Cambrian Flathead Sandstone begin to appear in the youngest Two Medicine deposits.

# VOLCANISM AND ASSOCIATED SEDIMENTATION IN A RETROARC FORELAND BASIN: THE UPPER CRETACEOUS TWO MEDICINE FORMATION OF WEST-CENTRAL MONTANA

by

Angela Elaine Smith

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Earth Sciences

MONTANA STATE UNIVERSITY-BOZEMAN
Bozeman, Montana

December 1998

APPROVAL

of a thesis submitted by

Angela Elaine Smith

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Dr. James Schmitt James Schmitt 12-11-98

Approved for the Department of Earth Sciences

Dr. Andrew Marcus Andrew Marcus Dec 10, 1998

Approved for the College of Graduate Studies

Dr. Joseph J. Fedock Joseph J. Fedock 12/17/98

## STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University-Bozeman, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Signature 

Date November 25, 1998

# ACKNOWLEDGMENTS

I would like to express my most sincere gratitude to Jim Schmitt. Without his assistance, advice, expertise, and encouragement, this work would be in dire straits. My other committee members were most helpful. Steve Custer provided insightful comments for improving this manuscript, and I thank him for his honesty and sensibility. Todd Feeley was invaluable for providing knowledge of volcanology and petrology that aided in my understanding of those fields, and I thank him for his patience in reading about dirt. Finally, Jack Horner brought years of experience from working in the Two Medicine Formation, and I thank him for showing me the multiple implications of this study. Thanks to all for the enthusiasm and patience you showed over the past few years.

Funding was provided by Robert and Jacque Smith, D. L. Smith Memorial Scholarship, Edwin Mckee Grant (SEPM), Love Award (WGA), federal loans, and a Department of Earth Sciences teaching assistantship.

Thanks also go to my friends and fellow graduate comrades who are so supportive and encouraging. It would have been more difficult if I didn't have you guys to lean on, in particular, Mike and Amy O'Connell, Becca Laws, Stewart Dixon, and Kate Chase.

My husband Jim deserves so many thanks for his emotional support throughout this endeavor. Ditto to my parents, Robert and Jacque Smith, who also provided faith that this would go well.

TABLE OF CONTENTS

Page

LIST OF TABLES....x

LIST OF FIGURES....xi

ABSTRACT....xv

INTRODUCTION....1

Objectives....3
Geologic Setting....4
Elkhorn Mountains Volcanics....4
Adel Mountain Volcanics....7
Wolf Creek Volcanic Center....8
Western Interior Cretaceous Seaway....9

TWO MEDICINE FORMATION....10

Description....10
Western Facies....13
Age and Correlation....15
Eastern Facies....15
Age and Correlation....16

METHODS....18

LITHOFACIES....23

Conglomerate Lithofacies....27
Matrix-Supported, Massive Conglomerate (Gmm, Gmmi, Gmin)....27
Interpretation....28
Clast-Supported, Massive Conglomerate (Gcm, Gcmi, Gcms, Gcin)....32
Interpretation....33
Trough Cross-Bedded Conglomerate (Gt)....35
Interpretation....35

TABLE OF CONTENTS---Continued

Page

Horizontally-Bedded Conglomerate (Gh).....37
Interpretation.....37
Sandstone Lithofacies.....39
Massive Sandstone (Sm).....39
Interpretation.....40
Horizontally-Stratified Sandstone (Sh).....41
Interpretation.....41
Low-Angle (<15°), Trough Cross-Stratified Sandstone (Sl).....43
Interpretation.....43
Trough Cross-Stratified Sandstone (St).....44
Interpretation.....44
Ripple Cross-Laminated Sandstone (Sr, Srs, Src).....44
Interpretation.....45
Mudrock Lithofacies.....47
Laminated Silt and Mud (Fl).....47
Interpretation.....47
Massive Silt and Mud (Fm).....47
Interpretation.....48
Rootbeds of Silt and Mud (Fp).....49
Interpretation.....50
Non-Clastic Lithofacies.....50
Organic Deposits (O).....50
Interpretation.....50
Carbonate (Cl, Cn).....50
Interpretation.....51
Pyroclastic Lithofacies.....52
Matrix-Supported, Massive Lapilli Tuff (Lmm).....55
Interpretation.....55
Matrix-Supported, Massive Tuff (Tmm, Tmmg).....55
Interpretation.....56
Massive Tuff (Tm).....57
Interpretation.....57
Antidunal Tuff (Ta).....58
Interpretation.....59
Climbing-Ripple Cross-Laminated Tuff (Trc).....59
Interpretation.....60
Horizontally-Stratified Tuff (Th).....60

TABLE OF CONTENTS---Continued

Page

Interpretation....60
Vitrophyric Tuff (Tv)....61
Interpretation....62

VOLCANIC ROCK DESCRIPTIONS....65

Unit B-Latite Lava Flows....65
Interpretation....69
Unit C-Rhyolitic Ash-Flow Tuffs....69
Unit E-Trachyte Lava Flows....73
Interpretation....78
Adel Mountain Volcanics....78

LITHOFACIES ASSOCIATIONS....80

Western Facies....80
Channel Association....80
Fluid Gravity Flow (FGF)....83
Debris Flow (DF)....84
Hyperconcentrated Flow (HF)....84
Interpretation....85
Floodplain Association....86
Fluid Gravity Flow (FGF)....86
Debris Flow (DF)....88
Hyperconcentrated Flow (HF)....88
Pyroclastic Flow/Surges....89
Lava Flow....91
Interpretation....92
Eastern Facies....93
Marsh Association....93
Interpretation....93
Beach Association....94
Interpretation....95
Lacustrine Association....97
Interpretation....97
Distributary Channel Association....97
Fluid Gravity Flow (FGF)....99

TABLE OF CONTENTS---Continued

Page

Debris/Hyperconcentrated Flow (DF/HF).....100
Interpretation.....101
Tidal Mudflat Association.....101
Fluid Gravity Flow (FGF).....103
Debris Flow (DF).....103
Hyperconcentrated Flow (HF).....104
Lava/Autobrecciated Flow.....104
Interpretation.....105

PROVENANCE.....108

Conglomerate Composition.....108
Description.....108
Clast Composition Modes.....109
Sandstone Composition-Western Facies.....110
Texture.....111
Framework Grains.....111
Quartz, Monocrystalline (Qm).....111
Feldspar (F).....112
Lithic Fragments (Lv, Lp, Ls).....112
Accessory Minerals.....112
Sandstone Composition Modes.....113
Sandstone Composition-Eastern Facies.....113
Texture.....115
Framework Grains.....115
Quartz, Monocrystalline (Qm).....115
Quartz, Polycrystalline (Qp).....116
Feldspar (F).....116
Lithic Fragments (Lv, Lp, Ls).....116
Accessory Minerals.....117
Sandstone Composition Modes.....117
Paleocurrents.....118
Potential Sediment Source Areas.....118
Conglomerate Sources.....118
Western Facies Sandstones Sources.....120
Eastern Facies Sandstones Sources.....121

TABLE OF CONTENTS---Continued

Page

VOLCANIC ROCK SOURCE AREAS....124

Latite Lava Flows....124
Rhyolite Ash-Flow Tuffs....124
Trachyte Lava Flows....125
Trachybasalt Coherent and Autobrecciated Lava Flows....126

DEPOSITIONAL SYSTEMS....127

Western Facies....127
Braid-Plain Deposits....127
Depositional Model....128
Eastern Facies....129
Braid-Delta Deposits....130
Depositional Model....131

DISCUSSION....135

Volcanic Influences on Sedimentation....135
Tectonic Implications....139

CONCLUSIONS....142

REFERENCES CITED....144

APPENDICES....157

Appendix A....158
Locations of Measured Sections....159
Appendix B....161
Clast-Count Data....162
Appendix C....163
Histogram Plots of Clast-Count Data....164
Appendix D....165
Point-Count Data....166
Appendix E....167
Histogram Plots of Point-Count Data....168

# LIST OF TABLES

Table Page

1. Table of lithofacies types and flow characteristics.....24

2. Table of conglomerate clast-count data.....162

3. Table of sandstone point-count data.....166

# LIST OF FIGURES

Figure Page

1. Schematic diagram of Cretaceous Sevier foreland basin and associated depozones with explosive volcanism occurring in the magmatic arc....2

2. Schematic diagram illustrating volcanic setting within terrestrial and paralic environments....3

3. Timing of tectonic, depositional, intrusive transgressive/regressive, and volcanic events that occurred during the Late Cretaceous....5

4. Regional tectonic map for north-western Montana....6

5. Geologic map of area north of Wolf Creek, Montana....11

6. Photo of western facies field area. View to the west-northwest....12

7. Photo of eastern facies field area. View to the east-northeast....12

8. Schematic stratigraphic section of the western facies....14

9. Schematic stratigraphic section of the eastern facies....16

10. Location map of field area. See Appendix A for stratigraphic section locations....19

11. Location map of detailed stratigraphic sections for the western and eastern facies....20

12. Matrix-supported, massive conglomerate (Gmm)....28

13. Matrix-supported, massive conglomerate (Gmm) with clast-supported zones within the deposit....29

LIST OF FIGURES---Continued

Figure Page

14. Stacked clast-supported, massive conglomerates (Gcm) evidencing crude horizontal bedding....33

15. Close-up of trough cross-bedded conglomerate (Gt), upper half of photo....36

16. "Couplets" of horizontally-bedded conglomerate (Gh) and horizontally-stratified sandstone (Sh)....38

17. Spreiten in massive, bioturbated sandstone (Sm), eastern facies....40

18. Thick deposit of horizontally-stratified sandstone (Sh)....42

19. Wave ripple bedform, eastern facies....45

20. Climbing-ripple cross-lamination (Src) with low-angle cross-stratification (Sl) above....46

21. Ripple cross-laminated sandstones (wavy-flaser bedding) interbedded with muddy stringers....48

22. Rootbeds (Fp) in massive, blocky mudstone (Fm)....49

23. Deposit of poorly-consolidated nodular carbonate (Cn)....51

24. Modified pyroclastic flow model and associated deposits....53

25. Pyroclastic flow model incorporating debris flow transportation mechanisms....54

26. Vitrophyre or vitrophyric tuff (Tv) with abundant feldspar phenocrysts....61

27. Outcrop of unit C illustrating interfingering of vitrophyric tuff (Tv) with ashy, massive tuff (Tm) and horizontally-stratified tuff (Th)....63

28. Schematic diagram illustrating zones of welding and devitrification and vapor phase crystallization for ignimbrites or tuffs....64

LIST OF FIGURES---Continued

Figure Page

29. Common appearance of latite lava flow. Abundant feldspar phenocrysts.....66

30. Outcrop exposure of unit B (latite lava flows), central section, western facies.....67

31. Schematic stratigraphic section of latite lava flows and associated textures.....68

32. Schematic stratigraphic section of unit C and associated lithofacies.....70

33. Example of outcrop exposure for unit C, northern section. Two sheets visible.....71

34. Example of flow banding in welded tuff.....72

35. Outcrop exposure for unit E (trachyte lava flow), central section.....74

36. Schematic stratigraphic section for unit E and associated textures.....76

37. Outcrop exposure of Adel Mountain Volcanics, uppermost part of section RE-Kte.....79

38. Schematic stratigraphic section of channel association deposits, unit D, western facies.....81

39. Schematic stratigraphic section of channel and floodplain deposits, unit F, western facies.....82

40. Example of channel-fill deposits above floodplain mudstones.....85

41. Schematic stratigraphic section of floodplain deposits, unit D.....87

42. Pyroclastic flow (Tmm) deposited above poorly visible massive mudstone (Fm), floodplain association, western facies.....90

43. Accidental lithic clast of laminated, resilicified mudstone (Fl) within latite lava flow, floodplain association, western facies.....92

LIST OF FIGURES---Continued

Figure Page

44. Schematic stratigraphic section of marsh and beach associations, eastern facies....94

45. Interbedded low-angle cross-stratified (Sl), horizontally-stratified (Sh) and ripple cross-stratified (Sr) sandstones in beach association....96

46. Schematic stratigraphic section of lacustrine and channel associations, eastern facies....98

47. Outcrop of channel-fill within the coastal plain deposits of the eastern facies....99

48. Outcrop exposure of crevasse splay deposits....100

49. Schematic stratigraphic section of tidal mudflat association....102

50. Example of lava flow/autobrecciated flow with incorporated mudstone (squeeze-ups) from tidal mudflat....105

51. Schematic stratigraphic section of eastern facies lithofacies associations....106

52. Ternary diagram of modal compositional data....114

53. Schematic diagram of braid-plain depositional system....128

54. Schematic diagram of braid-delta, tidal mudflat, and beach depositional systems....130

55. Schematic block diagram illustrating interaction of eastern facies lithofacies after eruptions from Adel Mountian volcanic center....132

56. Schematic stratigraphic cross-section of Upper Cretaceous rocks in western Montana and southern Alberta....134

# ABSTRACT

Deposits of the Campanian Two Medicine Formation near Wolf Creek, Montana, provide essential sedimentologic information necessary for interpretation of the response of alluvial systems to explosive and effusive intra-basinal volcanism. The Two Medicine Formation consists of approximately 1500 meters of interbedded sandstone, conglomerate, and mudstone, with lava flow and rhyolitic tuff. Lithofacies analysis implies deposition of the western facies was by sandy-gravelly braided systems within well-developed, fine-grained floodplains. In addition to normal fluid gravity flow processes, deposition also occurred via debris flow and hyperconcentrated flow. Channel response to volcaniclastic deposition was avulsion during high discharge events, reworking of choked braided systems, and incision into floodplain deposits.

Lithofacies analysis suggests deposition of the eastern facies was by braided distributary channels. Channels funneled sediments to the marsh, tidal mudflat, and beach environments. Fluid gravity flow, hyperconcentrated flow, and debris flow processes influenced the depositional setting by overwhelming the coastal plain with sediment. Lacustrine deposits formed after high discharge events plugged channels, resulting in restricted ponded water. Syn-eruption events resulted in progradation of the braid-delta; inter-eruption periods were characterized by the reworking of volcanic debris, and the reestablishment of beach, tidal mudflat, and marsh settings.

Source areas for the primary volcanic rocks most likely were from the local Wolf Creek volcanic centers. The volcaniclastic sediments are compositionally similar to the primary volcanic rocks; thus, sedimentation in the Two Medicine basin was likely dependent on the erosion of local volcanic carapaces. In addition, the eastern facies was deposited by sediment transported by longshore currents, the westerly braid-plain, and from the Adel Mountain volcanic center.

Volcanism-produced detritus ultimately mantled topography sufficiently to disguise tectonic activity in the Wolf Creek area. Thrust faulting was likely active near the end of Two Medicine deposition, as thrust-belt-derived clasts of Cambrian Flathead Sandstone begin to appear in the youngest Two Medicine deposits.

# INTRODUCTION

Retroarc foreland basins typically develop adjacent to fold-thrust belts, far removed from their coeval magmatic arc (Dickinson, 1974; Jordan, 1995; DeCelles and Giles, 1996). Basin-fill originates primarily from erosion of sedimentary rocks in the fold-thrust belt with volcaniclastic sediment input typically limited to infrequent and distally-derived ash-fall deposits (Elder, 1988; Christiansen et al., 1994). Active eruptive centers are rarely present within the foreland basin, therefore, the influence of volcanism on retroarc foreland basin sedimentation has not been thoroughly investigated. Models for foreland basin sediment dispersal generally propose a Sevier-style thrust belt that sheds detritus from uplifted thrust sheets into particular basin depozones (wedge-top, foredeep, forebulge, and back-bulge) via alluvial fans and fluvial systems (DeCelles and Giles, 1996) (Figure 1). As seen in Figure 1, volcaniclastic sedimentation may be an important component of the retroarc foreland basin. Thus, these models and examples do not account for instances in which episodic and catastrophic eruptive activity alters foreland basin depositional environments and transportation mechanisms.

Late Cretaceous time in western Montana was characterized by explosive volcanism. Volcaniclastic sediment derived from magmatic centers associated with the Cordilleran magmatic arc was delivered to the Sevier foreland basin by way of extensive fluvial systems. This study focuses on the influence of Late Cretaceous intra-basin volcanism on foreland basin sedimentation in west-central Montana; specifically, the influence of volcanic processes

and detritus on the fluvial systems that flowed into the Cretaceous Western Interior Seaway. The Upper Cretaceous Two Medicine Formation near Wolf Creek, Montana, was deposited in a volcanically-influenced, non-marine to paralic setting and provides an excellent opportunity to study the record of interaction between volcanism and sedimentation (Figure2).

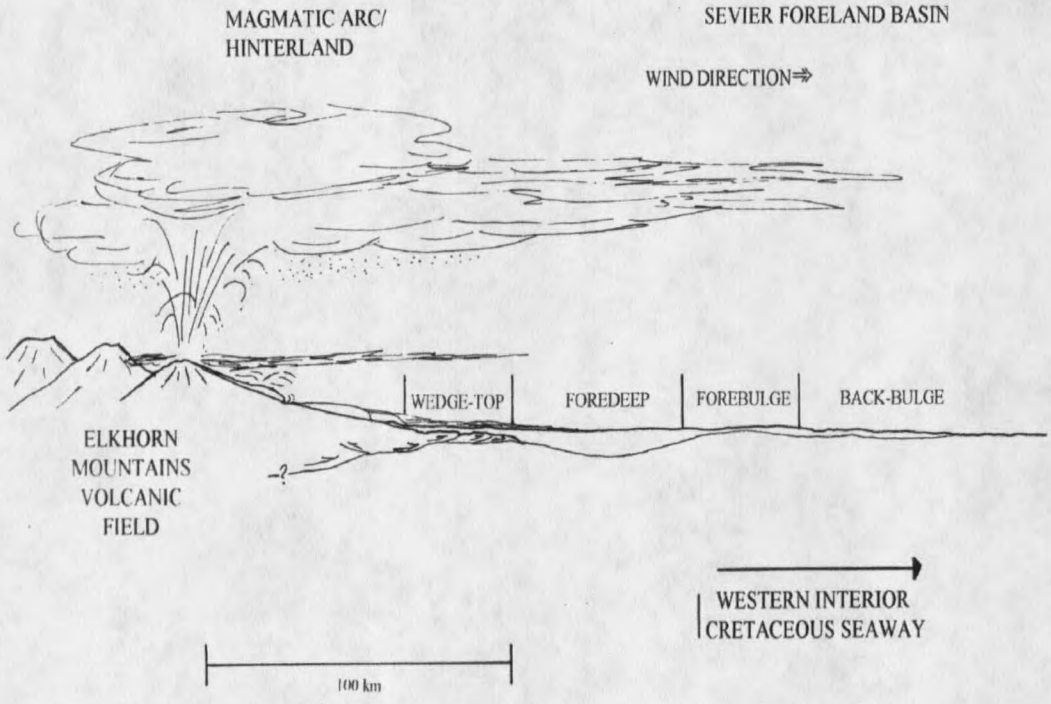


Figure 1: Schematic diagram depicting foreland basin depozones, and associated volcanic and tectonic features. Eruptions within the Elkhorn Mountains volcanic field sent volcaniclastic debris into the wedge-top depozone as proximal deposits. Medial deposits are found in the foredeep depozone, and are represented by the Two Medicine Formation. Air-fall comprises distal deposits in the back-bulge depozone, represented by bentonitic shales of the Western Interior Cretaceous Seaway. Modified from DeCelles and Giles (1996).

## Objectives

The objectives of this analysis are to: 1) document the abundance and occurrence of coherent and autoclastic lava flow, pyroclastic flow, pyroclastic surge, and debris flow deposits that comprise the alluvial basin-fill of the Upper Cretaceous Two Medicine Formation, and 2) identify changes in processes of alluvial sediment transport due to sporadic addition of large volumes of volcanic detritus by volcanically-derived debris flow, hyperconcentrated flow, pyroclastic flow, and coherent lava flow. Fulfilling these objectives will allow interpretation of the nature and influence of eruptive activity on the foreland basin fluvial systems. Production of volcaniclastic sediment from intra-basinal volcanic centers is hypothesized to have altered the Sevier foreland basin depositional systems, especially in the Wolf Creek, Montana, study area. Ultimately, the implications of volcanism for evolution of the Sevier foreland basin need to be addressed, but that is beyond the scope of this study.

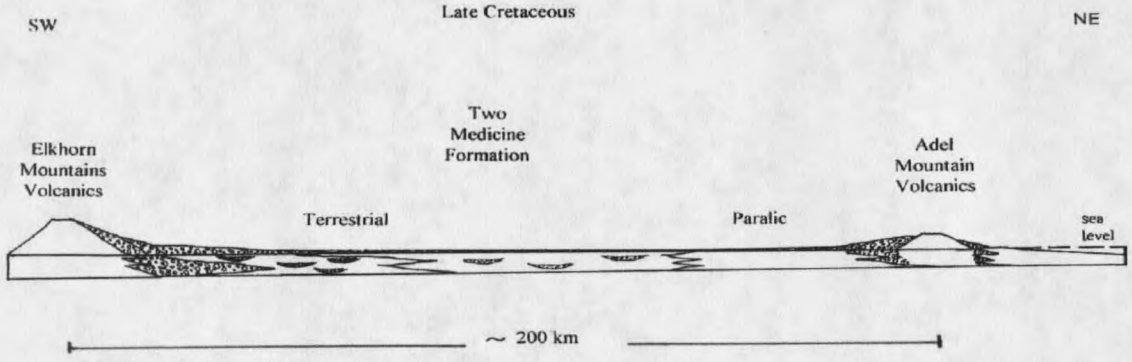


Figure 2: Schematic diagram depicting the interaction of volcanism from the Elkhorn Mountains and Adel Mountain volcanic centers in the Two Medicine depositional basin, during the Campanian.

## Geologic Setting

During Late Cretaceous time in western Montana, the Cordilleran magmatic arc swept into the foreland basin. Overlapping spatially and temporally with subduction of the Farallon plate and accretion of exotic terranes along the western continental margin, the Idaho and Boulder batholiths developed synchronous with Sevier thrust belt deformation. Associated with Cordilleran magmatism, large, compositionally distinct volcanic centers (Elkhorn Mountains and Adel Mountain volcanic fields) developed between 80-70 Ma within the Sevier foreland basin (Lyons, 1944; Gwinn and Mutch, 1965; Viele and Harris, 1965; Klepper et al., 1971; Tilling, 1974; Chadwick, 1981; Gunderson and Sheriff, 1991) (Figure 3). Effusive and explosive eruptions in these volcanic centers produced lava flows, pyroclastic flows, and tephra clouds that contributed to the foreland basin-fill of the Upper Cretaceous Two Medicine Formation. Synchronous with volcanism, the adjacent Sevier thrust belt propagated basinward, as depicted in Figure 3 (Robinson and Marvin, 1967; Mudge and Sheppard, 1968; Peterson, 1981; Harlan et al., 1988; Harlan et al., 1991a; Harlan et al, 1991b). The fold-thrust belt advanced eastward resulting in deformation of the Elkhorn Mountains volcanic carapace and westernmost edges of the Adel Mountain volcanic field. How this thin-skinned deformation affected the fluvial systems is unknown.

### Elkhorn Mountains Volcanics

The intrusion of the Boulder batholith at ~78-68 Ma (K/Ar) resulted in explosive eruptions producing voluminous (6000 $km^3$) volcanic deposits of the Elkhorn Mountains volcanic field (Tilling, 1974). The Elkhorn Mountains Volcanics consist of rhyolitic ash-flow

tuff, welded tuff, basaltic and andesitic lava flows, and volcanically-derived sandstone, mudstone, and conglomerate (Smedes, 1966). The Elkhorn Mountains Volcanics has been hypothesized to have once covered an area of 26,000 km$^2$, based on the areal distribution of rocks believed to be derived from the Elkhorn Mountains volcanic center (Smedes, 1966; Klepper et al., 1971; Tilling, 1974).

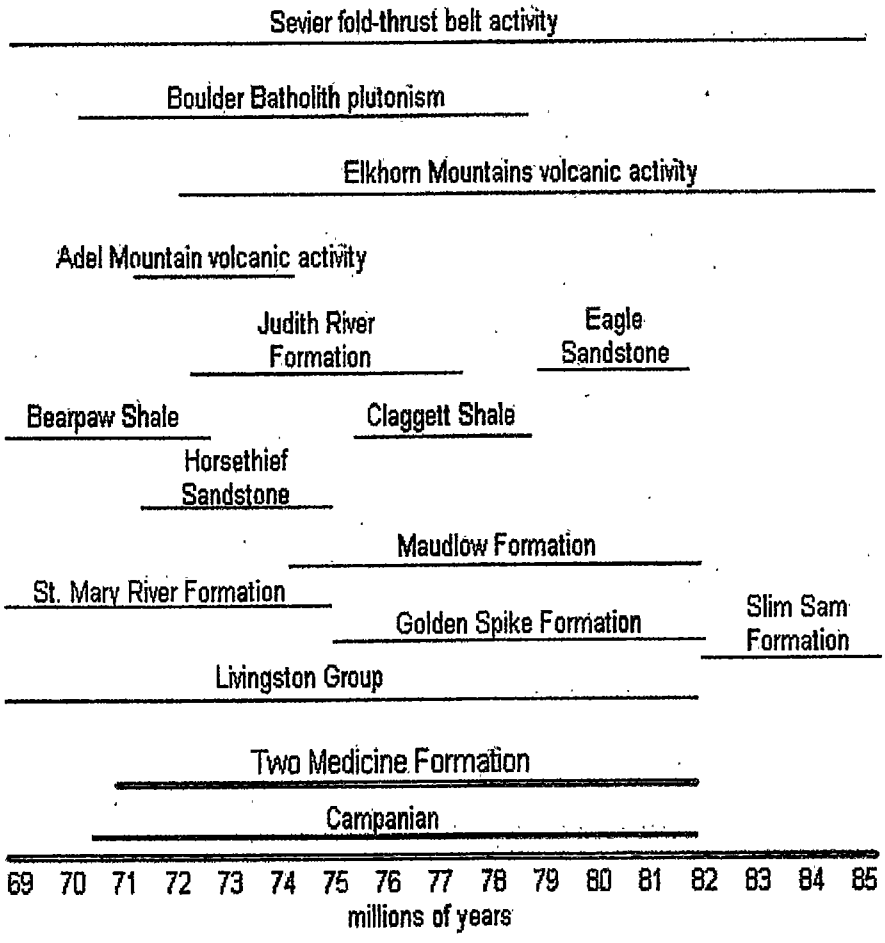


Figure 3: Timing of geologic and tectonic events associated with the Two Medicine Formation. From Lorenz (1981).