Knickpoint analysis of streams in North Dakota, South Dakota, and Nebraska

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KNICKPOINT ANALYSIS OF STREAMS IN NORTH DAKOTA, SOUTH DAKOTA AND NEBRASKA

by

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This thesis, submitted by Trent D. Hubbard in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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This thesis meets the standards for appearance, conforms to the style and format requirements of the graduate school of the University of North Dakota, and is hereby approved.

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5-30-97

Date

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Title	Knickpoint Analysis of Streams in North Dakota, South Dakota and Nebraska
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Signature Trent D Hubbard
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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

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ABSTRACT

Analysis of stream profiles, seismic reflection studies, engineering studies, and historical earthquakes indicates uplift in south-central South Dakota and north-central Nebraska over the last 5-10 ma. The purpose of this study was to determine if this uplift could be detected by constructing topographic profiles along, and in close proximity to several streams in this region. The Cannonball River, ND, was used to compare the streams in South Dakota and Nebraska to a stream beyond the affected area.

Data for the profiles were collected from 7.5 minute topographic maps as well as GPS surveys. Abrupt changes in slope (irregularities) were determined along the profiles based on visual inspection and spreadsheet calculation. The use of spreadsheet calculation assured consistency in identification of irregularities among profiles.

Profiles constructed along and in close proximity to streams in the study area contain numerous irregularities. In general, the profiles in close proximity to the streams (land surface profiles) show more irregularities than stream profiles. This is partly related to the method of construction of land surface profiles. Examination of the profiles has shown that some of the identified irregularities are the result of lithologic changes while others are the result of tributary streams. However, the reasons for many of the irregularities, which may include recent uplift, are not apparent and need to be field

checked. Future work should also involve collection of more data through GPS surveying, which would increase the data base from which profiles can be constructed.

INTRODUCTION

Purpose

Seismic reflection profiles, earthquake activity, identified faults, stream profile data, as well as damage to engineering structures indicate that uplift has occurred in the last 5-10 ma in south-central South Dakota and north-central Nebraska, and is still occurring (Schurr and others, 1994; Nichols and others, 1994). Much of the seismic activity , faulting and damage to engineering structures occurs within a region characterized by a negative Bouguer gravity anomaly (Figure 1). In addition, the area is also characterized by lineaments which reflect the boundaries of basement structural blocks (Schurr and others, 1994). Correlation of recent earthquakes with these lineaments suggests that the recent seismic activity is associated with reactivation of basement structures (Schurr and others, 1994; Nichols and others, 1994). Previous geomorphic studies have examined profiles of streams trending perpendicular to the east- west lineaments in the region (Nichols and others, 1994). However, several streams trend along these lineaments (Schurr and others, 1994). Recent uplift associated with reactivation of basement block structure should be reflected in profiles along and in close proximity to such streams.

The purpose of this study was to collect data for profile construction from 7.5 minute topographic maps and Global Positioning System (GPS) field surveys.

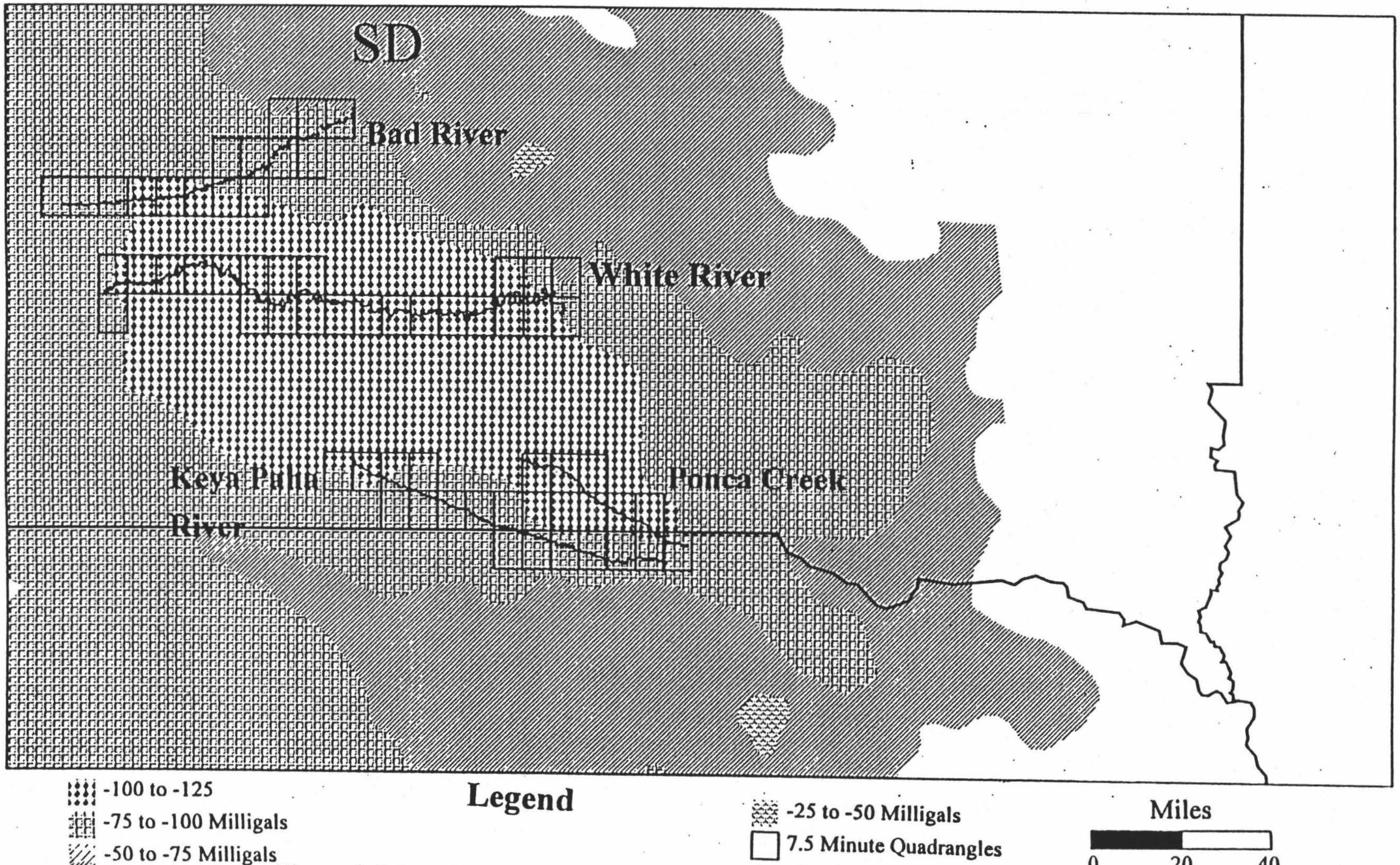


Figure 1. Map of negative gravity anomaly in South Dakota and Nebraska, showing its relationship to streams in the study area. (Modified from Lyons and O'Hara, 1982)

Knickpoints along such profiles were identified, and causes for their formation examined. If seismic activity is associated with basement block structure, it should be reflected in the origin of some knickpoints.

Stream and Land Surface Profile Locations

Streams selected for this study include Ponca Creek, and the Bad, White, Keya Paha, and Cannonball Rivers (Figure 2). The Bad River has been studied along a 150-mile stretch from Philip to near Fort Pierre, SD, and includes parts of Haakon, Jones, and Stanley Counties. Just east of the study area the Bad River drains into the Missouri River.

A 225-mile stretch of the White River, was studied from south of Kadoka, SD, to where the river discharges into the Missouri River south of Chamberlain, SD. This stretch includes, or borders, parts of Jones, Jackson, Lyman, Mellette, and Tripp Counties.

A segment of the Keya Paha River has been included, from the merger of Antelope and Rock Creeks southeast of Mission, SD, to where the river discharges into the Niobrara River southeast of Naber, NE. This 125-mile section includes parts of Todd and Tripp Counties in South Dakota, as well as parts of Keya Paha and Boyd Counties in Nebraska.

Ponca Creek has been studied along a 90-mile section from just east of Colome, SD, to just west of Butte, NE. This area includes portions of Tripp and Gregory Counties in South Dakota as well as Boyd County in Nebraska.

The Cannonball River, ND, was studied from just west of Regent, southeast to its juncture with Cedar Creek, a 180-mile stretch through Hettinger and Grant Counties.

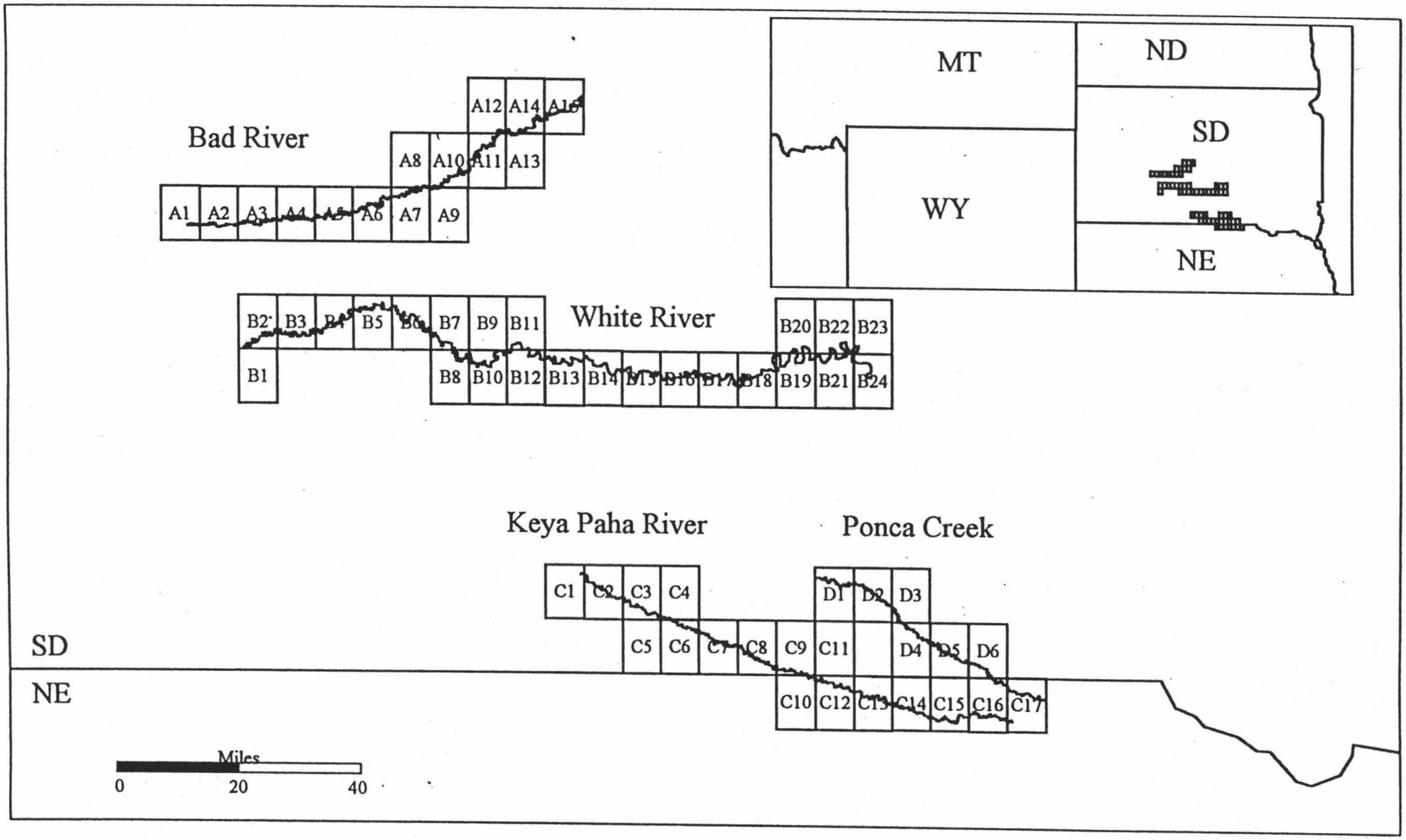


Figure 2A. Location of streams in South Dakota and Nebraska measured in this study. (7.5 minute quadrangles are numbered for identification. See Appendix B).

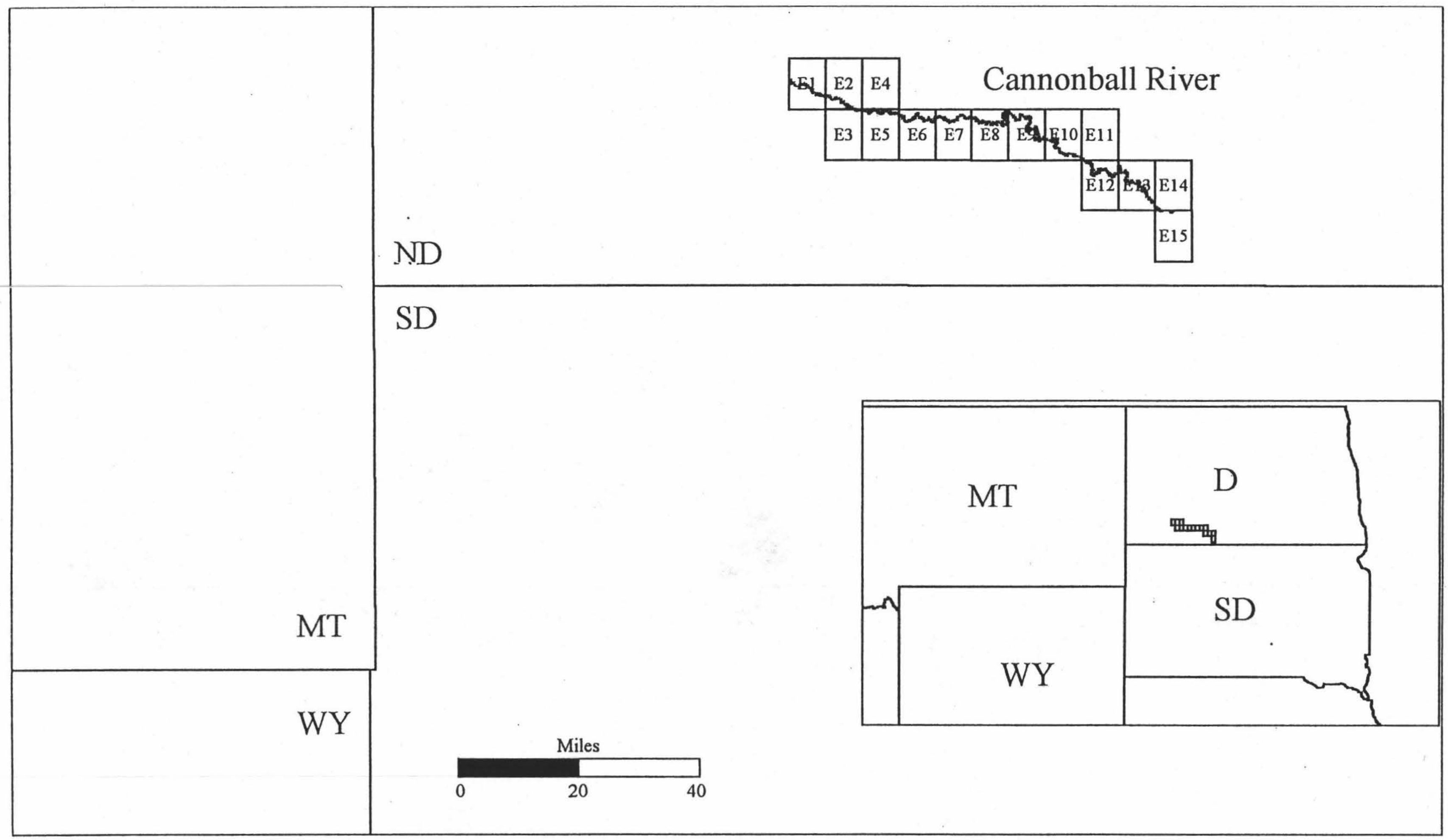


Figure 2B. Location of Cannonball River measured in this study. (7.5 minute quadrangles are numbered for identification . See Appendix B).

Profile Theory

Stream Profiles

General

In order to interpret profiles constructed in this study it is necessary to understand what profiles represent and the factors influencing their development. A longitudinal

profile for a stream is a plot of elevation vs. distance, which is typically concave. It is difficult to differentiate among the many factors influencing the shape of the stream profile because slope can be influenced by environmental conditions, stream channel conditions or even some combination of both (Leopold and others, 1964, p. 250). For example, an environmental parameter that can result in a change in the stream profile is lithology. Changes in velocity, as well as channel width and depth, are stream conditions that also can influence the slope of a stream profile. And flow resistance, which influences slope, is a function of clast size and the form of channel deposits. For purposes of discussion, the several factors affecting stream slope are considered separately.

Discharge

Many researchers believe that the concave shape of the general stream profile is in part related to an increase in discharge downstream (Morisawa, 1968, p. 100; Richards, 1982, p. 225; Leopold and others, 1964, p. 251). Tributaries and, in some cases groundwater flow, provide a stream with more water in a downstream direction. This increase in discharge results in an increase in stream energy, allowing channel slope to be reduced through erosion, while sediment load is still transported downstream. The rate at which discharge changes over the length of a stream influences slope and thus the overall shape of the long profile (Richards, 1982, p. 227).

Changes in discharge also influence slope, indirectly, through alteration of several other stream factors. Increases or decreases in discharge can result in changes in width, depth, velocity and even sinuosity of a stream (Leopold and others, 1964, p. 251). For example, an increase in velocity may increase erosion along the cutbank of a stream, resulting in a meander cutoff. Thus, decrease in sinuosity causes stream length to be less for a given elevation change. As a result the shape of the longitudinal profile will be altered.

A change in velocity also will change the erosional and depositional capabilities of a stream. A stream may respond to these changes by altering the width and/or depth of its channel. Whenever the erosional and depositional characteristics of a stream are altered, a change in slope may result. The manner in which width and depth are altered is influenced by many factors, to be discussed later.

Stream Load Character

Several authors have noted that a direct relationship exists between the slope of a stream and grain size (Richards, 1982, p. 229; Morisawa, 1968, p. 100). Two main reasons have been suggested for the downstream decrease in grain size (Paola and others, 1992; Richards, 1982, p. 230). As attrition of particles occurs during transport, a reduction in grain size results. Alternatively, as gradient decreases downstream, coarse materials are selectively deposited as they can no longer be transported on the reduced gradient. This process, known as selective sorting, can result in the relationship observed. It is likely that some combination of selective sorting and attrition results in the relationship between the slope of a stream and grain size.

Not only does the decrease in grain size downstream appear to be related to the slope of the stream profile, but the rate at which particle size changes take place also influences its slope (Leopold and others, 1964, p. 256). The more quickly the bed material decreases in size downstream the more concave is the longitudinal profile. However, if particle size increases downstream the profile may have appear less concave, or it may even be convex (Leopold and others, 1964, p. 254).

The relationship between particle size and slope is not simple, however, because of sedimentary particle influx from tributaries and bank erosion (Richards, 1982, p. 232). As a result, particle size does not always decrease in a systematic manner downstream. Adding further complication is that grain size and sediment distribution are also influenced by discharge.

Another important factor to consider in the relationship between particle size and slope is the depositional form of sediments. Configuration of deposits into ripples and channel bars, for example, can influence stream characteristics such as flow resistance and competence (Leopold and others, 1964, p. 255). Any alteration of flow can influence the pattern of erosion and deposition in a stream channel, and this, in turn, influences the slope of a stream profile.

Lithology

Lithology in and adjacent to a stream channel also influences the slope of a stream profile. The slope of stream segments flowing over uniform lithology, with other factors being held constant, has been determined for a variety of rock types (Morisawa, 1968, p. 106; Hack, 1957, p. 88). It was found that stream slopes are steepest on sandstones, gentler on shales, and even less on limestones. If rock type changes over the course of a stream, slope will also likely change, given that each type has a different resistance to erosion.

Lithology is not only important because it affects slope through resistance to erosion but also because it influences other stream characteristics, such as sediment load and sediment size (Richards, 1982, p. 240). Rock such as shale is more easily eroded than, say, granite and thus provides more sediments to a stream. As discussed earlier (in the preceding section), sedimentary load influences stream channel characteristics and thus stream channel slope.

Not only is the amount of sediment provided to a stream influenced by lithology but the size of clasts is as well. A stream flowing in a granitic area may contain larger clasts than a stream that flows over an area dominated by shale, because shale breaks down into smaller-size particles more easily than does granite. It should be noted, however, that initially it may be more difficult to erode the granite than the shale. Whatever the clast size characteristics of a stream, they certainly influence slope.

Stream Channel Character

Several researchers have noted that the shape of a longitudinal profile is influenced by the dimensions of the stream channel (Hack, 1957, p. 45 ; Richards, 1982, p. 225; Leopold and others, 1964, p. 251). Hack (1957, p. 61) noted that both width and depth of a stream tend to increase downstream. However, in general, width tends to increase at a faster rate than depth. Thus, there is a direct correlation between the change in depth-width ratio and slope. This change may occur as a result of increased discharge, as discussed above, or a change in sediment load (See Stream Load Character and Lithology).

Land Surface Profiles

The shape of profiles in close proximity to streams (land surface profiles) is influenced by erosional and depositional processes. Factors such as vegetation, climate and lithology influence these processes. Vegetation serves to stabilize the land surface and reduce erosion. Climate is also important because it determines the amount of water available for erosional and depositional processes; in general, the more water the faster the erosion, although water may also increase vegetation thereby decreasing erosion.

Lithology influences the shape of land surface profiles because certain rock types are more easily modified than others. Shales are much easier to erode than granitic rocks resulting in profiles with a more gentle gradient than granitic rocks.

Tectonics also influences the shape of the land surface profile, in that it creates instability on the land surface that will subsequently be modified by erosion and deposition. For example, if an area is uplifted, erosion and deposition will occur to reduce the gradient difference between the uplifted sections and the area beyond.

Because land surface profiles were determined in close proximity to streams, and even cross them in places, stream processes influence the shape of these profiles. During periods of flooding streams will modify their valley through erosion and deposition. Depending on the exact location of the profile with respect to the flood plain of a river, valley erosion and deposition can influence the shape of the land surface profile.

In addition to being influenced by many of the same factors as stream profiles, the shape of land surface profiles is also a function of the method of profile construction. In this study land surface profile lines have been drawn to follow both large-and small-scale meander patterns of streams (to be discussed in more detail later) making sinuosity important in determining the resulting profile shape. Greater sinuosity results in greater land surface profile length with respect to elevation change, whereas decreased sinuosity results in shorter profile length with respect to that same change in elevation. If change in elevation is kept constant, changes of profile length and thus sinuosity should influence the shape of the profile. Stream sinuosity is influenced by such factors as lithology, discharge, velocity and stream load character.

Development of Knickpoints

Knickpoints represent areas along a stream channel where there is an abrupt break in slope, and thus are visible on stream profiles (Richards, 1982, p. 246; Morisawa , 1968, p. 108; Ritter and others, 1995, p. 225). For purposes of this study abrupt breaks in slope along land surface profiles will also be termed knickpoints. Many of the factors discussed above, such as lithologic and discharge changes are responsible for alterations in base level and thus knickpoint development. Identification of knickpoints is important in using stream profiles to understand Holocene geologic processes.

Recognition of knickpoints or irregularities in a stream profile is dependent on scale. Irregularities along a profile at a given large scale will be more evident than along the same profile at a much smaller scale. This is because at smaller scales irregularities due to minor variations in factors such as sediment supply, sediment caliber, discharge, and lithology, will be more evident than at the smaller scale (Richards, 1982, p. 225).

Knickpoints are not permanent features and are formed in response to disequilibrium conditions. Upon formation, they are modified and eventually removed as equilibrium is reestablished. Several processes are responsible for knickpoint modification (Morisawa, 1968, p. 108-110). First of all, increased erosion occurs at the knickpoint causing it to migrate up-slope. Deposition occurs downslope from the knickpoint. By erosion at the knickpoint, and deposition downslope, the gradient is reduced, until the slope of the original surface is restored.

Because of the variety of conditions under which knickpoints are modified, the time required for their removal varies. Mayer (1985, p. 255) suggests that knickpoints in streams resulting from large base level changes can remain for time periods on the order of a million years, whereas knickpoints resulting from smaller perturbations may survive for less than a year.

The time required for knickpoint removal is largely influenced by channel material as well as the volume of runoff. Several authors demonstrate that knickpoints in streams consisting of noncohesive channel materials tend to be eliminated more quickly than those occurring in bedrock channels (Knighton, 1984, p. 158; Morisawa, 1969; Mayer, 1985, 225; Ritter and others, 1995, p. 225). A study by Morisawa (1969) of streams in the Hebgen Lake area of Montana, found that knickpoints resulting from an earthquake in 1959, were almost completely eliminated within a year. These knickpoints occurred in streams consisting of noncohesive materials, including pebbles, cobbles, boulders and some sand. The effect of runoff volume can be seen in this study in that those streams with a greater runoff eliminated knickpoints more quickly than those with less runoff (Morisawa, 1959)

Stream gradient is influenced by the removal of knickpoints. Leopold and Bull (1979) studied the change in gradient of streams in response to changes in base level by placing dams on ephemeral streams to represent relative uplift. For Big Sweat Dam near Santa Fe, NM, they found that gradient was altered 50 feet upstream from the dam in the first year and 80 feet upstream after four years. The maximum distance upstream that gradient changed was 110 ft upstream from the dam. A study of the Ramah Dam near Ramah, NM, between 1905 and 1974 found that the slope of the stream channel was altered 2900 ft upstream (Leopold and Bull, 1979). However, very little of this change occurred in the last 35 years of the study. In general, Leopold and Bull (1979) found that gradient changed rapidly at first, followed by a longer period of much slower change. They suggested that the distance a knickpoint migrates upstream is determined by the original slope of the stream channel, the depositional slope, and the height of the barrier (or uplift).

Stream Profile Studies in Other Areas

Introduction.

Many researchers have examined stream profiles in active tectonic regions to determine stream response to geologic processes (e.g., Begin and others, 1981; Bull and Kneupfer, 1987; Merritts and Vincent, 1989; Ouchi, 1985; Reed, 1981; Rhea, 1989; Seeber and Gornitz, 1983). For these studies knickpoints were first located and the conditions responsible for their formation determined, which may include recent uplift. Often more than one cause for knickpoints is possible for a given area. The following are examples of studies elsewhere.

Himalayas.

Seeber and Gornitz (1983) examined profiles of streams in the Himalaya Mountains to determine if any knickpoints could be associated with recent uplift in the region. They proposed several explanations for knickpoints observed in stream profiles. First, they could be the result of eustatic lowering of base level, which would result in increased stream downcutting, and migration of knickpoints upstream.

Secondly, changes in stream gradient could reflect lithologic changes. Less resistant rocks tend to have lower gradients than more resistant rocks. In the High Himalayas there are erosion-resistant metamorphic rocks, whereas in the Lesser Himalayas there tend to be less resistant sedimentary rocks. As rivers flow from the High Himalayas to the Lesser Himalayas there is a sharp decrease in stream gradient. Although streams tend to decrease in gradient downstream, it is usually not abrupt. Seeber and Gornitz (1983) suggested that the change in gradient at least partially reflects the lithology change.

Seeber and Gornitz (1983) also suggested that changes in stream gradient could be the result of faulting, or tectonics. If a stream crosses a fault with the upthrown block on the headward side the stream will tend to have a steeper gradient on that side. The boundary between the Lesser Himalayas and the Higher Himalayas is marked by intensive faulting, and thus knickpoints are observed along streams in the area.

Seeber and Gornitz (1983) suggested that a significant change in base level is not a likely cause of knickpoints in this area because terrigenous sediments have accumulated continuously since the Mid-Miocene without any major breaks in sedimentation. The correlation of knickpoints with faulting suggests possible uplift in the area, although some of the knickpoints are probably related to lithologic changes.

Ozark Mountains.

McKeown and others (1988) analyzed stream profiles from the eastern Ozark Mountain for knickpoints and their possible causes. Several factors were considered for the development of knickpoints here, including lithologic boundaries, meander cutoffs, changes in discharge, recent uplift, and changes in size, as well as composition of bedload material.

Meander cutoffs and changes in lithology were both found to correlate directly with the location of some knickpoints. Despite differences in bedload material, the profile shape for streams in the area remains similar, suggesting particle size is probably not responsible for knickpoint development. Changes in stream discharge do not seem to correlate with knickpoint development, either.

Although some of the factors examined correlated with knickpoints, the relationship of uplift to knickpoint development could not be adequately determined from profile studies alone.

Piedmont/Atlantic Coastal Plain

Reed (1981) examined stream profiles along the east coast of the United States near Washington, D.C., for evidence of possible Quaternary tectonic activity. Two explanations were postulated for stream profile irregularities observed. First, they could be due to changes in base level as a result of sea level being lower during the Pleistocene. Secondly, they could be due to tectonic activity along the boundary between the Piedmont Plateau and the Atlantic Coastal Plain. Lithologic differences do not seem to correlate with irregularities in the area.

Reed (1981) believed that while lower base level during the Pleistocene must have had a significant effect on streams, several lines of evidence suggest tectonic activity also had some effect. Profiles of upper stream reaches were projected from a sharp break in slope to the Piedmont/Atlantic Coastal Plain boundary. Differences in elevation between the projected and actual stream profiles were determined across this boundary. The elevation differences tended to increase in a northward direction. It is suggested that the trend in elevation difference, as well as the prevalence of terraces on the north side of the Potomac are both consistent with a northward increase in uplift of the Piedmont relative to the Coastal Plain, and cannot easily be explained as a result of adjustments entirely due to lower base levels.

Another indication of possible uplift is that profiles of tributaries to the Potomac River upstream from this major change in gradient plot as straight lines on log plots, whereas those tributaries below this change in gradient do not. Straight line reaches of the upper parts of profiles for these lower streams, projected to their intersection with the Potomac, reveal present tributaries are 40-50 meters lower than the projections. Also, these projections seem to correspond to the projection of the Potomac downstream from its major break in slope, thus indicating possible uplift (Reed, 1981)

South Dakota

Because rejuvenation of a drainage basin occurs first in its lower part and progresses up basin, a stream profile should be steeper in downstream reaches during the early part of uplift (Schumm and others, 1987). As a result, profiles will be less concave in these regions than in areas where there is no uplift. Many tributary streams to the Bad River near Pierre, SD, show a very subtle concave profile which may be associated with tectonic activity (Nichols and others 1994).

Many stream profile irregularities in tributary streams of the Bad River are associated with faults (Nichols and others, 1994). West of Pierre, SD, many of these faults have been mapped and described. Vertical displacements on these faults range from less than one to 37 meters (Nichols and others, 1994). Evidence that some of the faulting is Pleistocene age or younger is found from a high resolution seismic profile showing high angle faults extending at least 180 meters below the surface, displacing older nearly horizontal Pleistocene rebound fractures (Nichols and others, 1994).

In the studies discussed above, stream profile irregularities have been traced to many causes, such as lithologic changes, discharge changes and faulting. As a result of the many factors involved in their formation great care must be taken in the interpretation of knickpoints. Sometimes examination of profiles may prove inconclusive, such as the study by McKeown and others (1988) in the Ozark Mountains, where more evidence was needed to support the hypothesis of recent tectonic activity.

General Geology

Because the flow of streams and their profile shape are influenced by lithology and structures it is appropriate to begin this study by examining the general geology of the study area. The Cannonball River, ND, is cut into sedimentary units laid down as the Western Cretaceous Interior Seaway retreated from the midcontinent region (Dyman and others, 1994; Crandall, 1958; Frazier and Schwimmer, 1987; Cherven and Jacob, 1985). As a result, there are near-shore marine, deltaic, river, lake and paludal sediments. Ages of deposits traversed by the Cannonball River range from Late Cretaceous to Early Tertiary, and formations include the Hell Creek, Ludlow, Cannonball, Slope, Bullion Creek and Sentinel Butte (Clayton and others, 1980).

Deposits in South Dakota and Nebraska consist largely of marine shales also deposited in the Cretaceous Interior Seaway (Dyman and others, 1994; Crandall, 1958; Frazier and Schwimmer, 1987). The Bad River flows across one such formation, the Pierre Shale. This unit has been subdivided into the Virgin Creek and Sully Members just west of Fort Pierre (Petsch, 1953). The White River is also cut into the Pierre Shale as well as the Niobrara Formation (Petsch, 1953). Along this river the Pierre Shale has been differentiated into the Virgin Creek, Sully, Gregory, and Sharon Springs Members. Ponca Creek also flows across the Cretaceous Pierre Shale, which in some areas is differentiated into the Elk Butte Member (Petsch, 1953; Burchett, 1969). The Keya Paha River flows across the Pierre Shale, as well as the Oligocene White River Group (Petsch, 1953; Burchett, 1969).

PROCEDURE

Field Methods

Data Collection.

Field work was carried out between August 19 and August 28, 1995. The purpose was to obtain location and elevation data for streams and terraces of the Cannonball, Bad, White, and Keya Paha Rivers as well as Ponca Creek.

A North Dakota Geological Survey (NDGS) Magellan NAV 5000 Pro Global Positioning System, rated to sub-meter accuracy, was used in the field to collect position data. The system consisted of a tripod, an antenna, the main control box and a 386 computer in which data were stored (Figure 3).

At each site the system was set up for fourteen minutes of data collection, during which time the control box was locked onto 4 satellites. The 4 satellites chosen were the ones likely to give the best accuracy for location and elevation at that specific time of day. The satellites chosen also had to remain higher than 15 degrees above the horizon during the entire data collection process. If one or more of the satellites dropped below this level its signal would be lost. This would mean fewer satellites with which to determine the location of the field site, with decreased accuracy.

Figure 3. Global Positioning System equipment used for determining location and elevation at sites along streams in this study.

All elevations obtained using the system were to the level of the antenna. Once the system was set up at a site, the distance from the antenna to the ground was measured to correct for actual ground elevations. Stream location and elevation for each site were measured at the vegetation edge bordering the stream, because it was assumed that this would be the highest level of the water in the channel except during flooding. Also, this position gave a consistent measurement marker for each site. For terrace locations and elevations, a position was chosen as near as possible to their centers as determined from 7.5 minute topographic maps.

Data Sites

Data were collected at 21 sites along the Cannonball River. The location and elevation were determined for the river at 14 of these sites, while the elevation and location was determined for terraces at the other seven. For the Bad River, ten sites were examined. Nine sites were occupied along the White River. Along the Keya Paha River, seven sites were occupied. Due to time constraints no sites were occupied along Ponca Creek.

In addition to obtaining location and elevation measurements along the streams and at terrace locations, data were also collected at a point of known elevation south of Lieth, North Dakota, to ensure that the system was working properly and to check its accuracy.

Data Analysis

Elevations determined using the GPS system were not measured from sea level but rather in terms of height above ellipsoid. In order to convert to elevation above mean sea level, latitude and longitude values at each site were entered into the program "Geoid 93" in order to calculate the geoid height of each site (Milbert, and Schultz, 1994). Then, geoid height and antenna height were subtracted from ellipsoid height to convert to elevation above mean sea level. Next, distances between successive stations were determined (Appendix A), and then used in profile construction.

Lab Methods

Program Setup

Data for stream profile analyses were collected using a Summagraphics Summagrid IV digitizing table (Summagraphics Corporation, 1992) and the Atlas Geographic Information Systems (GIS) program for Windows (Strategic Mapping Inc., 1995.) Data were collected from 7.5 minute topographic maps as well as state geologic maps secured to the digitizing table. Before data collection could begin the map had to be linked to the digitizing table and "layers" had to be created to store the data. Layers represent data collection and storage mechanisms in the Atlas GIS program (Strategic Mapping Inc., 1995). They allow data to be organized and displayed as defined by the user.

Linking of the map to the digitizing table was accomplished by entering the latitude and longitude of four known points on the map into the system from the keyboard, followed by entering these points with the digitizing puck. In linking the map to the digitizing table the distance between the latitude/longitude points at the corners of the map, as entered with the digitizer, were kept within 20 percent of the actual distance based on the manually entered latitude/longitude data. If the error was greater than this the setup was examined and the linking processes repeated. Some of the errors encountered were the result of the map not being fixed flat on the digitizing table or the digitizing puck not being centered exactly on the correct latitude/ longitude point when entering data.

Once the error was minimized, data layers were created to collect and store data in a useful manner. Line layers were created for streams and profile lines, point layers for elevation points and region layers for geologic map data. These layers were displayed on the computer screen as either line segments, points or regions. Layers could be turned on (visible) or off (not visible), depending on the data being examined at any one particular time. When a layer was created a data table with 5 columns was automatically established. There was an "ID" column, two" name columns", an "area" column, and a "length" column. Other columns had to be created to record such data as elevations.

Data Collection

Geologic Data

Region layers were established for each of the geologic formations or members present in the study area. Data were then entered into the GIS (Strategic Mapping Inc., 1995) system by tracing the boundaries of these geologic units with the digitizing puck.

The edges of regions with common borders had to be matched to avoid overlapping regions as well as gaps in the data. As a common border was encountered during digitizing, a system command could be used to specify its beginning and ending positions, which were then entered with a digitizing puck. Once these positions were established the program created a common border between the regions.

Stream and Land Surface Profile Data.

The process of digitizing is described only for streams, as digitizing of land surface profile layers follows the same basic procedure; the main difference was that lines had to be drawn on the map representing each of the land surface profiles. For land surface profile "A" the lines were drawn along the river valley following the large scale meander patterns of the river (Figure 4). For land surface profile "B" the lines were drawn across each 7.5 minute quadrangle from the most upstream position of a stream to the most downstream position (Figure 4). Occasionally profile line B had to be adjusted, as a stream might meander back and forth across a quadrangle boundary. This was done by drawing the profile line to follow the general path of the river in the area of such boundaries. In such cases the profile line did not always go from the most upstream to the most downstream positions in the quadrangle. This allowed the profile line to better follow the stream valley across most of the quadrangle. For land surface profile "C" the lines were drawn to follow small scale meander patterns of the river (Figure 4).

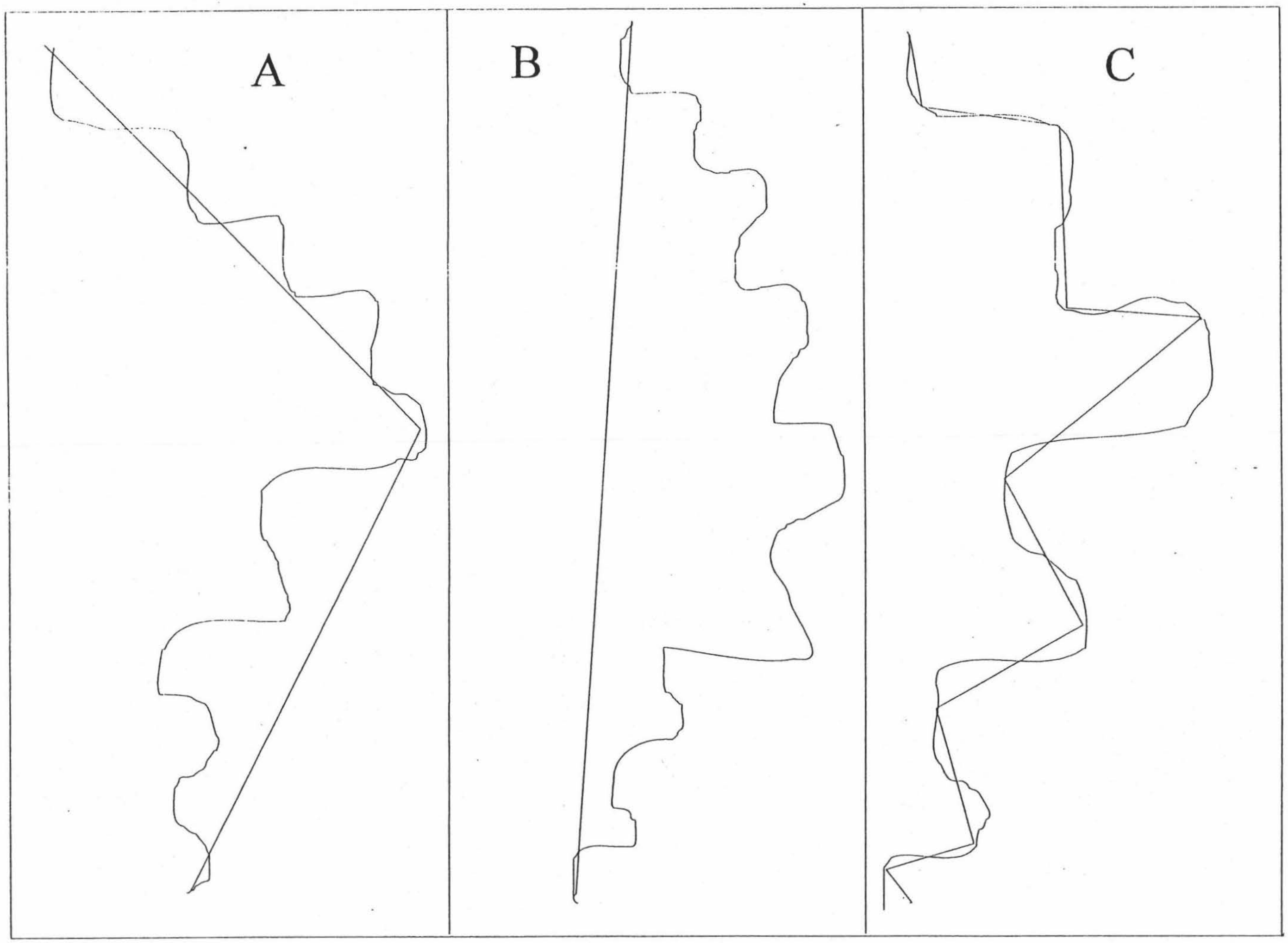


Figure 4. Sketch showing how profile lines were drawn with respect to streams. A) Land surface profile A drawn with respect to the stream. B) Land surface profile line B drawn with respect to the stream. C) Land surface profile line C drawn with respect to the stream.

Streams were digitized in segments, with the beginning and ending of each segment being determined by where a stream intersected successive contour lines on the topographic map. Where the stream was truncated at the edge of the quadrangle, this served as the marker for the beginning or ending of the stream segment. Beginning and ending elevations for each segment were recorded in a table. If a stream or profile segment began or ended at a quadrangle boundary this column was left blank, and adjustments made later.

In order to digitize stream segments the program was set to "continuous mode", which allowed the digitizing of several points for each segment. The digitizing puck was simply traced over the stream segments, clicking on the button periodically to record a series of points. The program automatically connected each point to the previous point with a line. This was done until data for the entire segment had been collected. The process was repeated for each successive segment until a series of stream segments representing the entire stream was digitized. Data collection proceeded from upstream to downstream and, for consistency, when both banks of the stream were visible on the topographic map, the stream was always traced along the right bank.

The positions where streams crossed contour lines were also digitized and the elevations entered in the created columns. These points served as visual markers for elevations. Once data had been collected for a particular map another map was placed on the table and additional data collected.

Once streams were digitized, corrections had to be made for all line features to appear continuous, both between digitized segments and quadrangles. The GIS program could be set up to display all the points along the stream segment and these could then be adjusted manually with a mouse, as necessary, to achieve alignment of the linear features.

Preparation of Profile Data.

Once elevation and line segment distances had been collected, the data had to be checked to ensure that they were in order from upstream to downstream so profiles could be constructed. Streams often meandered from one quadrangle to another and thus segments were not always digitized in order from upstream to downstream. Data were imported into the spreadsheet"Excel" version 5.0 (Microsoft Corporation, 1993), and then compared with the visible data from "Atlas" version 3.0 (Strategic Mapping Inc., 1995) to ensure proper order.

Next, a table of elevation and distance values was created. These values were obtained using the imported ending elevation and distance values. When an elevation value was missing, due to a stream segment beginning or ending at a quadrangle boundary, the distance value for this segment was combined with the distance value of the next sequential segment that had an ending elevation. The end result was a table of distance and elevation with no missing data values for each stream. These data could then be graphed for a visual representation of the profiles.

Methods of Analysis.

As mentioned earlier four profiles have been constructed for each stream area. The first was constructed using elevations and lengths following the stream course. The next three followed the slope of the land surface near the stream. The land surface profiles were constructed in order to allow the examination of each stream area from different perspectives. It was thought that this would lead to a better understanding of the existing Holocene geologic processes.

For the three land surface profiles, distances and slopes were determined between successively lower elevation values. Slope changes of greater than 5 ft/mi between segments on land surface profiles were identified as knickpoints because this corresponded well with visual inspection. The exception to this was where elevation points were close together and where the land surface profiles crossed tributaries or valleys.

On stream profiles, slope changes of more than 10 ft/mi were identified as knickpoints. The different values used for knickpoint identification in stream profiles and land surface profiles is due to their difference in length. The horizontal distance on the stream profiles is approximately twice that of the land surface profiles because streams meander.

Once knickpoints were determined, their possible causes were investigated. First, digitized geologic maps of the area were examined to determine if any relationship existed between lithology and knickpoints. Next, tributary junctures were examined to see if they corresponded to any of the knickpoints.

For several profiles in this study a trendline was calculated for a segment up elevation from a selected knickpoint. The trendline was then extended down elevation from the knickpoint to the end of the profile in order to observe the difference between trendline elevation and actual elevation at profiles end. It was thought that projections would give some idea of how knickpoints have affected profiles in the area.

Also, stream and land surface profiles for each stream area were plotted on the same axis so that a visual comparison between them could be made. In conjunction with this visual comparison, a series of tables was constructed showing knickpoint elevations that occur in more than one profile for a particular stream area.

RESULTS

Cannonball River

Profiles were constructed for an area along and adjacent to the Cannonball River between elevations of 2450 and 1880 ft (Figures 5-8). These profiles show a linear to slightly concave form (Figures 9-12). Knickpoints have been determined and comparisons made with lithologic maps in order to discern any relationship (Figures 5-8; Appendix C). In the Cannonball River area no knickpoints related to lithology were identified along the river profile or land surface profiles B and C (Appendix D). However, along land surface profile A knickpoints two and three have been related to a change in lithology. (Knickpoint numbers begin at the head of profiles and increase downslope). Lithology changes from the Slope Formation to Tertiary/Quaternary sediment (undivided) at knickpoint two, while at knickpoint three the lithology changes from Quaternary/Tertiary (undivided) to the Slope Formation (Figure 6).

Tributary junctures were examined to determine if a relationship exists with the knickpoint identified in the Cannonball River Profile (Appendix D). No relationship was found.

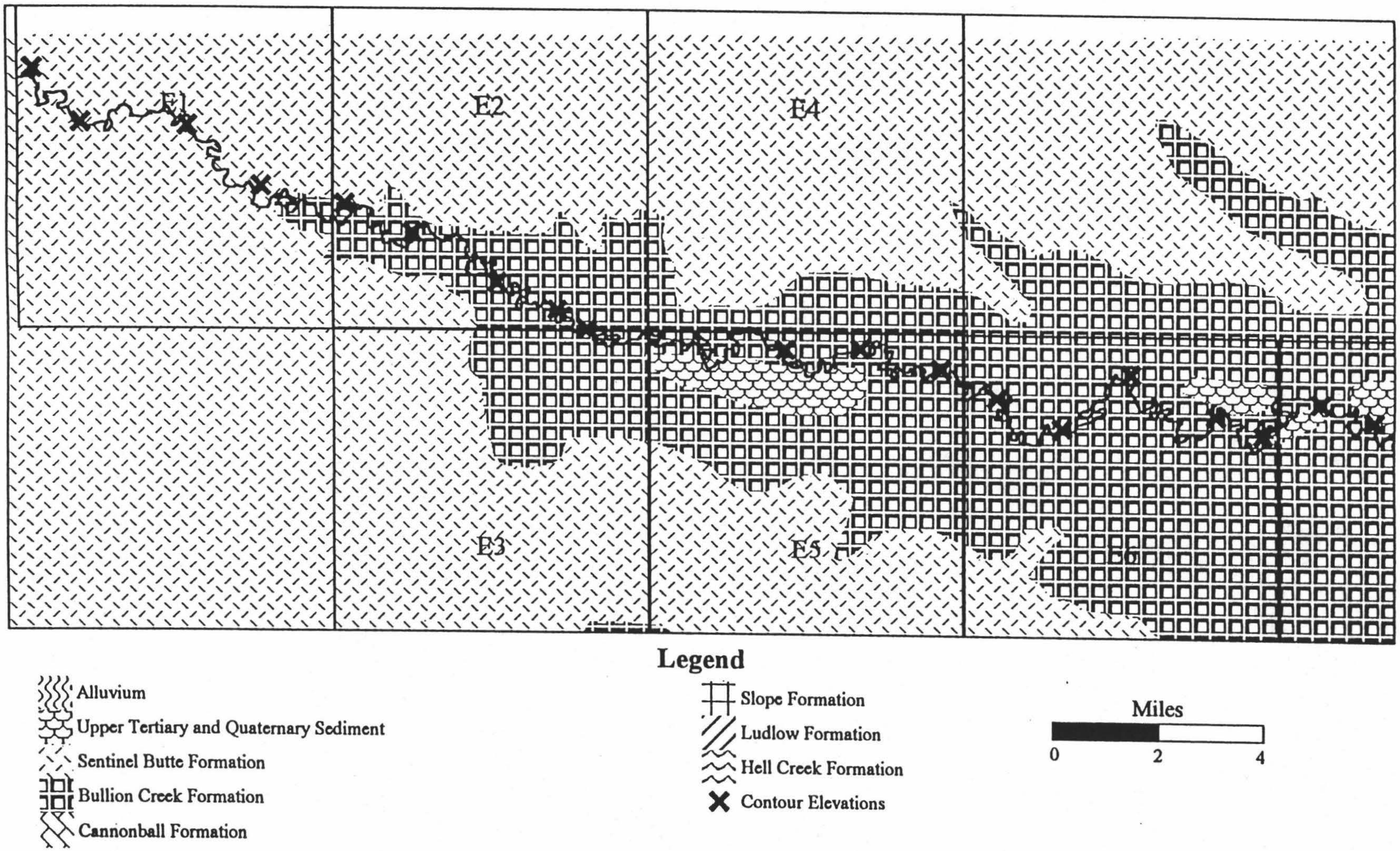


Figure 5. Map showing relationship of geology to elevations and knickpoints along the Cannonball River. (From Clayton and others, 1980a) (See Figure 2B for quadrangle locations.)

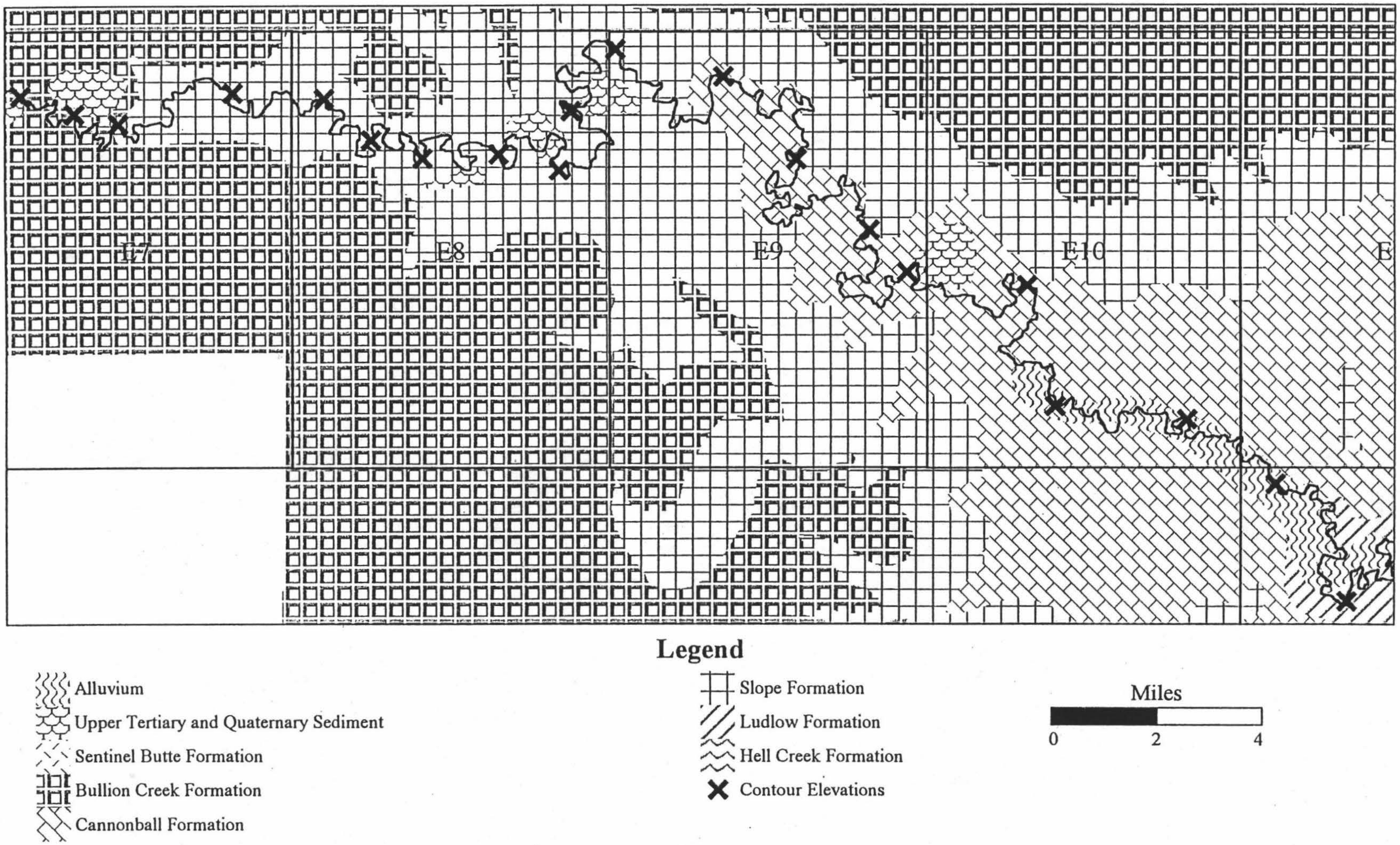


Figure 5. continued.

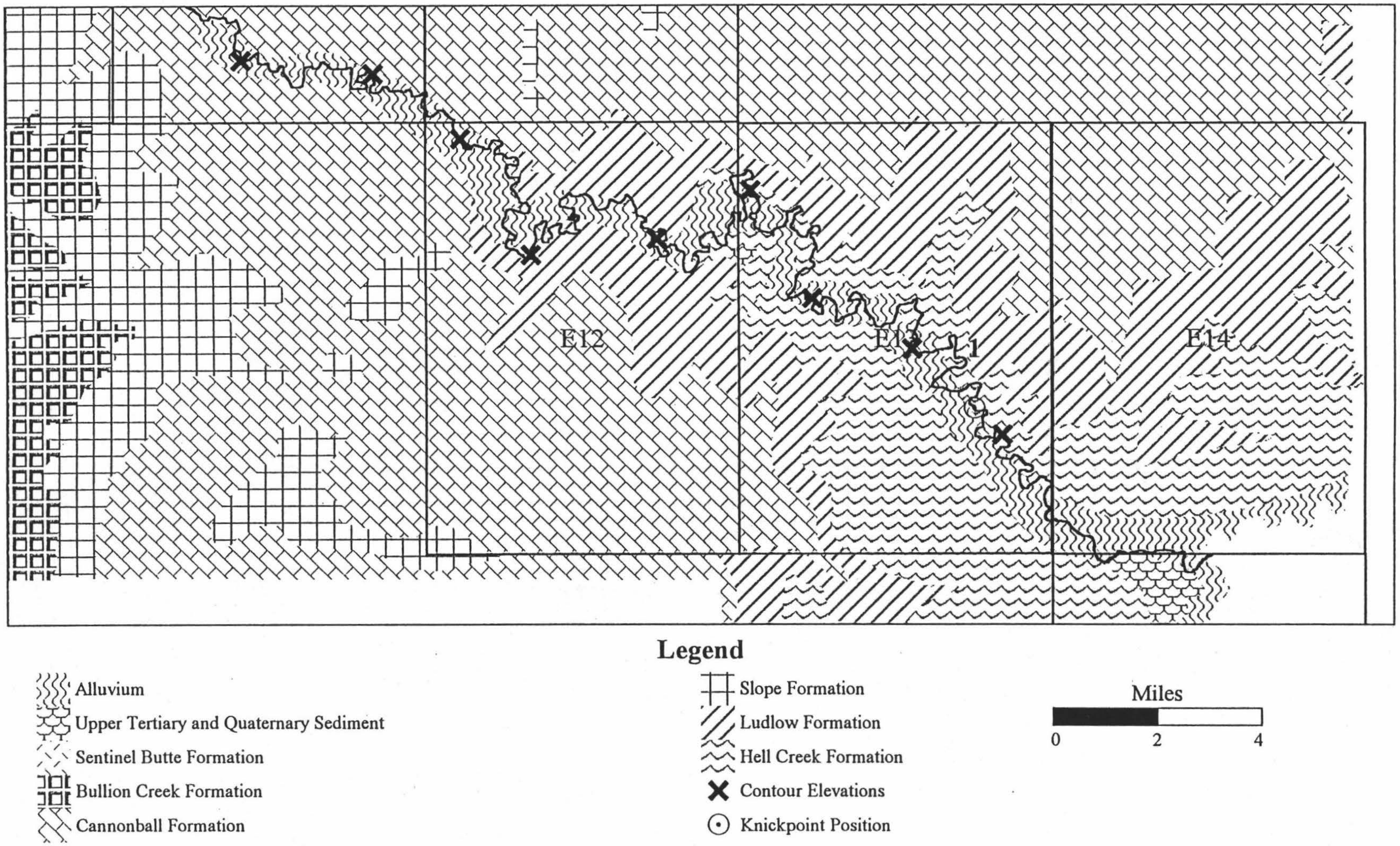


Figure 5. continued.

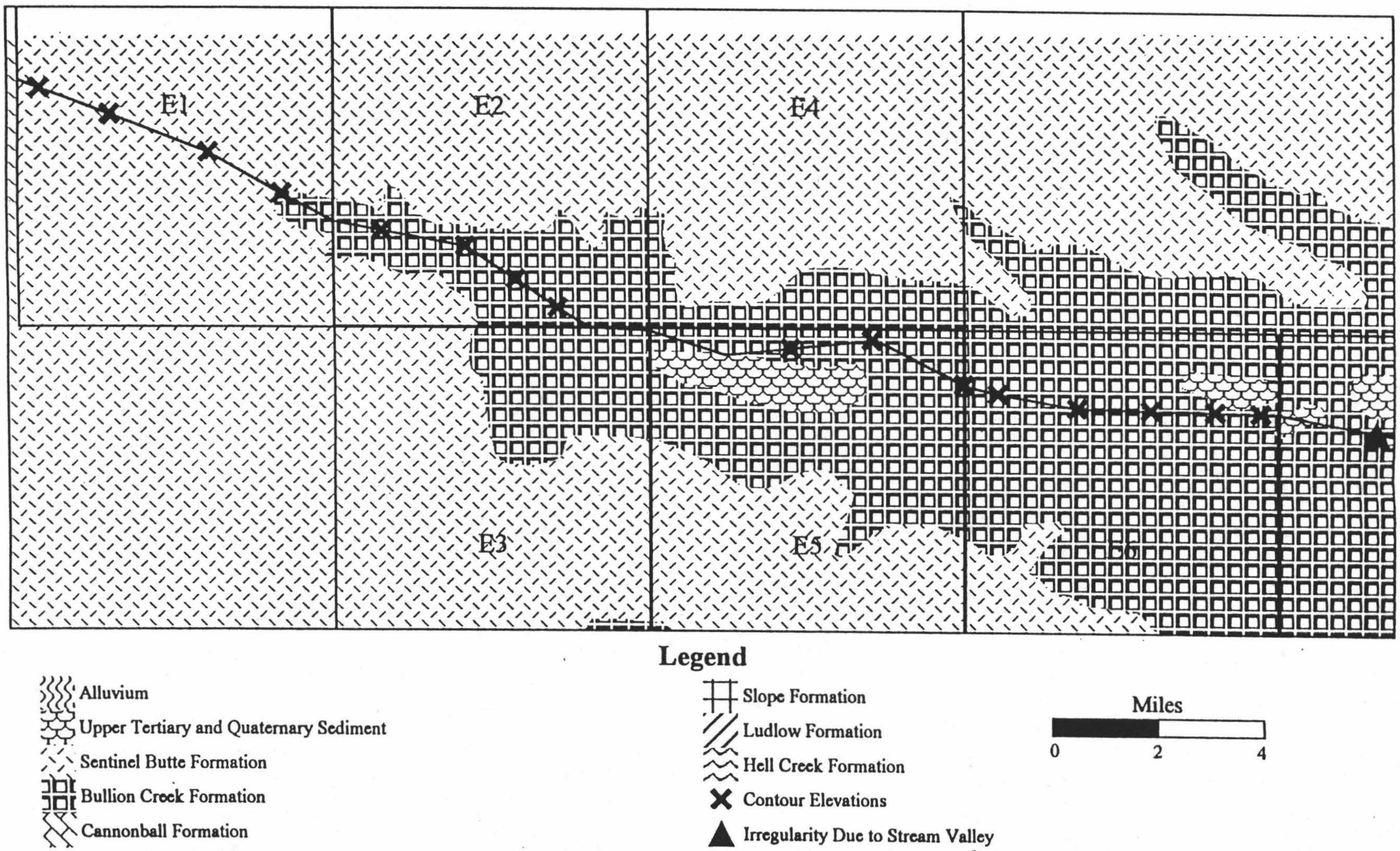


Figure 6. Map showing relationship of geology to elevations, knickpoints and stream valley irregularities along Cannonball River land surface profile A. (From Clayton and others, 1980a) (See Figure 2B for quadrangle locations.)

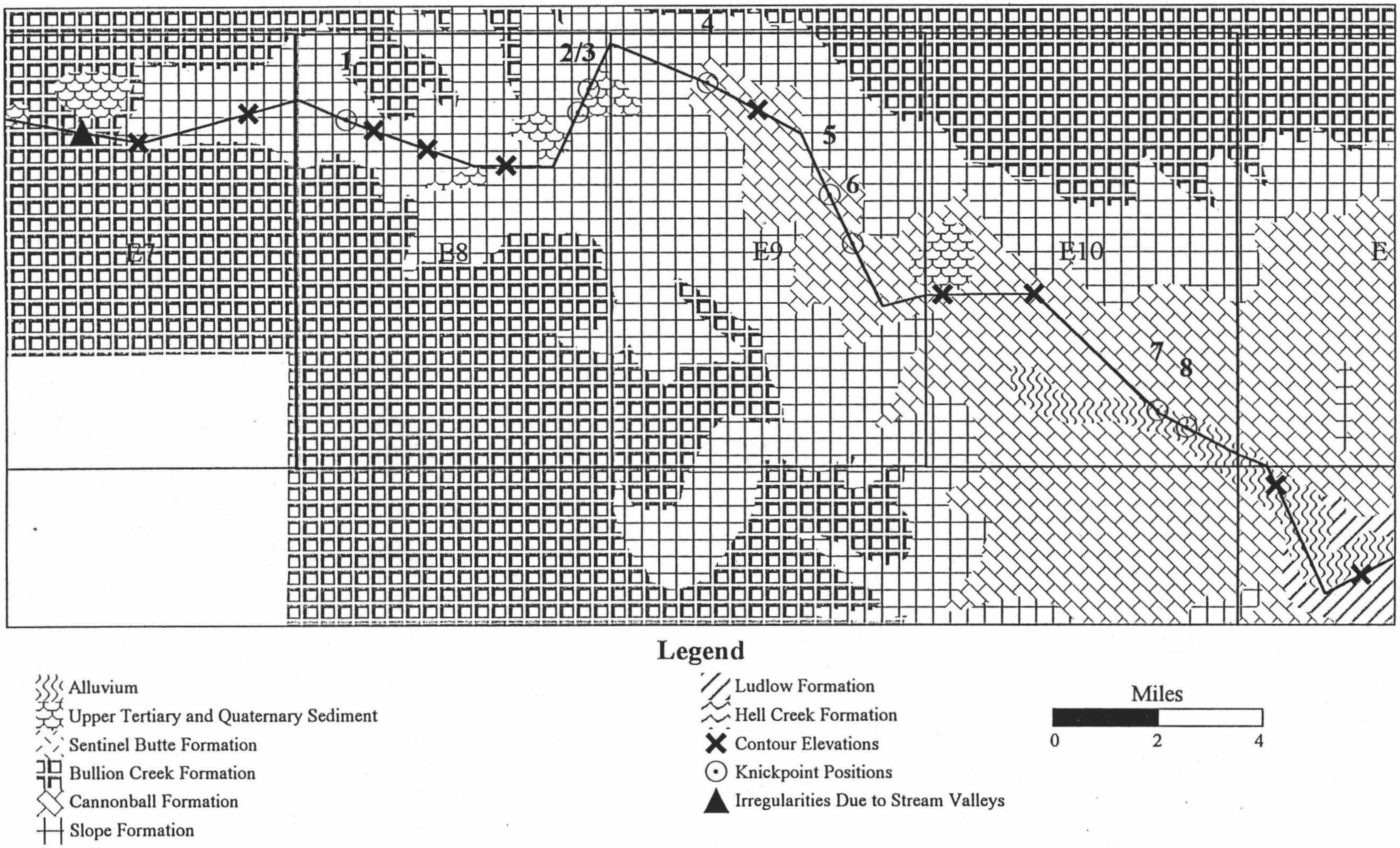


Figure 6. continued.

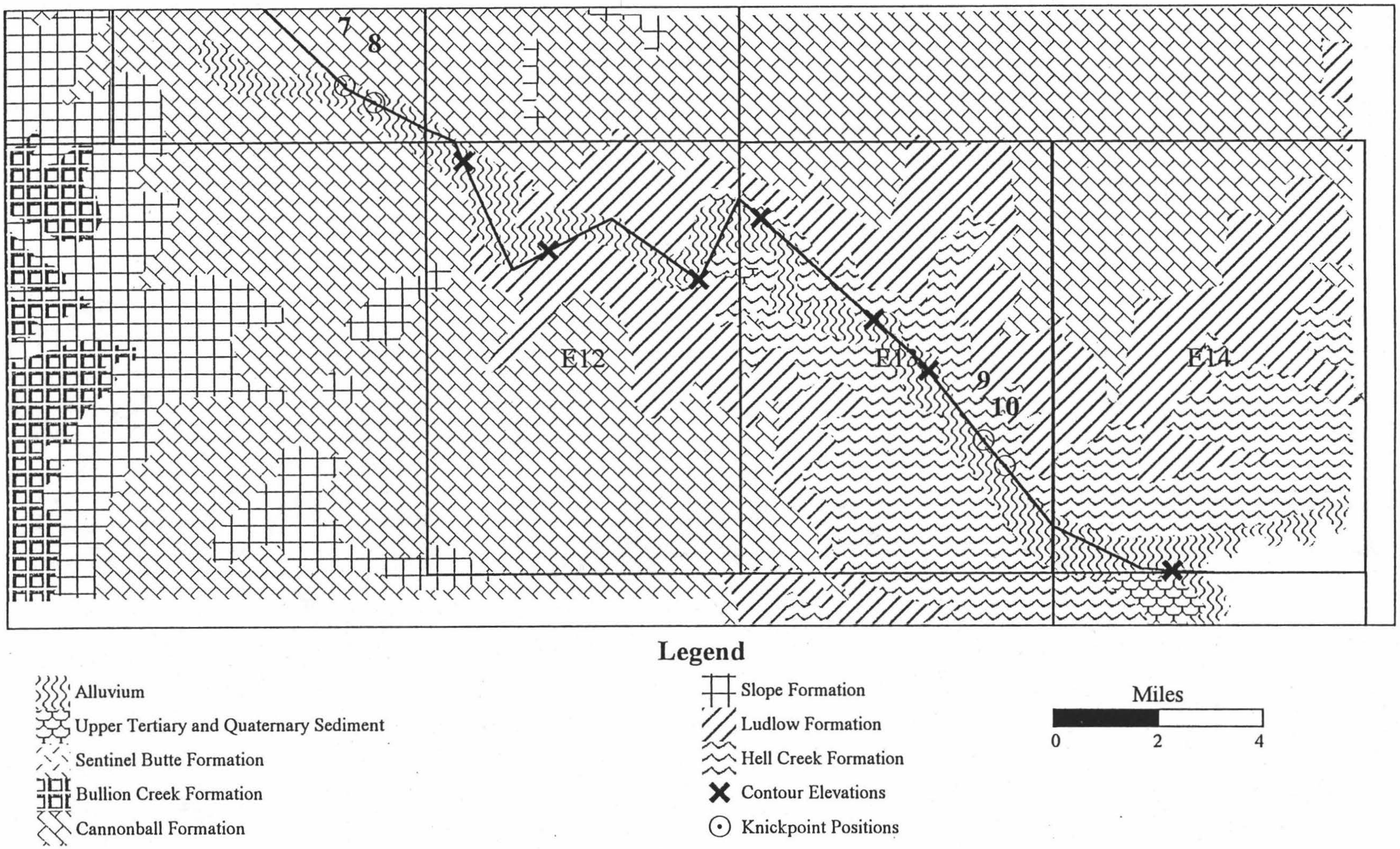


Figure 6. continued.

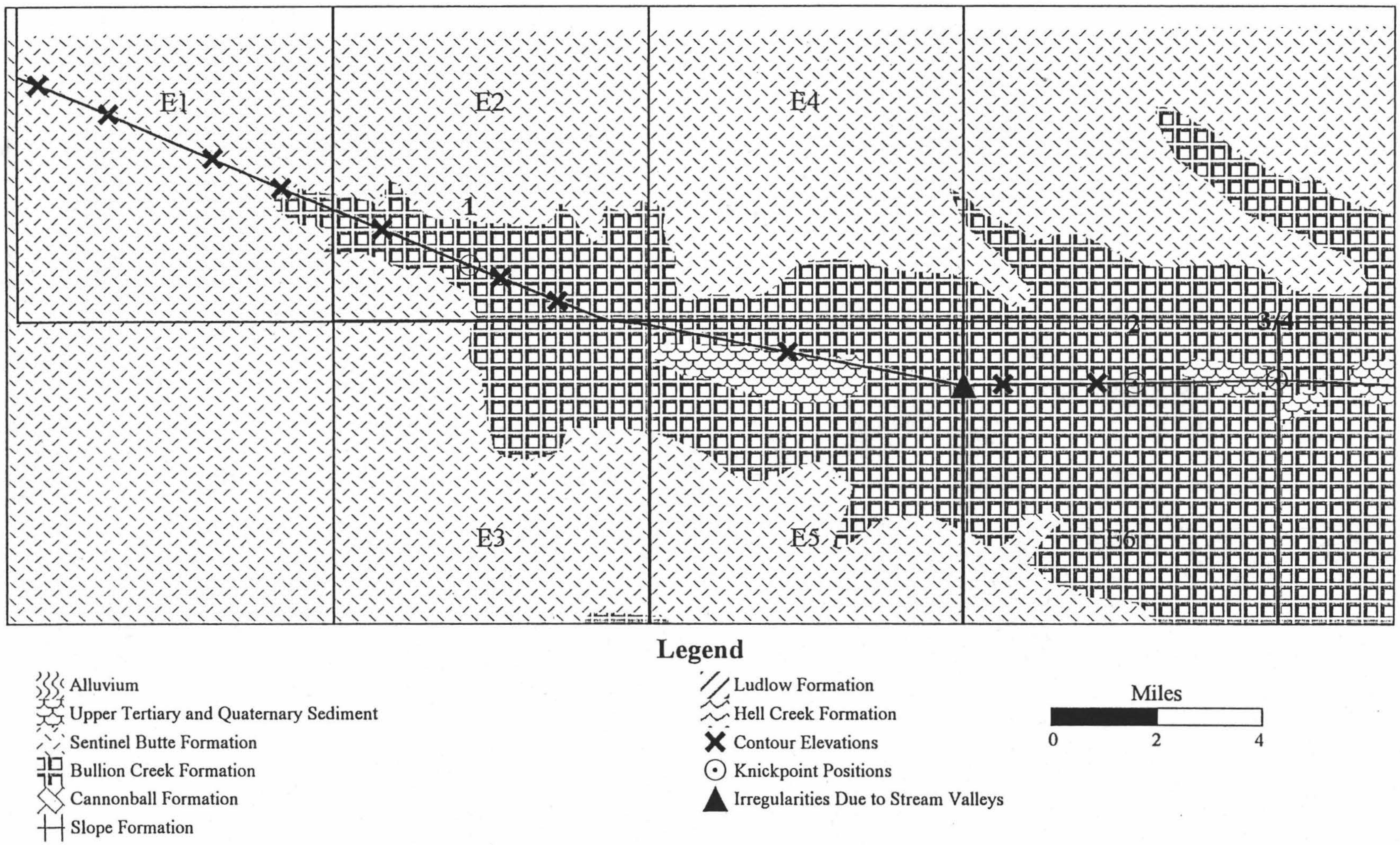


Figure 7. Map showing relationship of geology to elevations, knickpoints, and stream valley irregularities along Cannonball River land surface profile B. (From Clayton and others, 1980a) (See Figure 2B for quadrangle locations.)

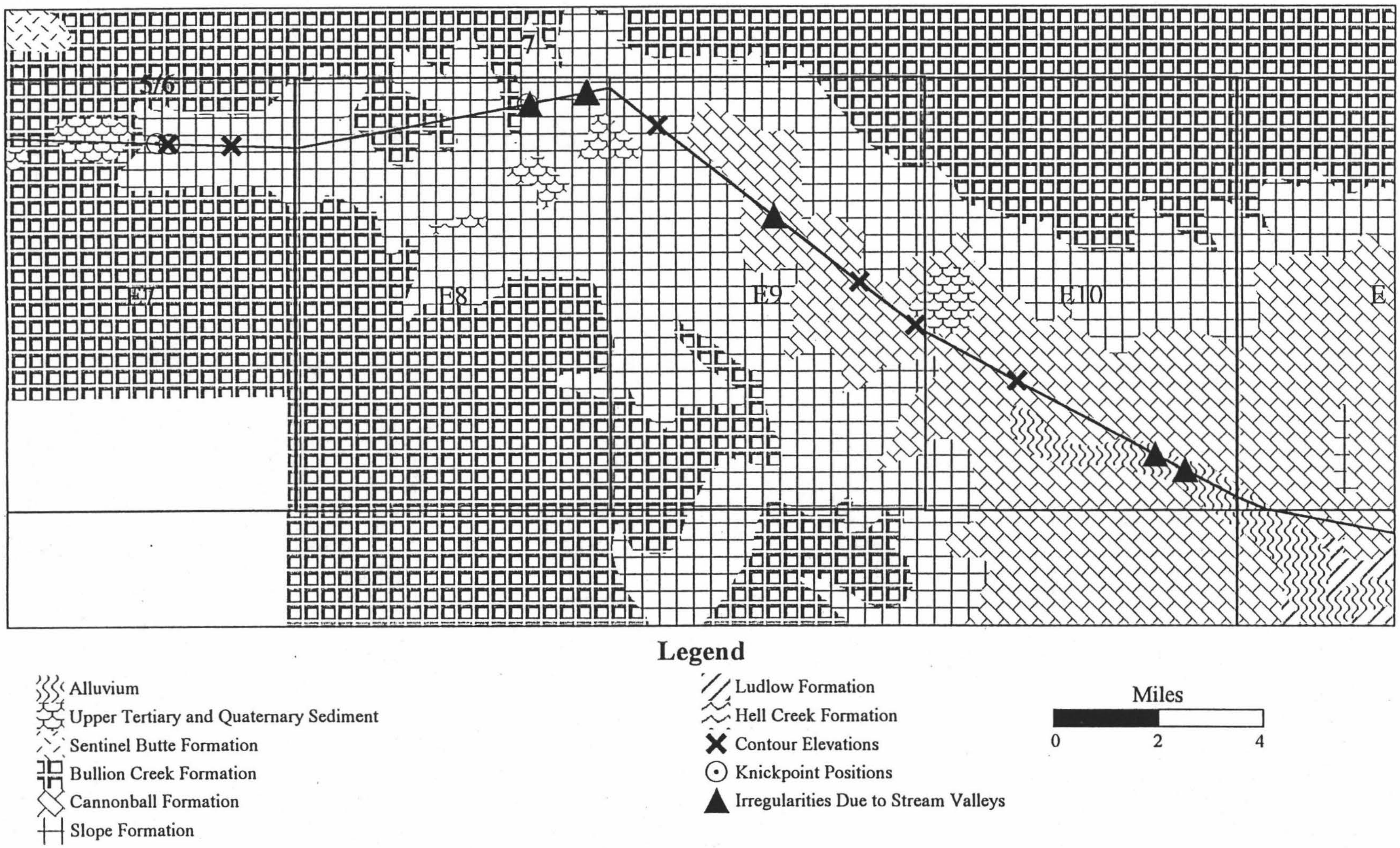


Figure 7. continued.

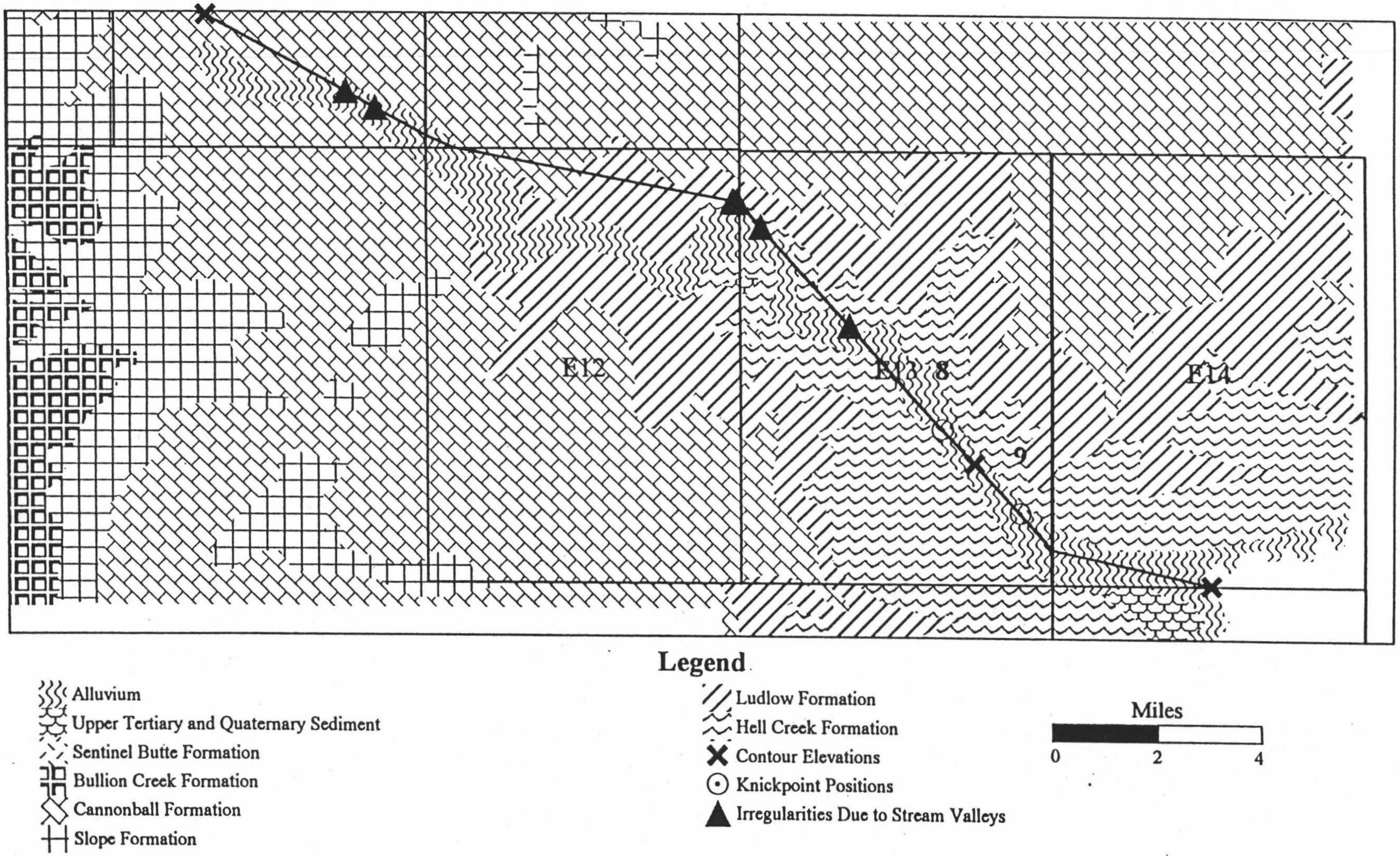


Figure 7. continued.

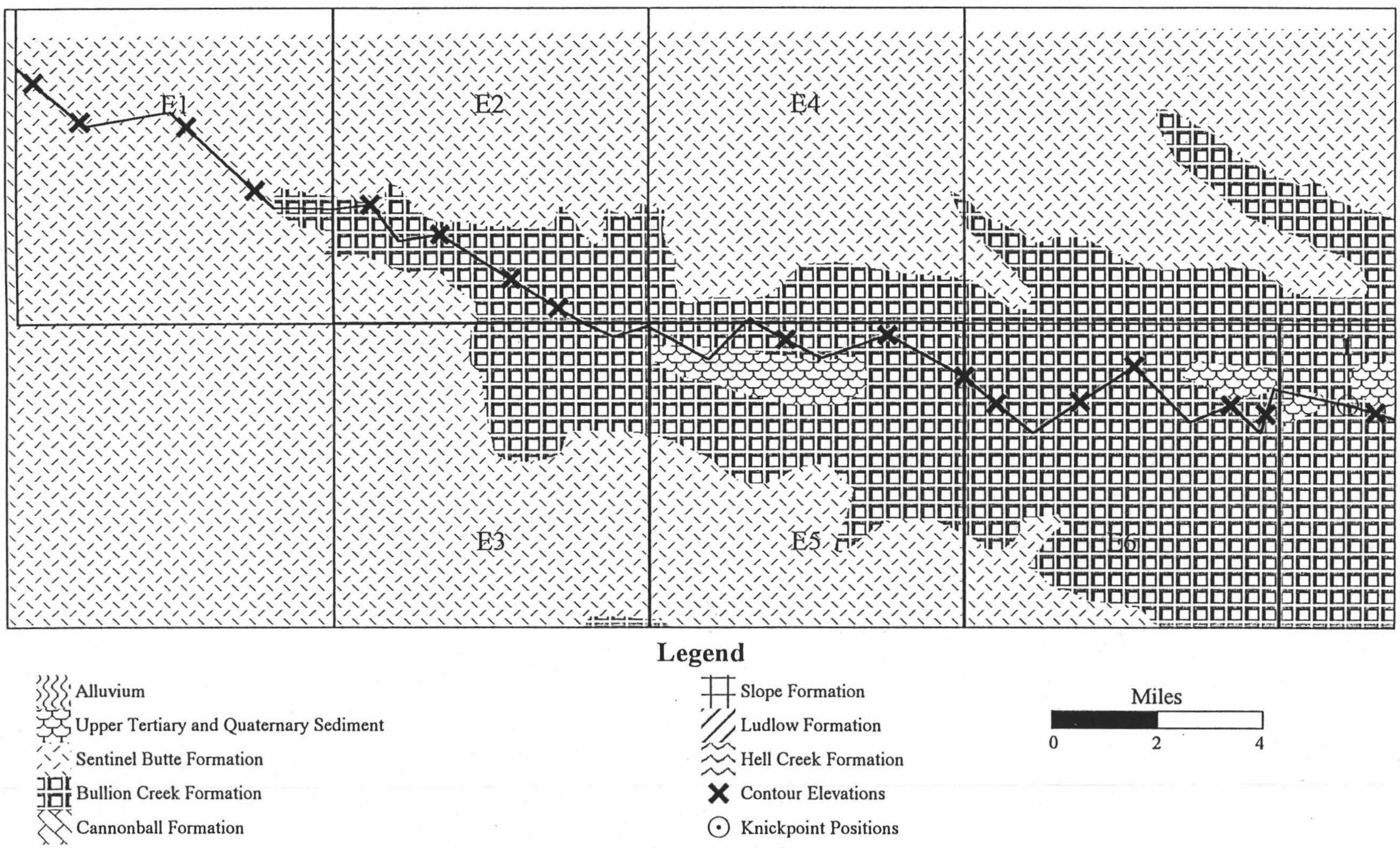


Figure 8. Map showing relationship of geology to elevations, knickpoints, and stream valley irregularities along Cannonball River land surface profile C. (From Clayton and others, 1980a) (See Figure 2B for quadrangle locations.)

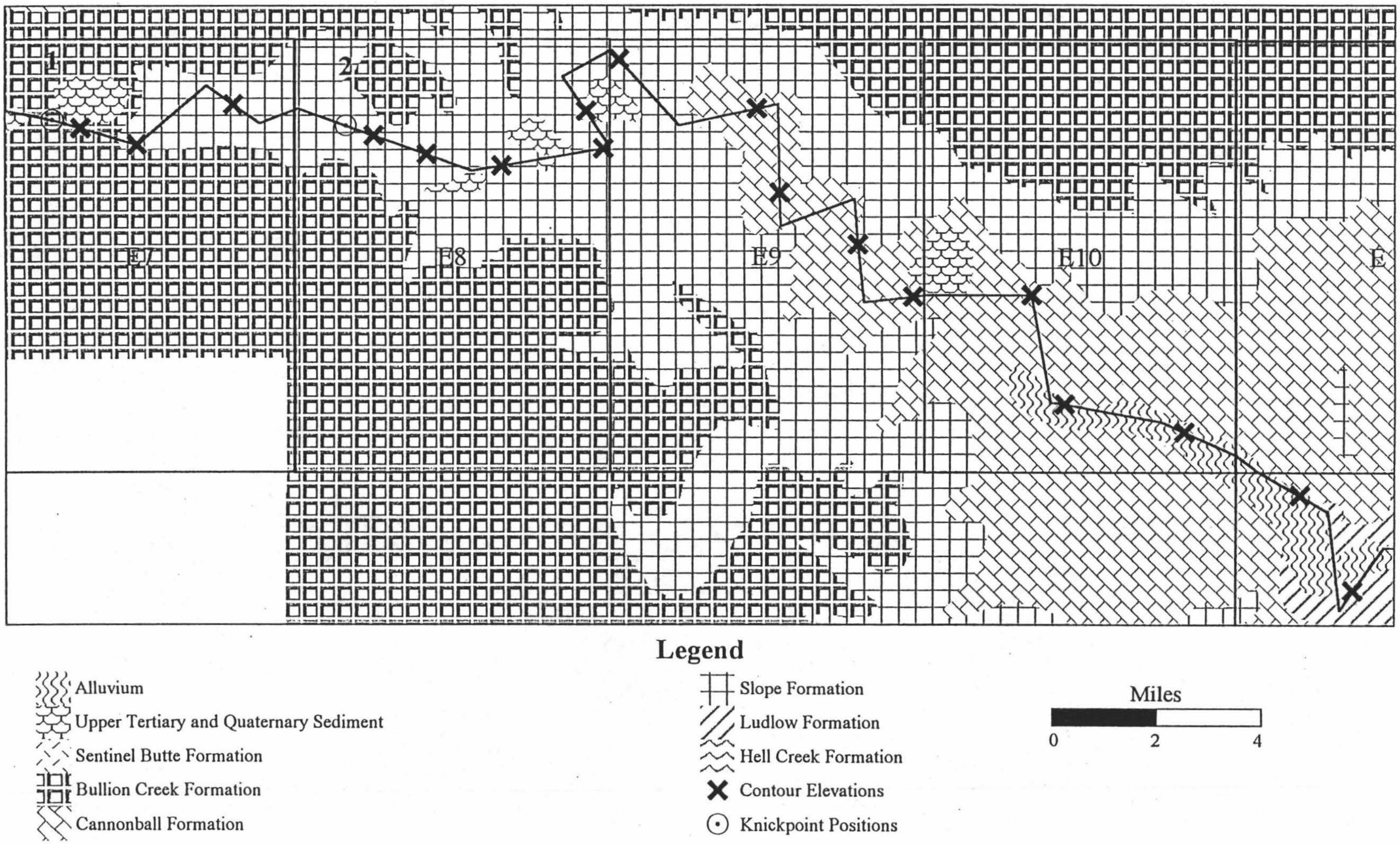
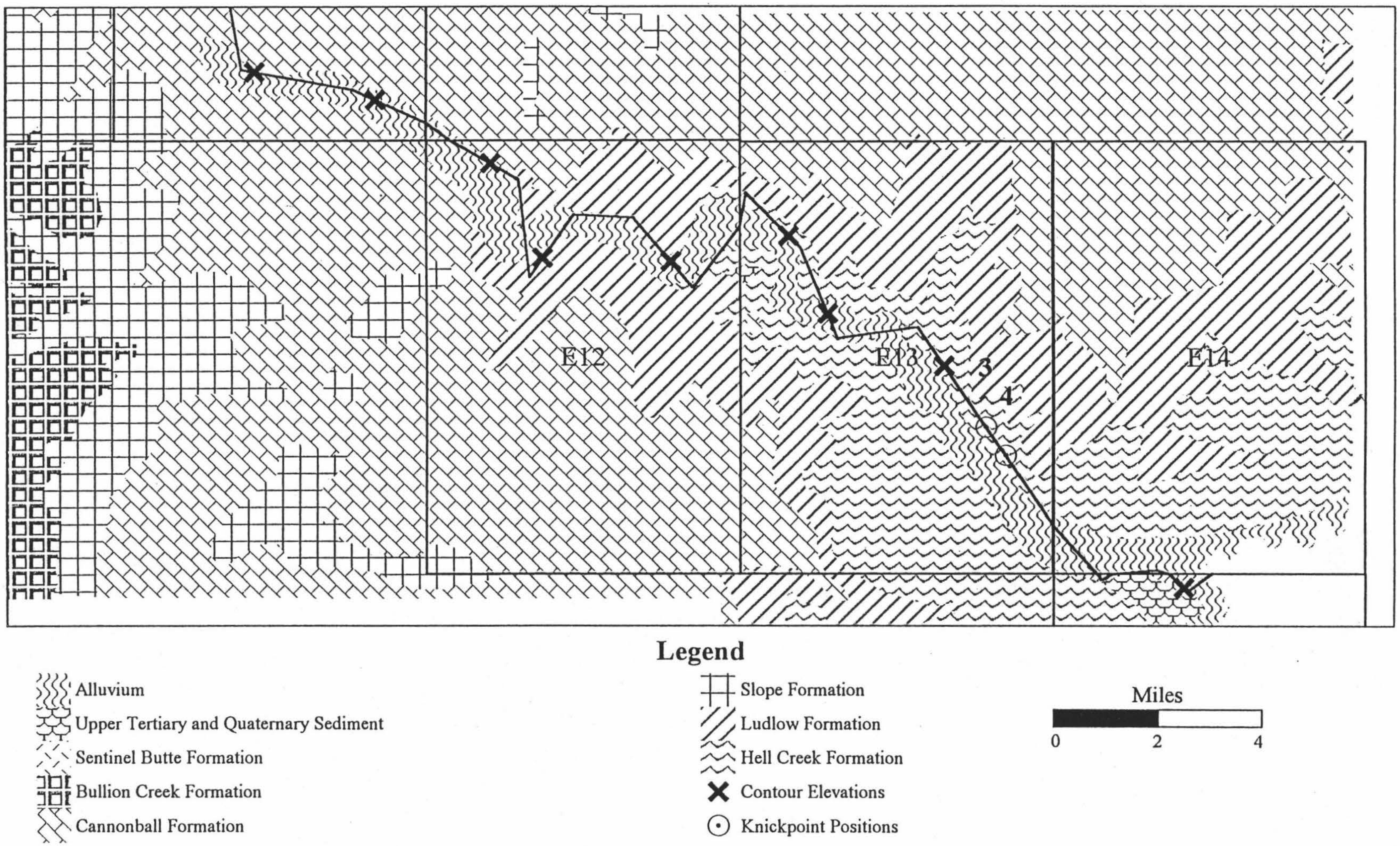


Figure 8. continued.



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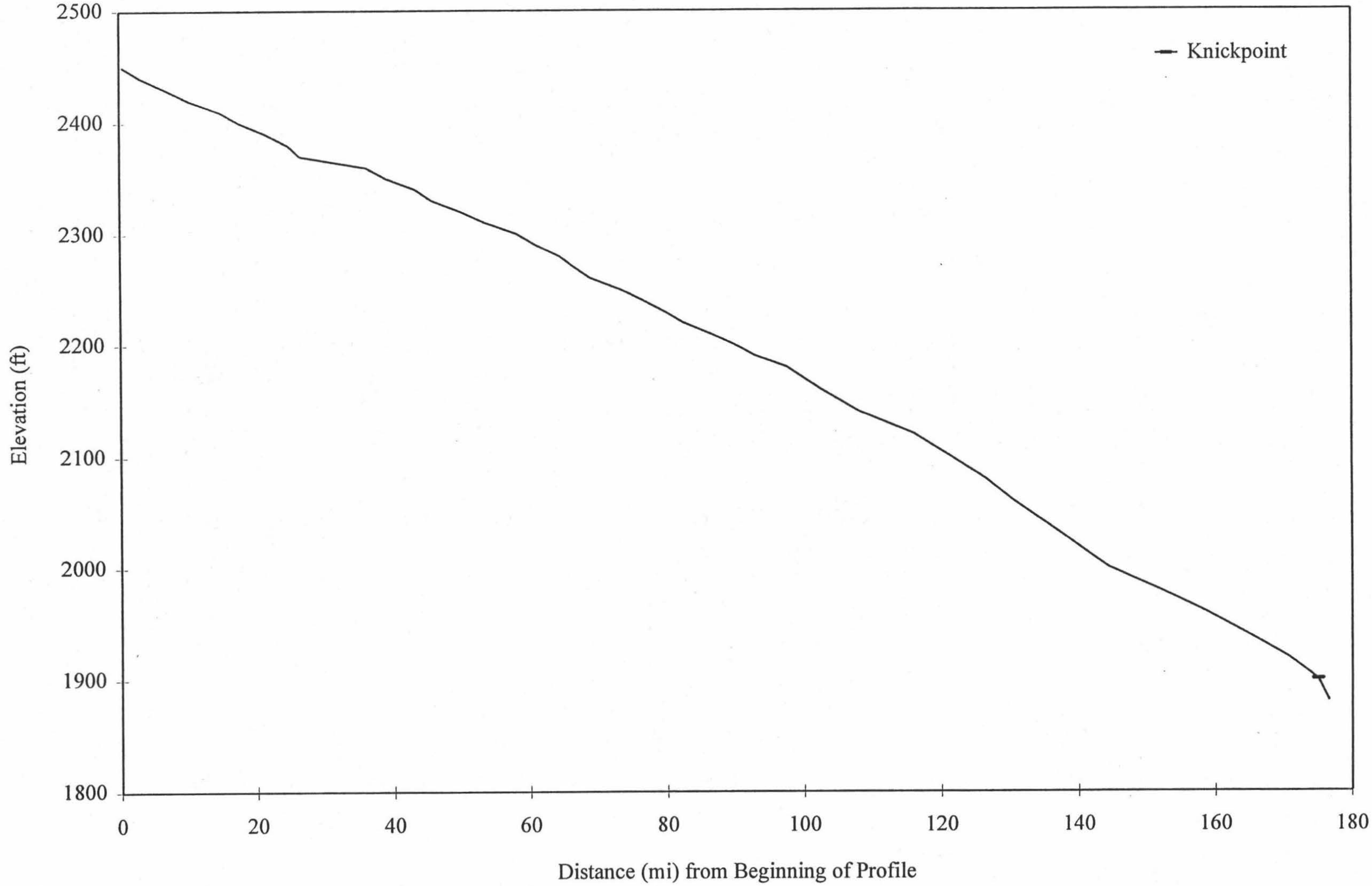


Figure 9. Cannonball River profile showing identified knickpoint. (See Figure 5 for knickpoint location.)

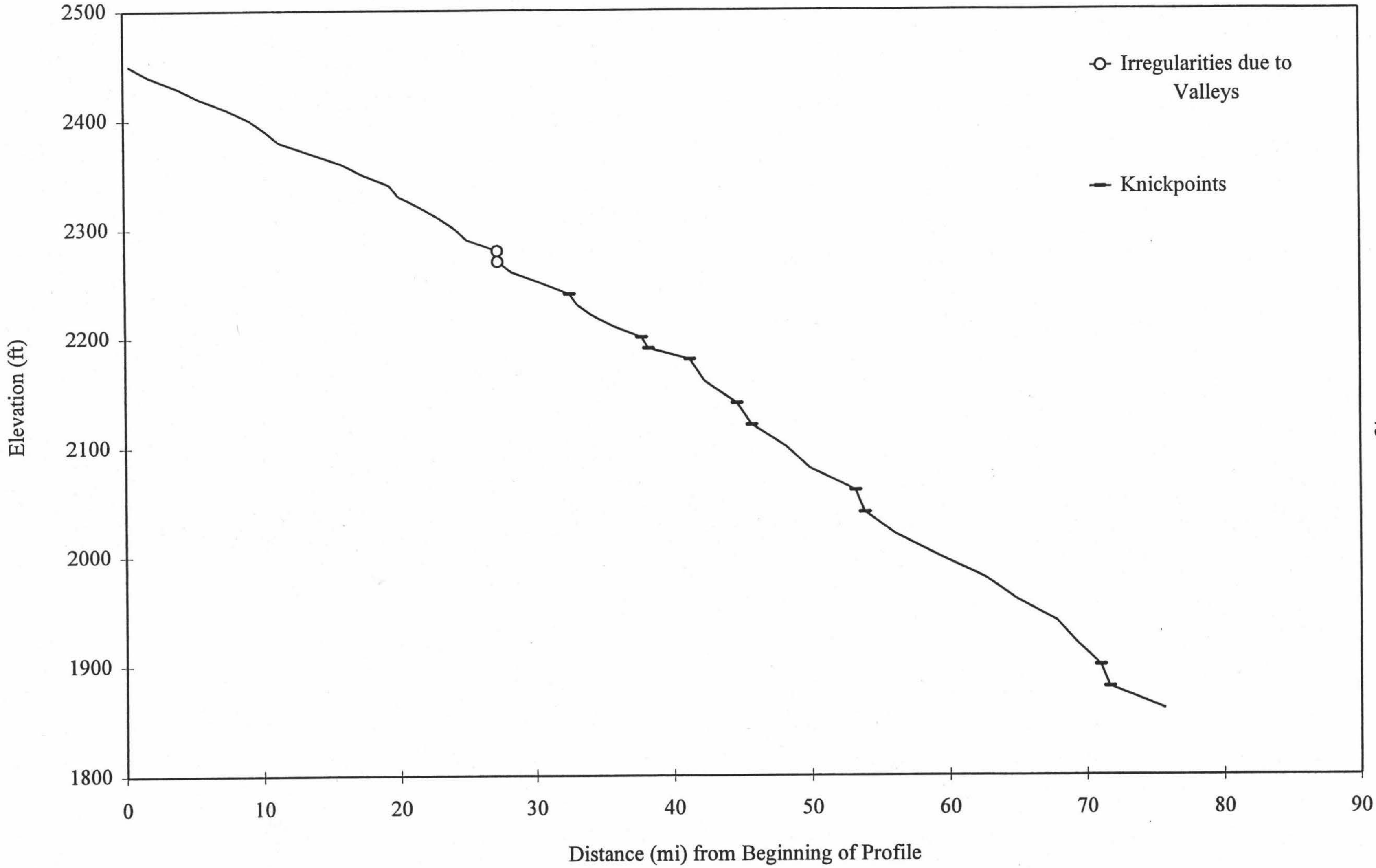


Figure 10. Cannonball River land surface profile A. (See Figure 6 for valley irregularity and knickpoint locations.)

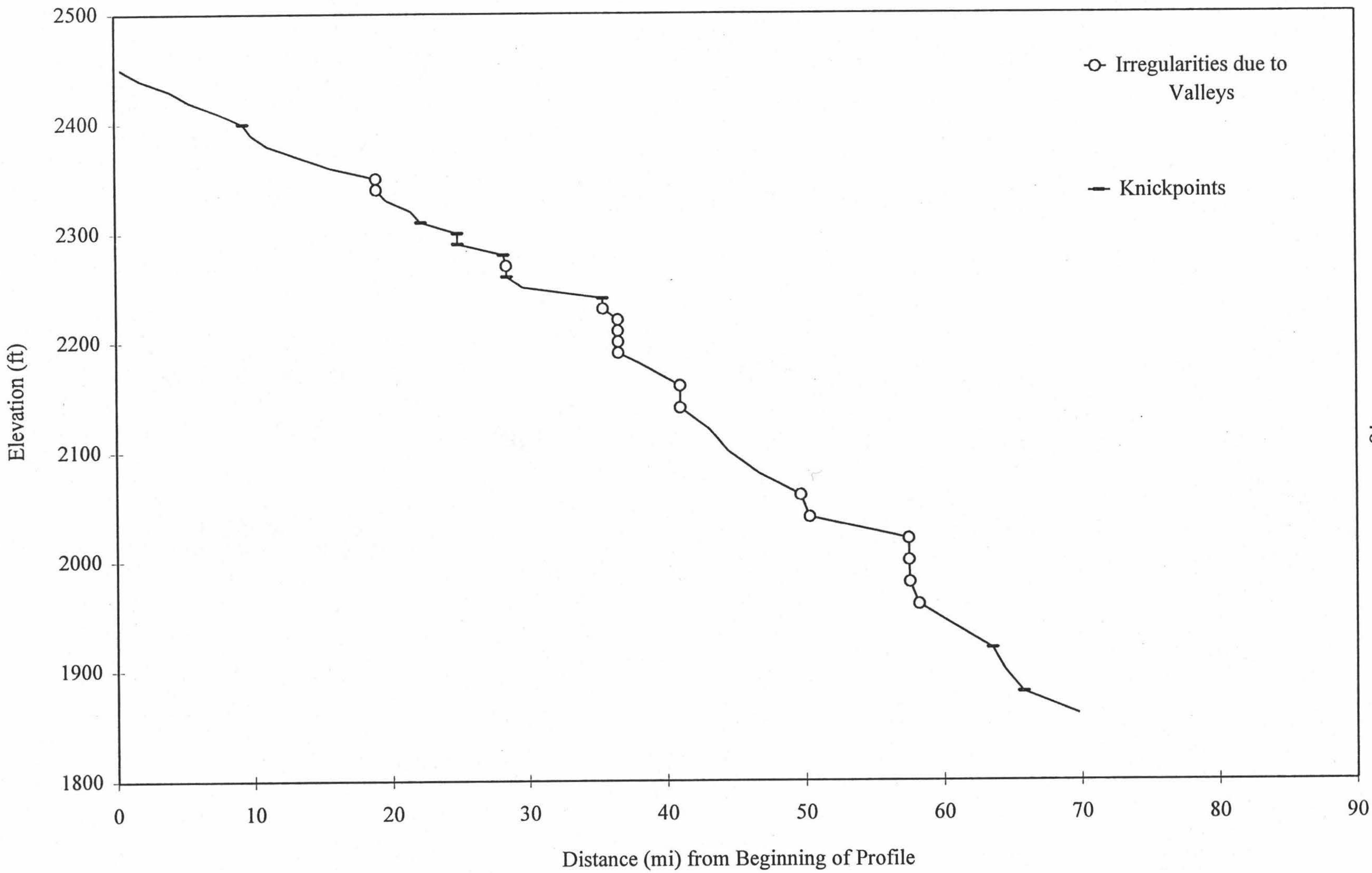


Figure 11. Cannonball River land surface profile B. (See Figure 7 for valley irregularity and knickpoint locations.)

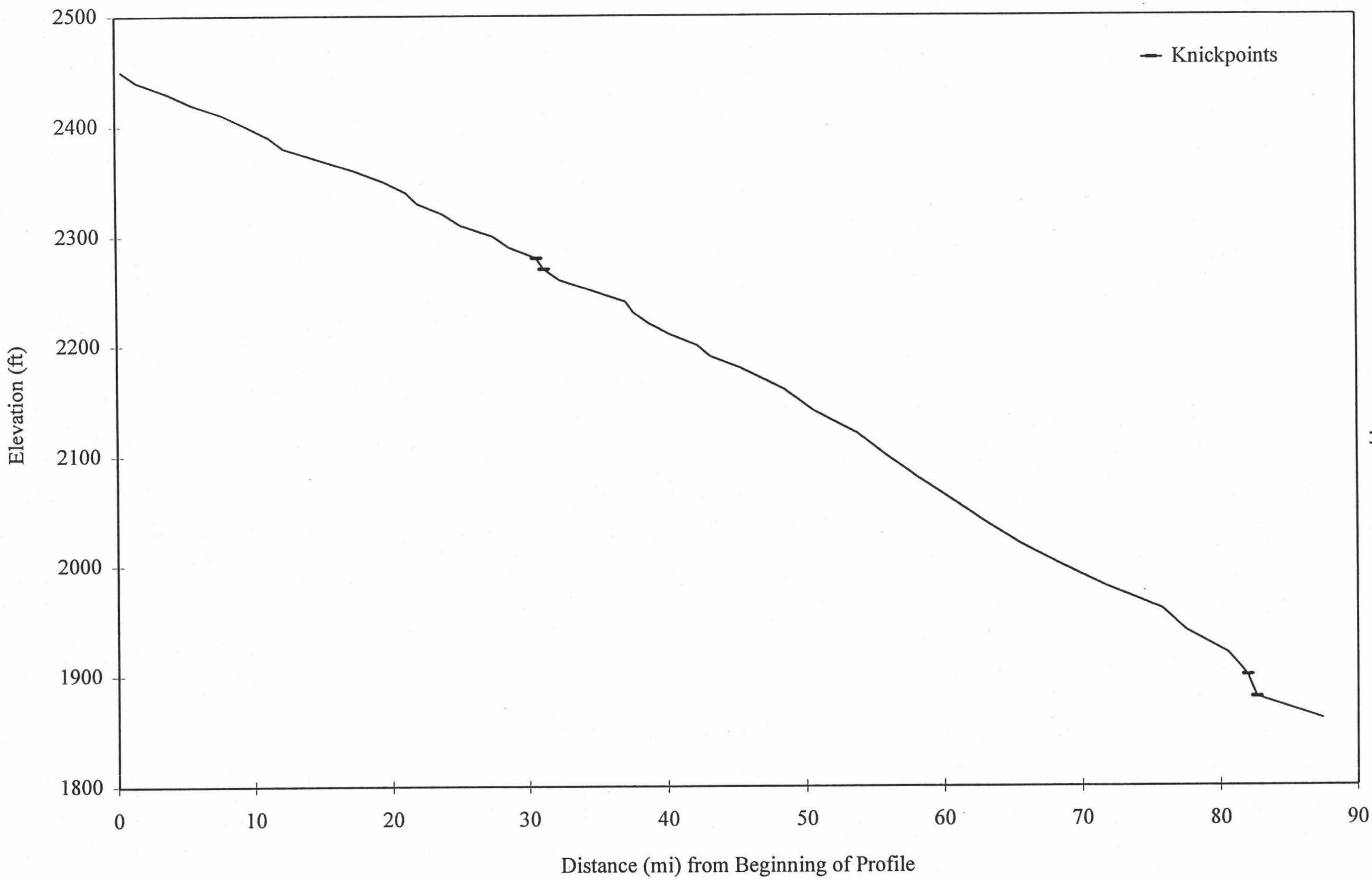


Figure 12. Cannonball River land surface profile C. (See Figure 8 for knickpoint locations.)

The equation of a trendline for the reach of land surface profile A above 2200 ft has been calculated (Table 1). Based on this, the difference between the trendline value and the actual elevation value at the end of the profile was determined to be 117.4 ft. The equation for a trendline was also determined for the reach of land surface profile C above 2200 ft (Table 1). The difference between the elevation of the trendline and the actual elevation of the profile at its end is 115.96 ft.

A comparison also was made to see if knickpoint elevations were similar between profiles (Table 2). Knickpoints at elevations of 2240 ft and 1880 ft were common to all three land surface profiles. A knickpoint at an elevation of 1900 ft was common to the Cannonball River profile as well as land surface profiles A and C. Land surface profiles B and C both have knickpoints at an elevation of 2280 ft.

All four profiles from this area have been plotted together (Figure 13). This graph shows the land surface profiles to be steeper than the river profile. Only land surface profiles were plotted on another graph in order for easier comparison (Figure 14). This plot of only land surface profiles shows land surface profile C to have a more gentle slope than land surface profiles A and B. Land surface profile B is generally steeper than land surface profile B although the two cross in several places.

Bad River

Profiles were constructed for an area along and adjacent to the Bad River between the elevations of 2140 and 1420 ft. (Figures 15-18). These profiles show a linear to

Table 1. Differences between actual elevations and those predicted from trendline equations at the end of selected profiles.

Profile	Trendline Equation	Beginning - Ending Elevations of Trendline (ft)	Length of Profile (mi)(x)	Predicted Profile Ending Elevation (ft) (y)	Actual Profile Ending Elevation (ft)	Difference (ft)
Cannon A	$y=2462.9e^{(-.0029x)}$	2450-2200	75.65	1977.74	1860	117.74
Cannon C	$y=2459e^{(-.0025x)}$	2450-2200	87.48	1975.96	1860	115.96
Bad River	$y=2126.1e^{(-.0027x)}$	2140-1820	150.81	1458.29	1430	28.29
Bad River A	$y=2129.9e^{(-.0056x)}$	2140-1820	69.8	1440.79	1430	10.79
White A	$y=2110.6e^{(-.0037x)}$	2100-1460	115.01	1379.11	1320	59.11
White B	$y=2083.4e^{(-.0041x)}$	2100-1540	103.37	1363.68	1320	43.68
Keya A	$y=2382.2e^{(-.0044x)}$	2370-2160	76.447	1701.75	1640	61.75
Keya C	$y=2363.7e^{(-.004x)}$	2370-2090	77.44	1734.06	1640	94.06
Ponca A	$y=2199.1e^{(-.0054x)}$	2370-1970	43.057	1742.88	1650	92.88
Ponca C	$y=2203.1e^{(-.0053x)}$	2370-1880	45.944	1726.96	1650	76.96

A= Land surface profile A
B= Land surface profile B
C= Land surface profile C

Table2. Knickpoints common, to multiple profiles in a river area, and their elevations

Cannonball River						
ABC	RAC	BC				
2240	1900	2280				
1880						
Bad River						
ABC	AB	AC				
2120	1930	1880				
1980	1890	1860				
1970	1770	1820				
1940	1760	1800				
		1720				
		1710				
		1590				
		1530				
White River						
BC						
1850						
Keya Paha River						
RAB	RAC	RA	ABC	AB	AC	BC
2270	2290	2360	1870	2260	2300	1770
2230		2310		2250	2090	
		2280		1960	1740	
		2220		1780	1730	
		2050				
		2040				
Ponca Creek						
AC	AB	BC				
2040	1930	1880				
1790	1920	1760				
	1770					

R =River Profile
A=Land Surface Profile A
B=Land Surface Profile B
C=Land Surface Profile C

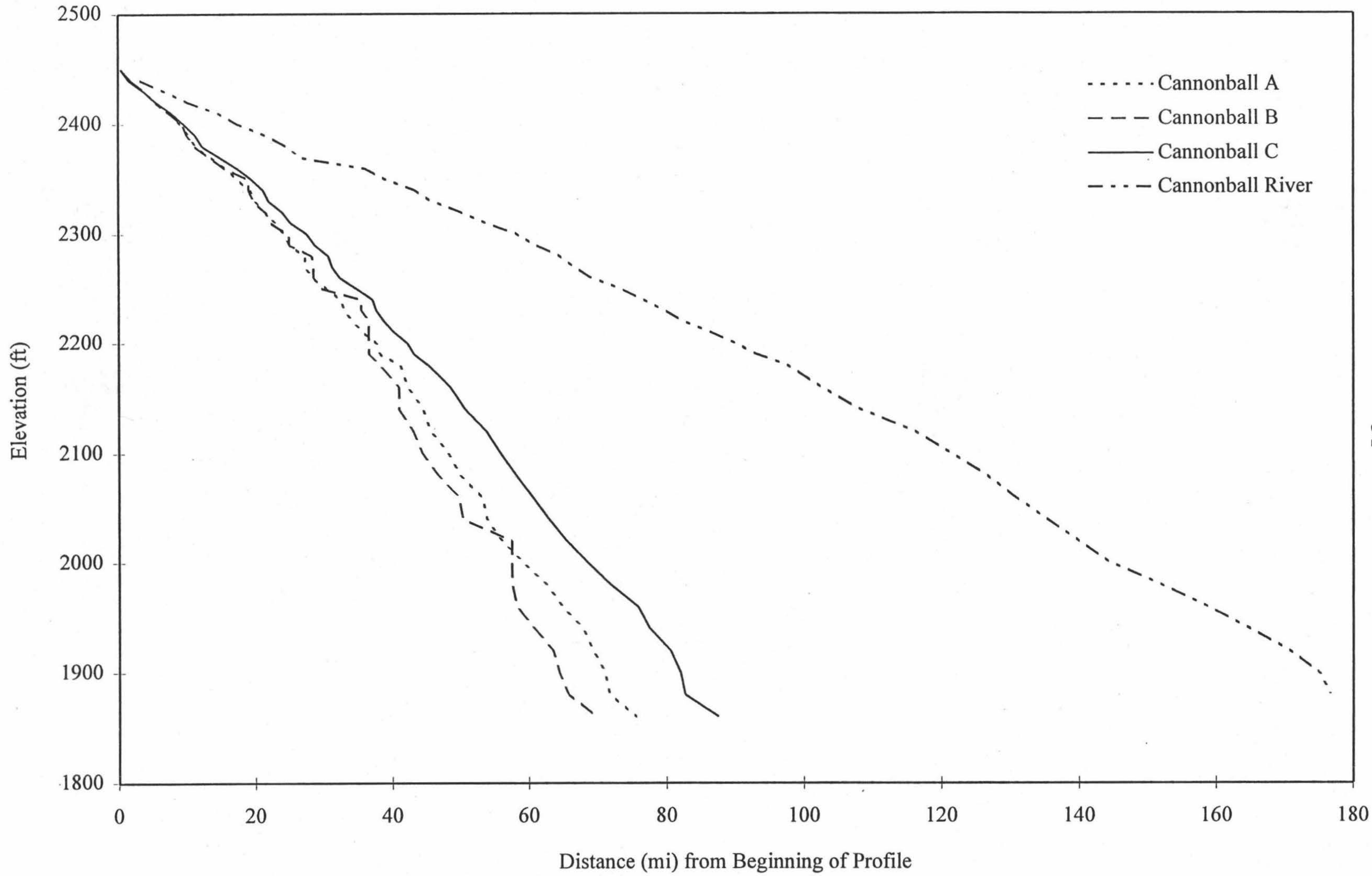


Figure 13. Cannonball River and land surface profiles.

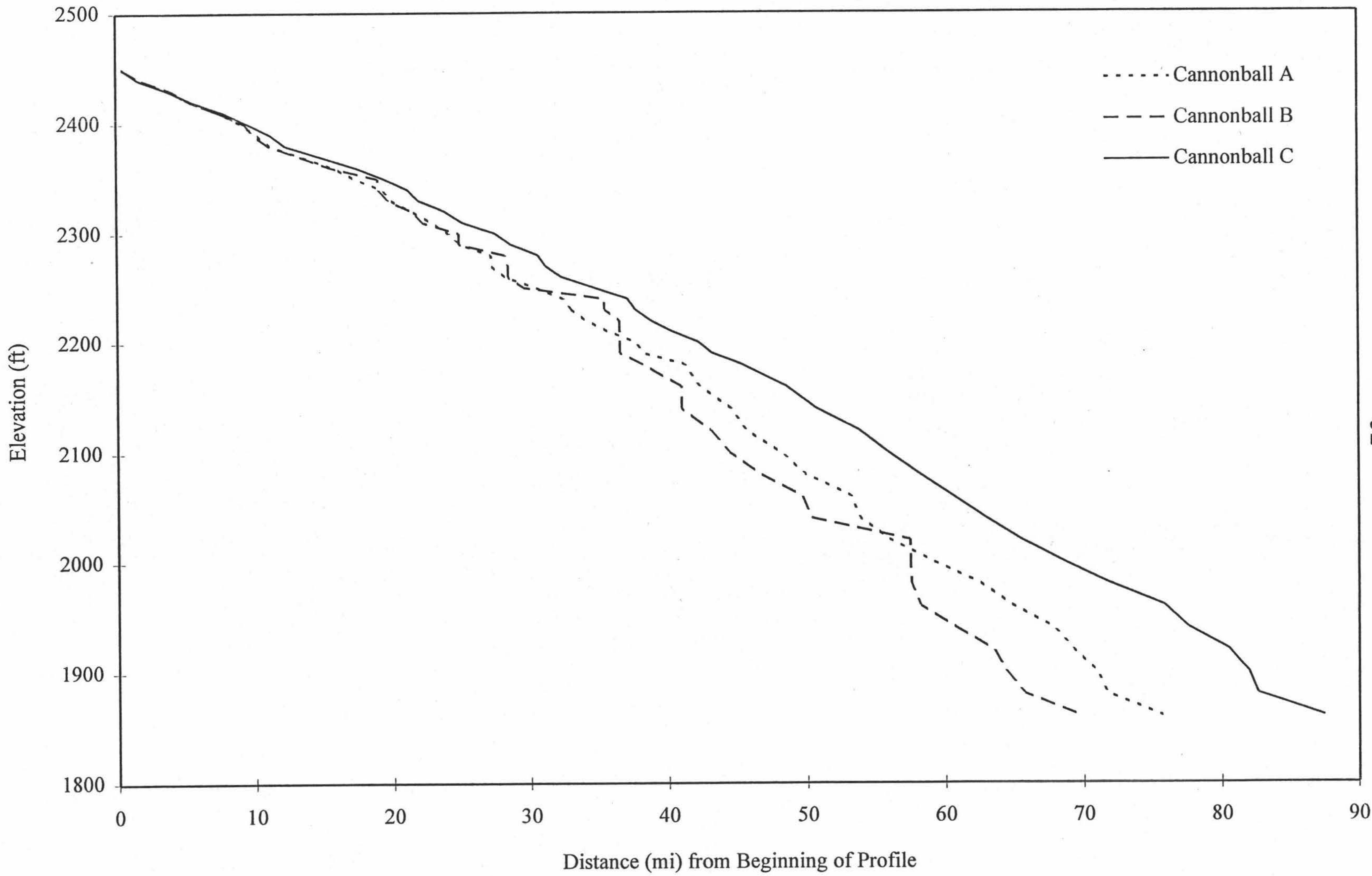


Figure 14. Cannonball River land surface profiles.

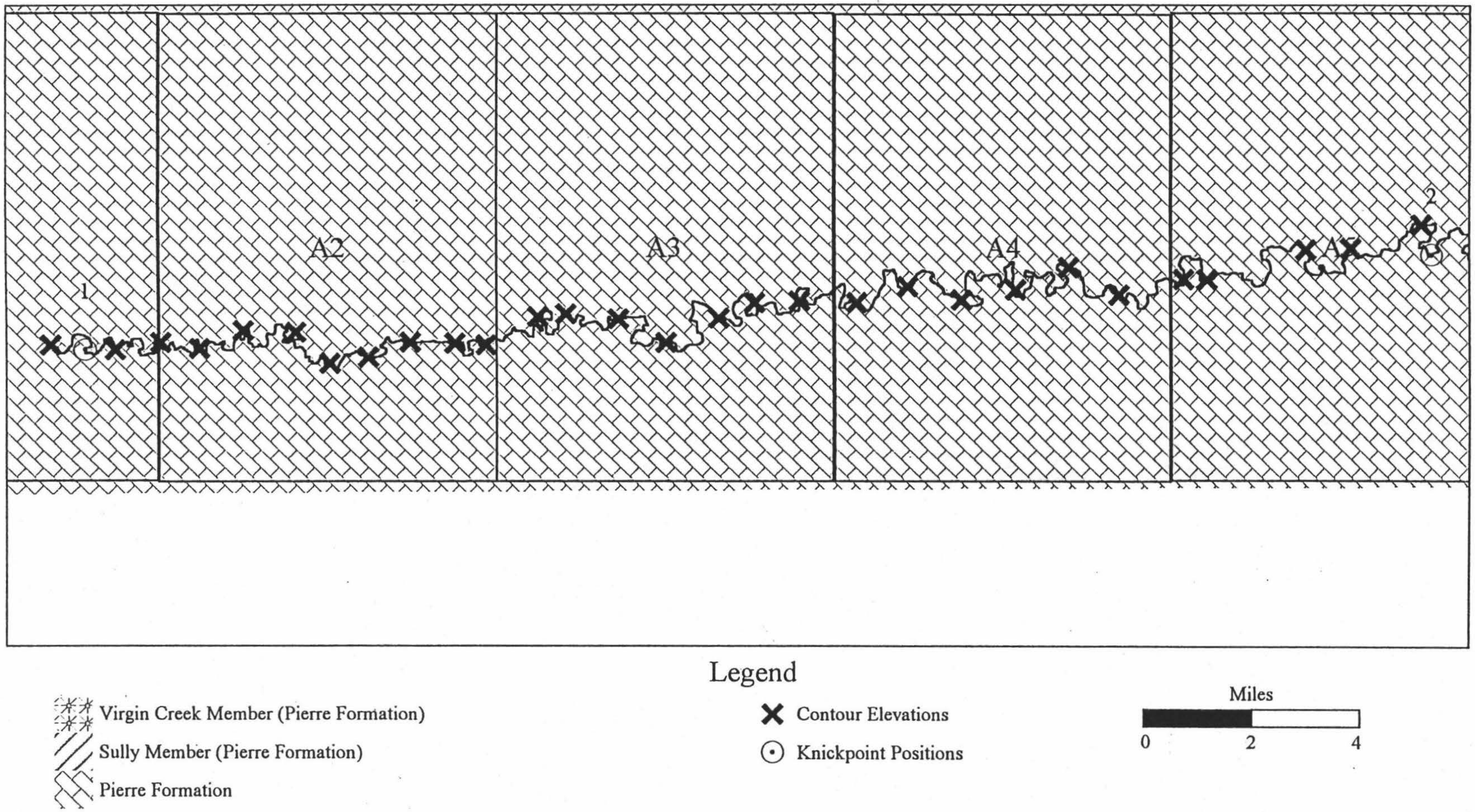
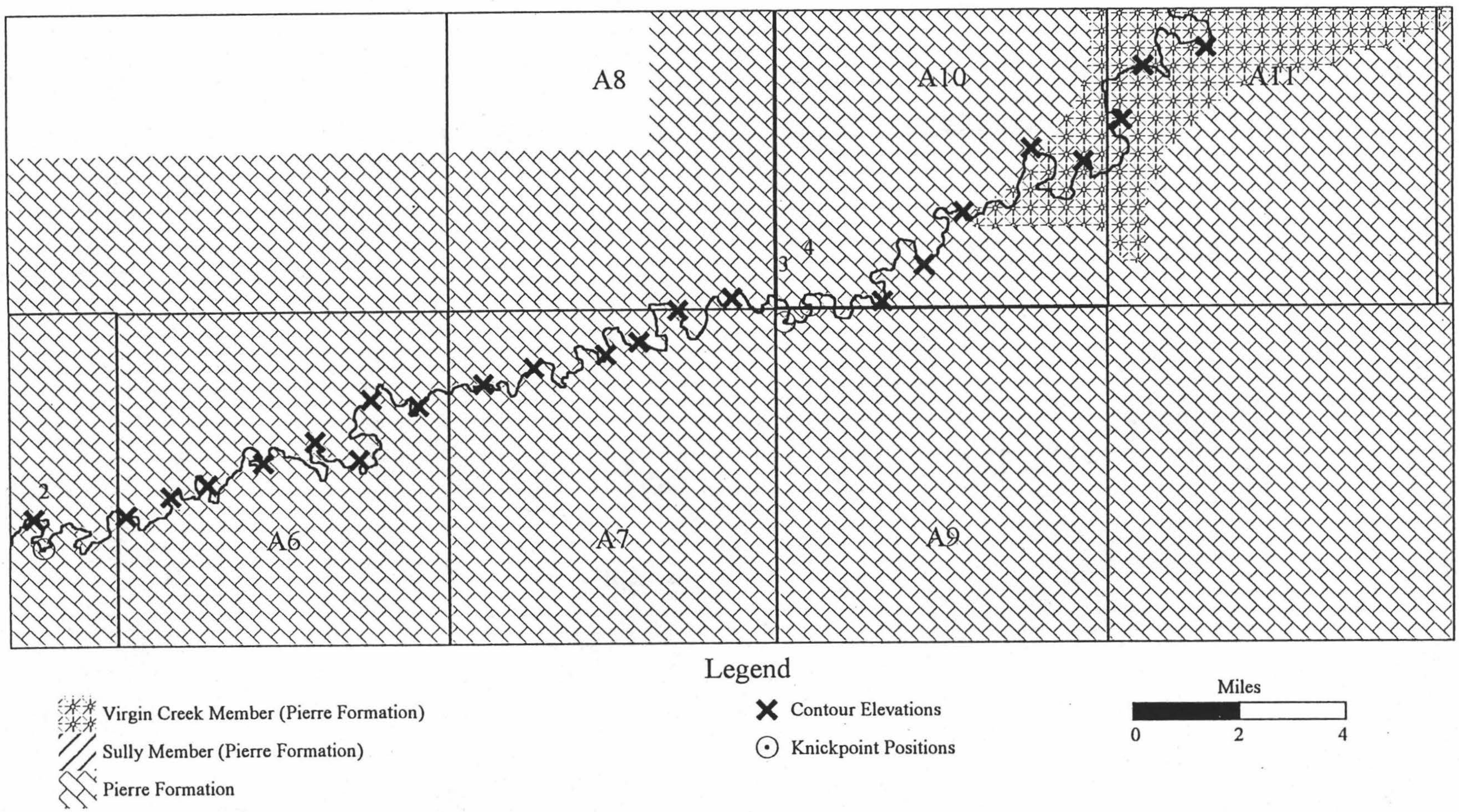


Figure 15 . Map showing relationship of geology to elevations and knickpoints along Bad River. (From Petsch, 1953) (See Figure 2A for quadrangle locations.)



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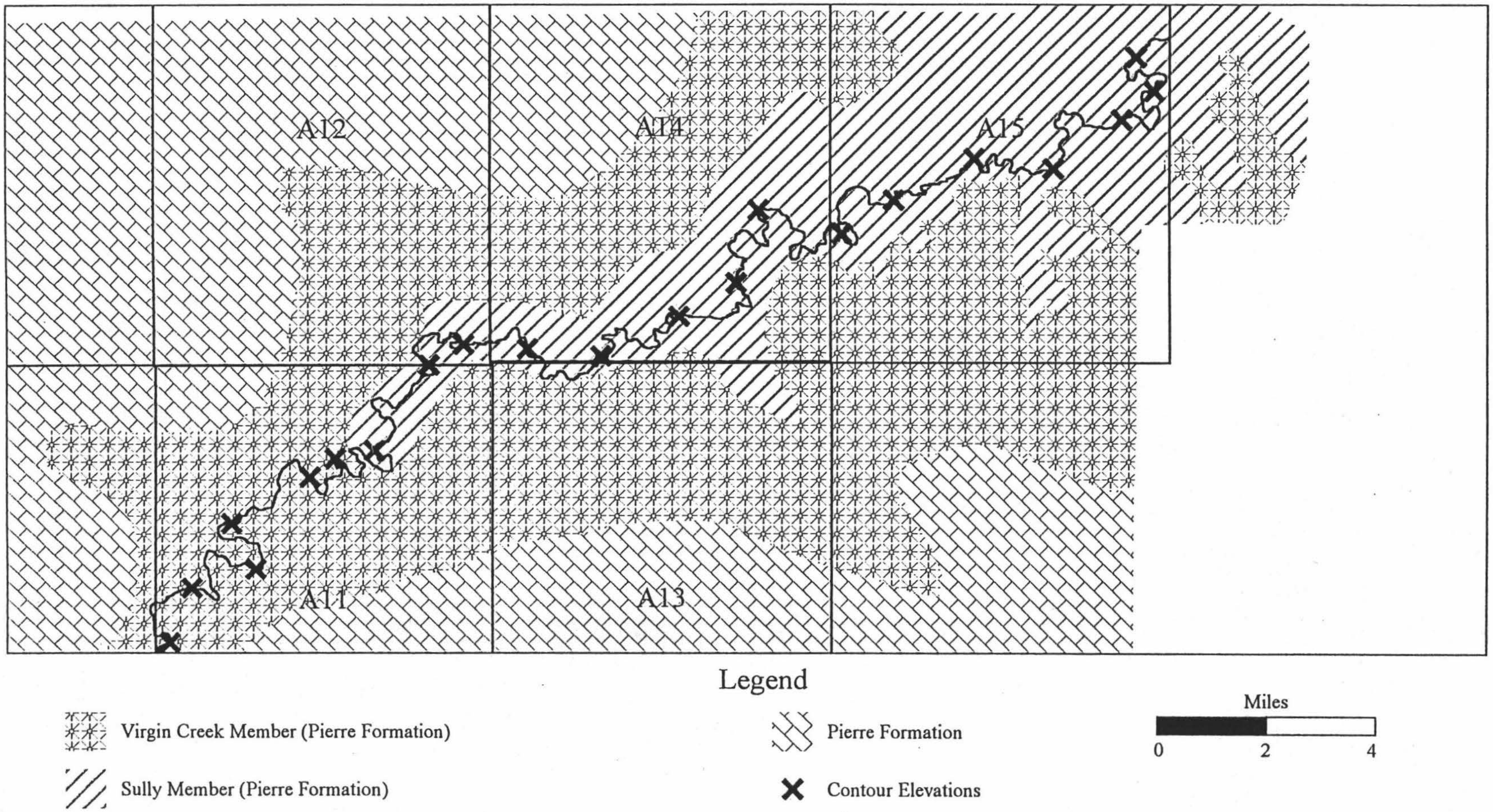

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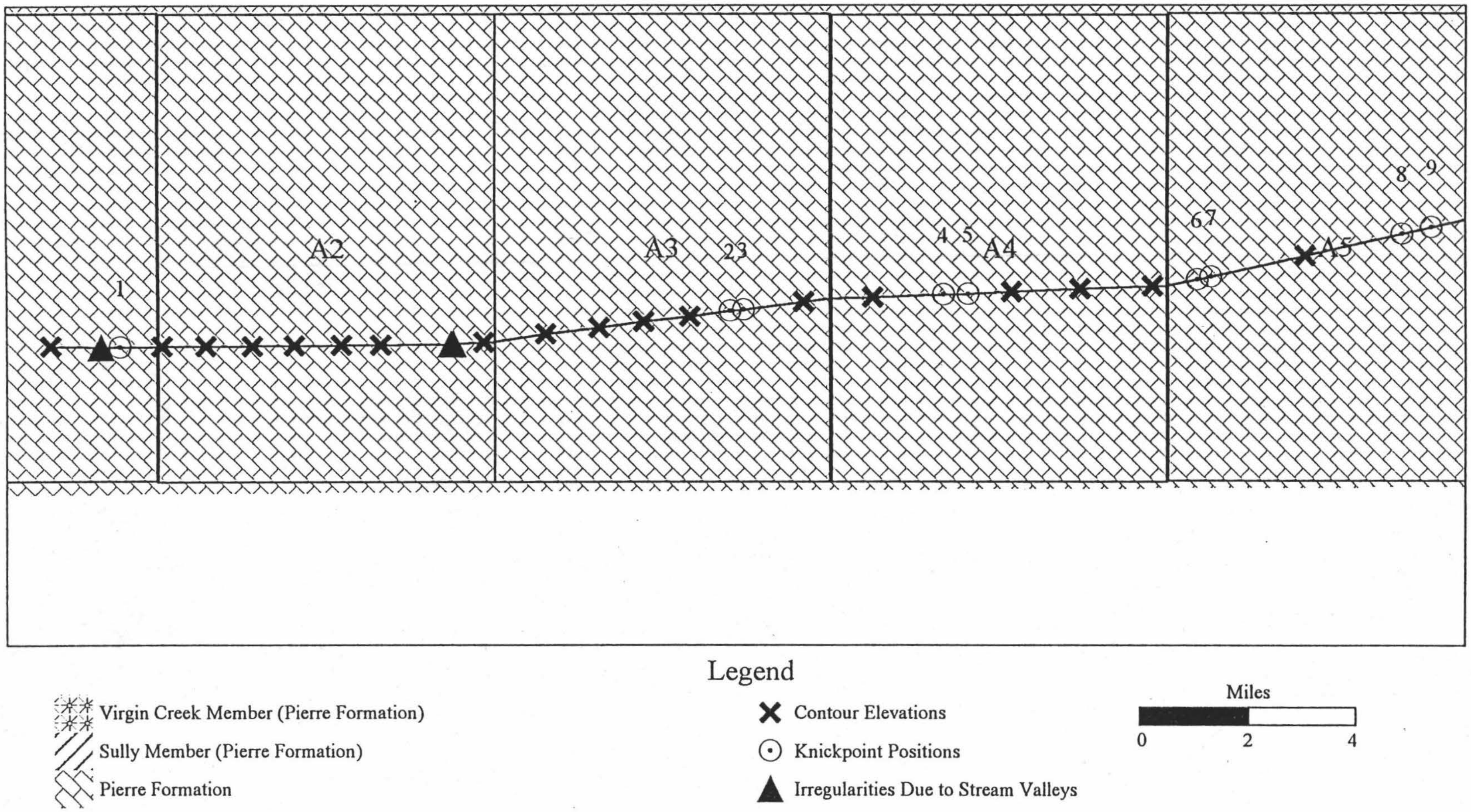
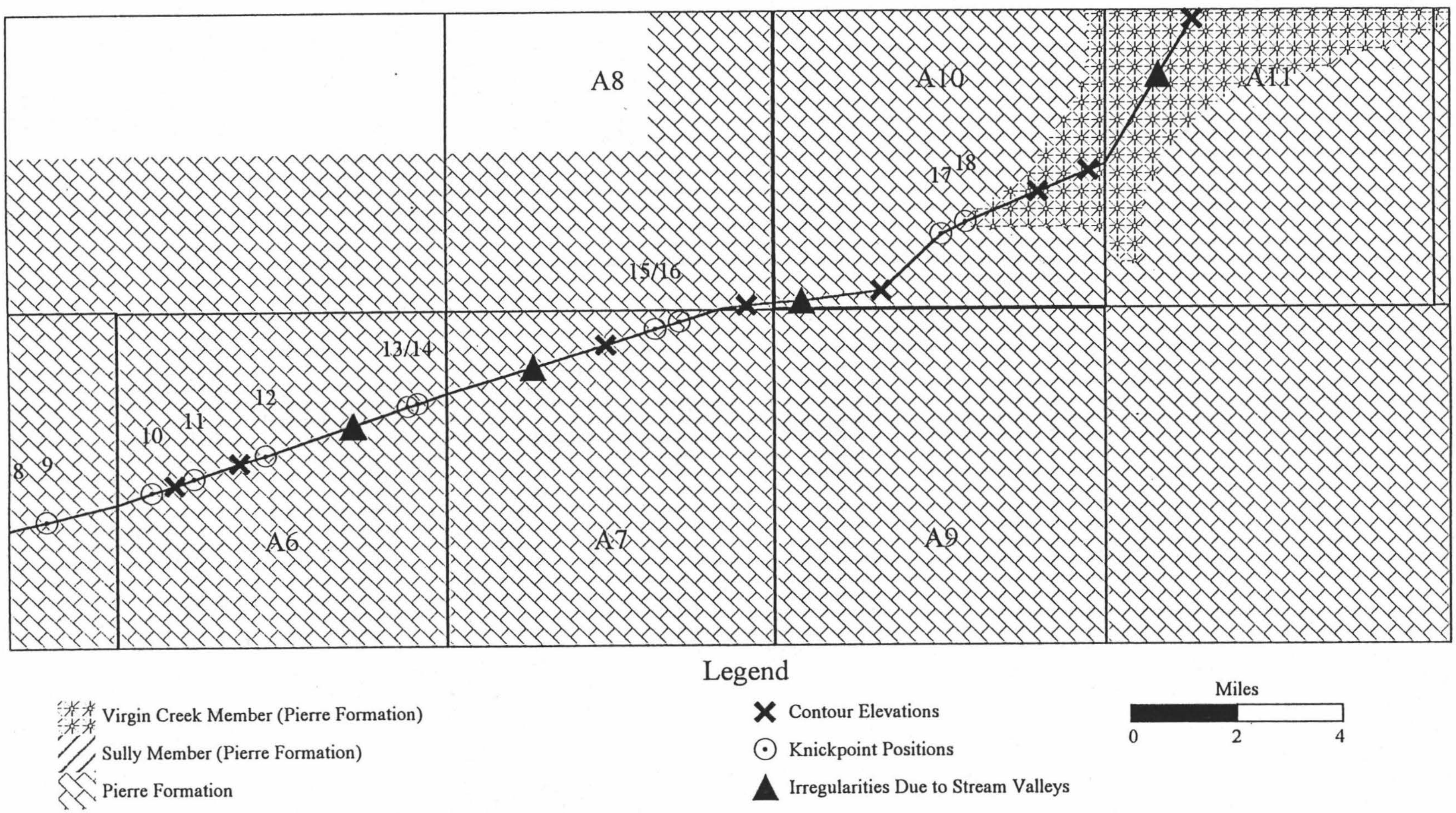


Figure 16. Map showing relationship of geology to elevations, knickpoints, and stream valley irregularities along Bad River land surface profile A. (From Petsch, 1953) (See Figure 2A for quadrangle locations.)



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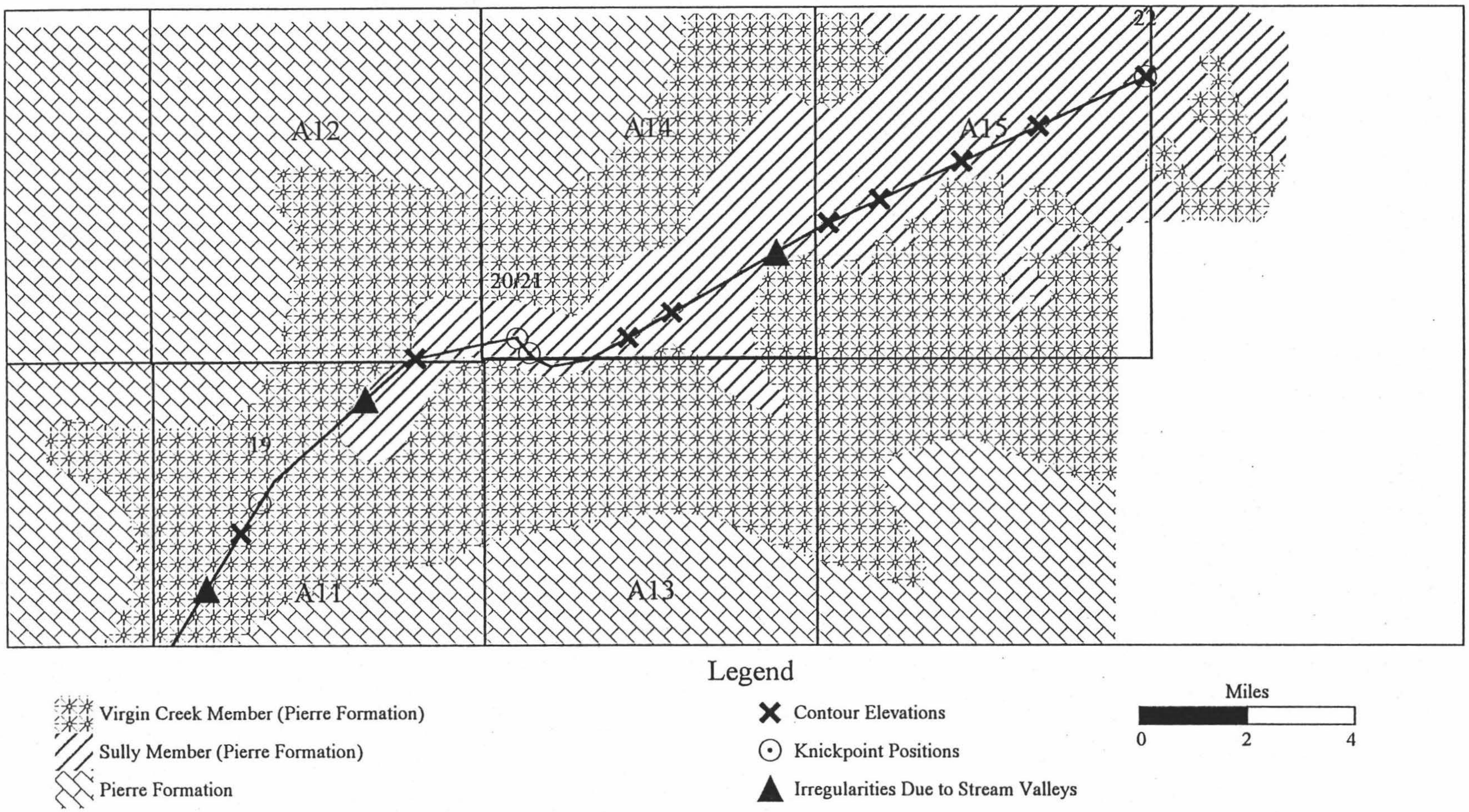

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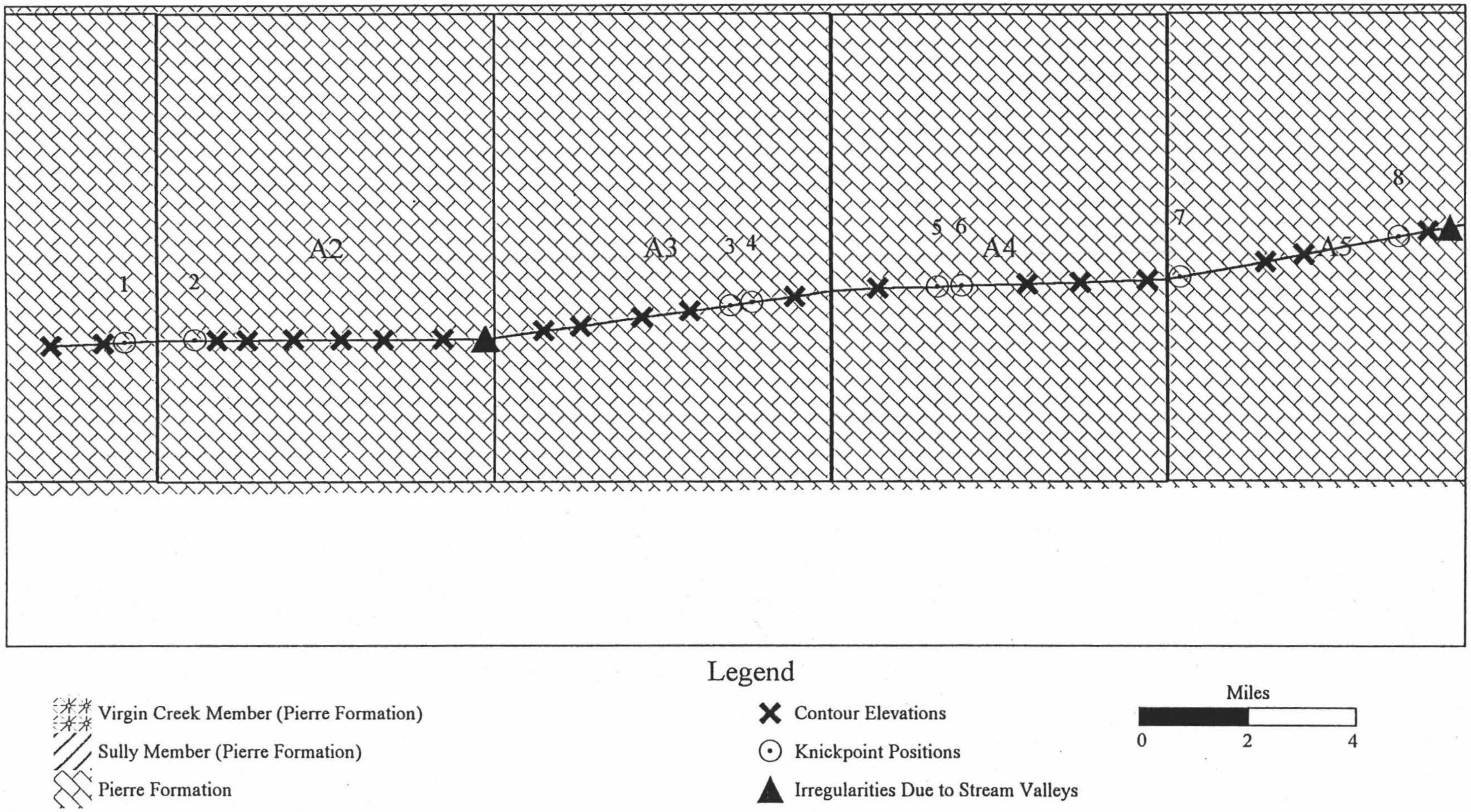


Figure 17. Map showing relationship of geology to elevations, knickpoints, and stream valley irregularities along Bad River land surface profile B. (From Petsch, 1953) (See Figure 2A for quadrangle locations.)

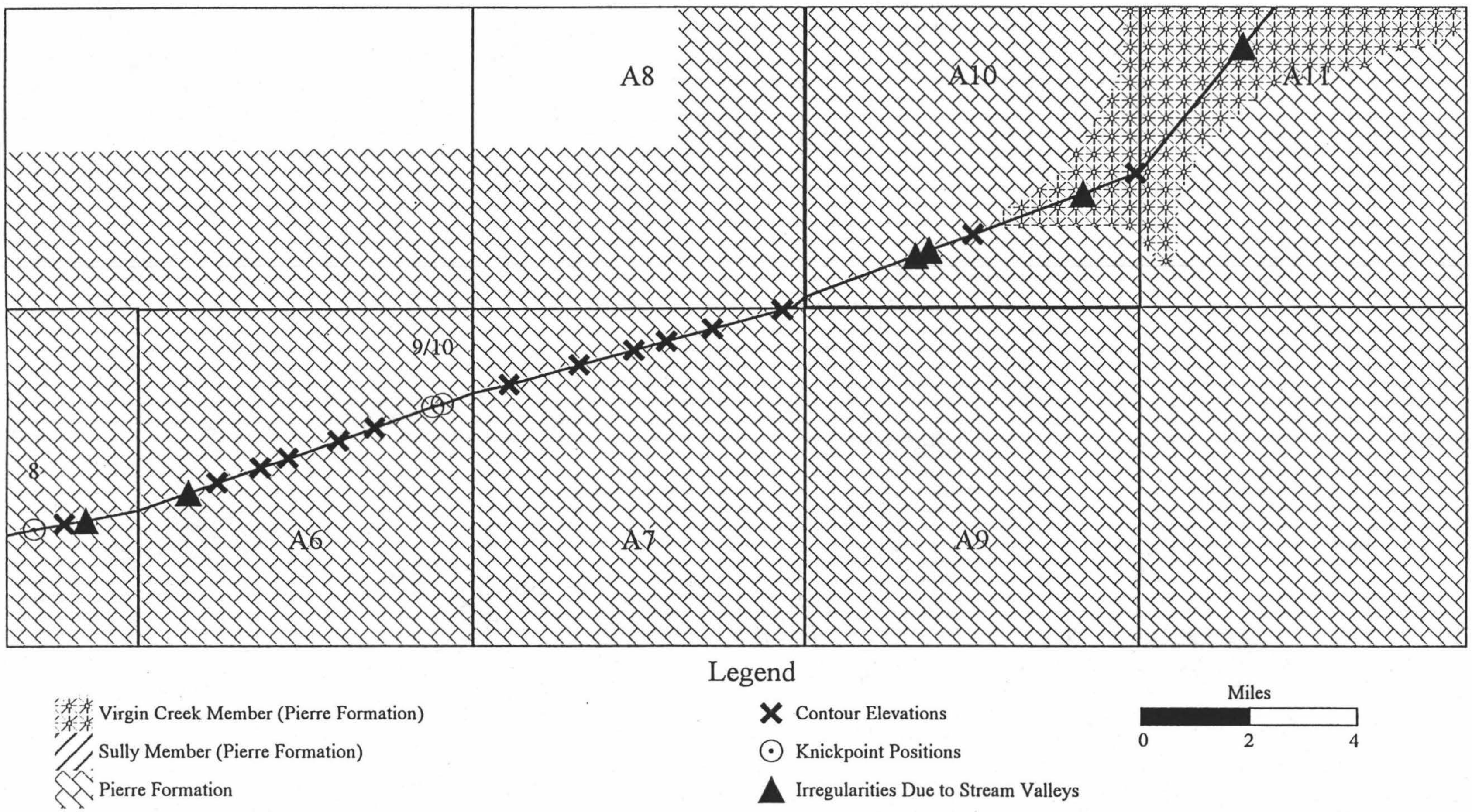
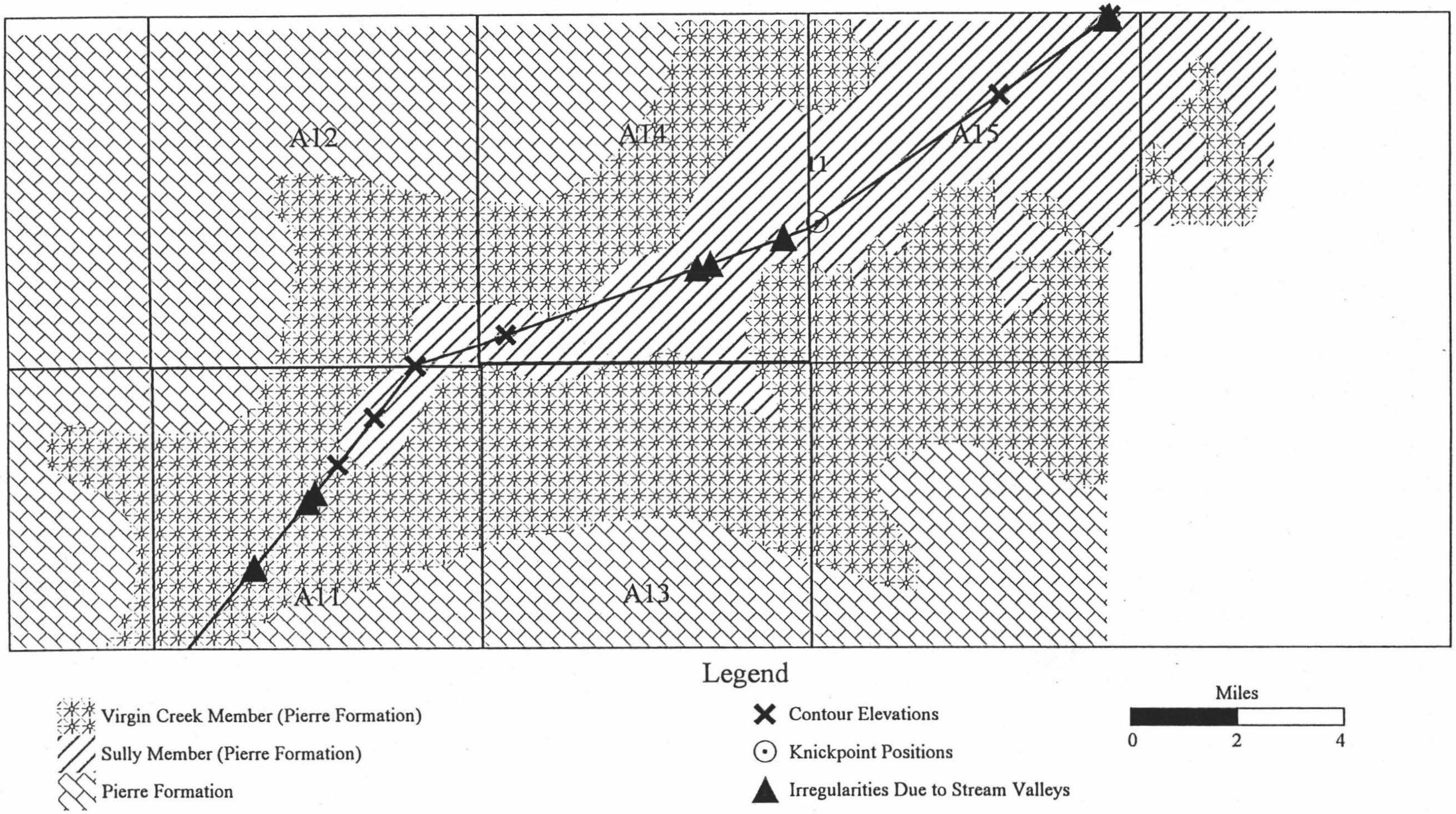


Figure 17. continued.



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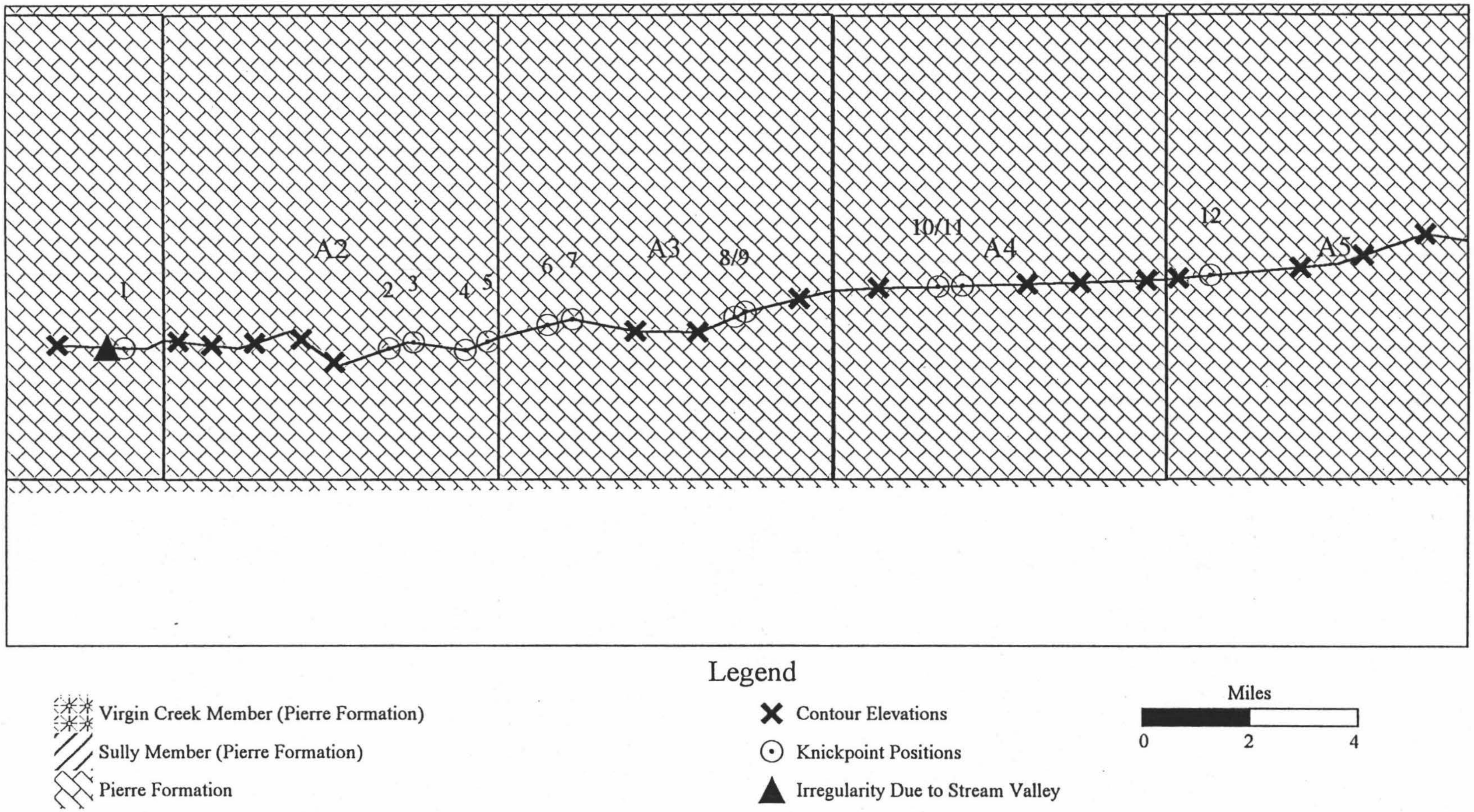


Figure 18. Map showing relationship of geology to elevations knickpoints and stream profile irregularities along Bad River land surface profile C. (From Petsch, 1953) (See Figure 2A for quadrangle locations.)

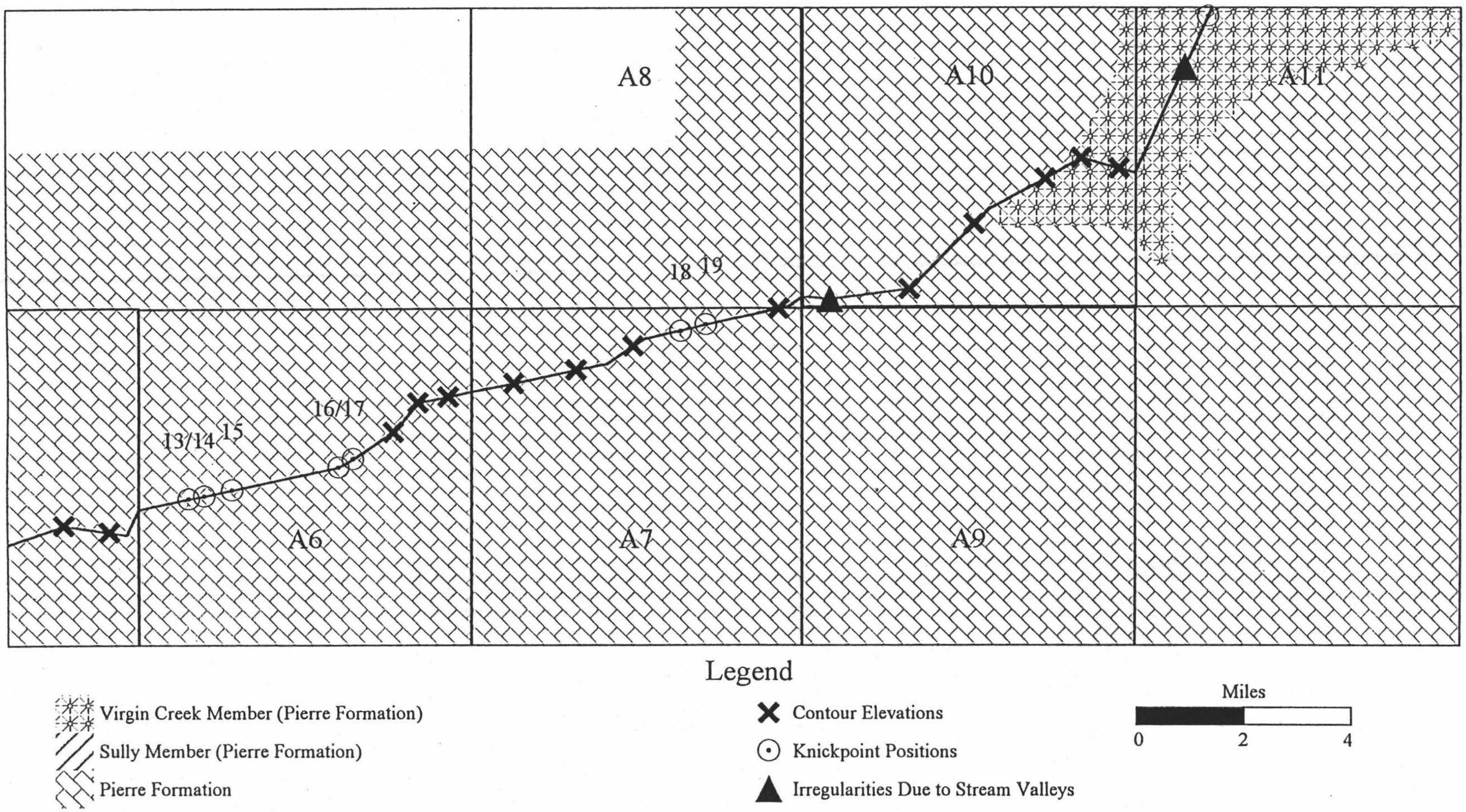


Figure 18. continued.

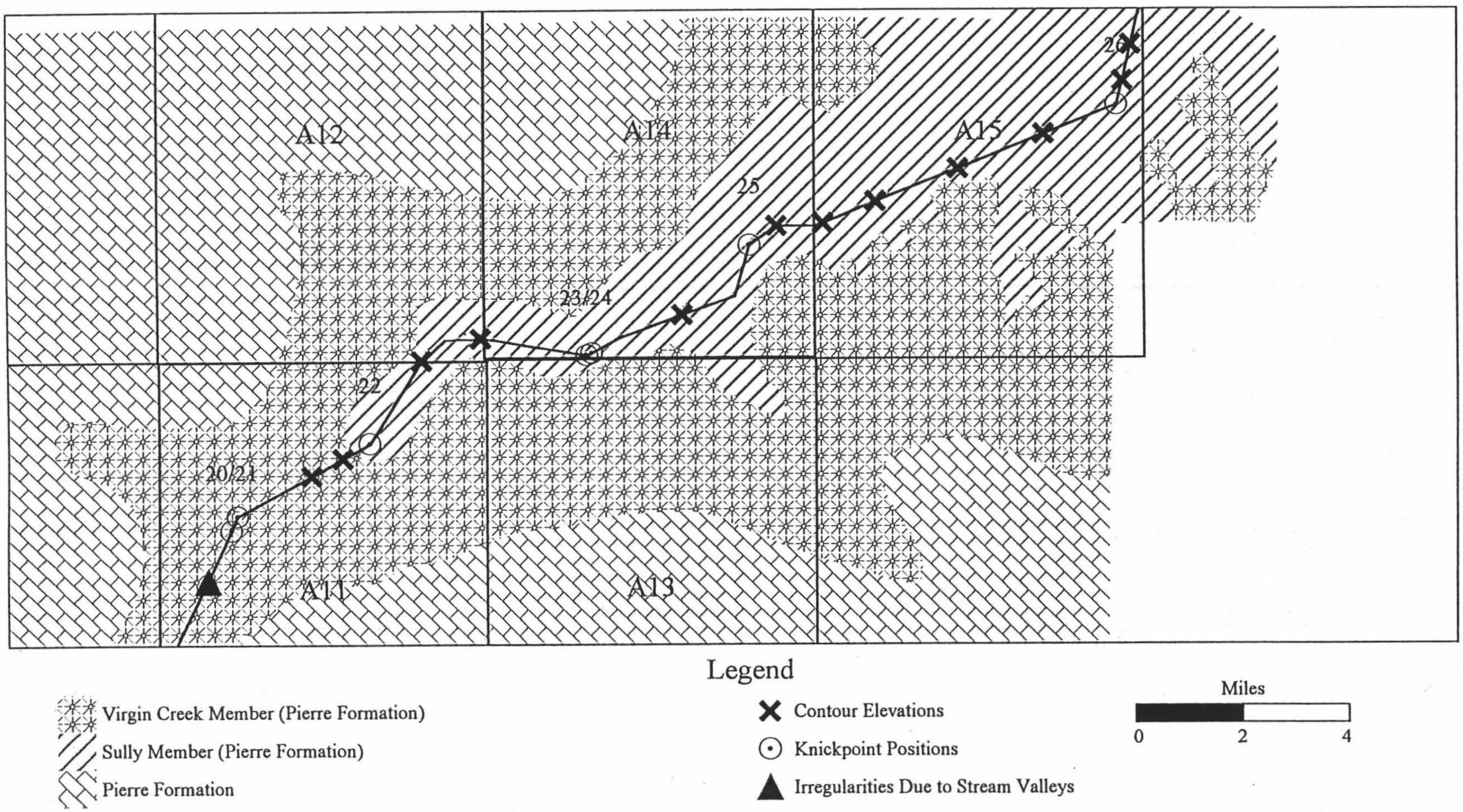


Figure 18. continued.

slightly concave form (Figures 19-22). Knickpoints have been determined and comparisons made with lithologic maps in order to discern any relationship (Figures 15-18; Appendix C; Appendix D). Knickpoints along profiles in this area do not seem to correlate with any lithologic changes, although knickpoints 17 and 18 on land surface profile A (Figure 16.) occur where the Virgin Creek Member becomes differentiated within the Pierre Shale Formation. The significance of this differentiation in terms of lithologic changes is uncertain without field checking.

Tributary junctures to the Bad River were also examined for any possible relationship with knickpoints identified from the stream profile (Appendix D). No knickpoints along this profile correspond with any tributary junctures.

The equation of a trendline for the section of the Bad River profile above 1820 ft. was determined (Table 1). The elevation of the trendline at the end of the profile, as determined from the equation, is 28.29 feet above the actual elevation. An equation for the trendline of land surface profile A above 1820 ft was also determined (Table 1). The elevation of this trendline is 10.79 feet higher than the actual elevation at the end of the profile.

Four knickpoints were common to all three land surface profiles (Table 2). Four knickpoints were common to just land surface profiles A and B , and eight knickpoints were common to land surface profiles A and C.

The four profiles from this area have been plotted together (Figure 23). This plot shows the land surface profiles having a steeper gradient than the stream profile, as explained earlier. The land surface profiles have also been plotted on the same graph

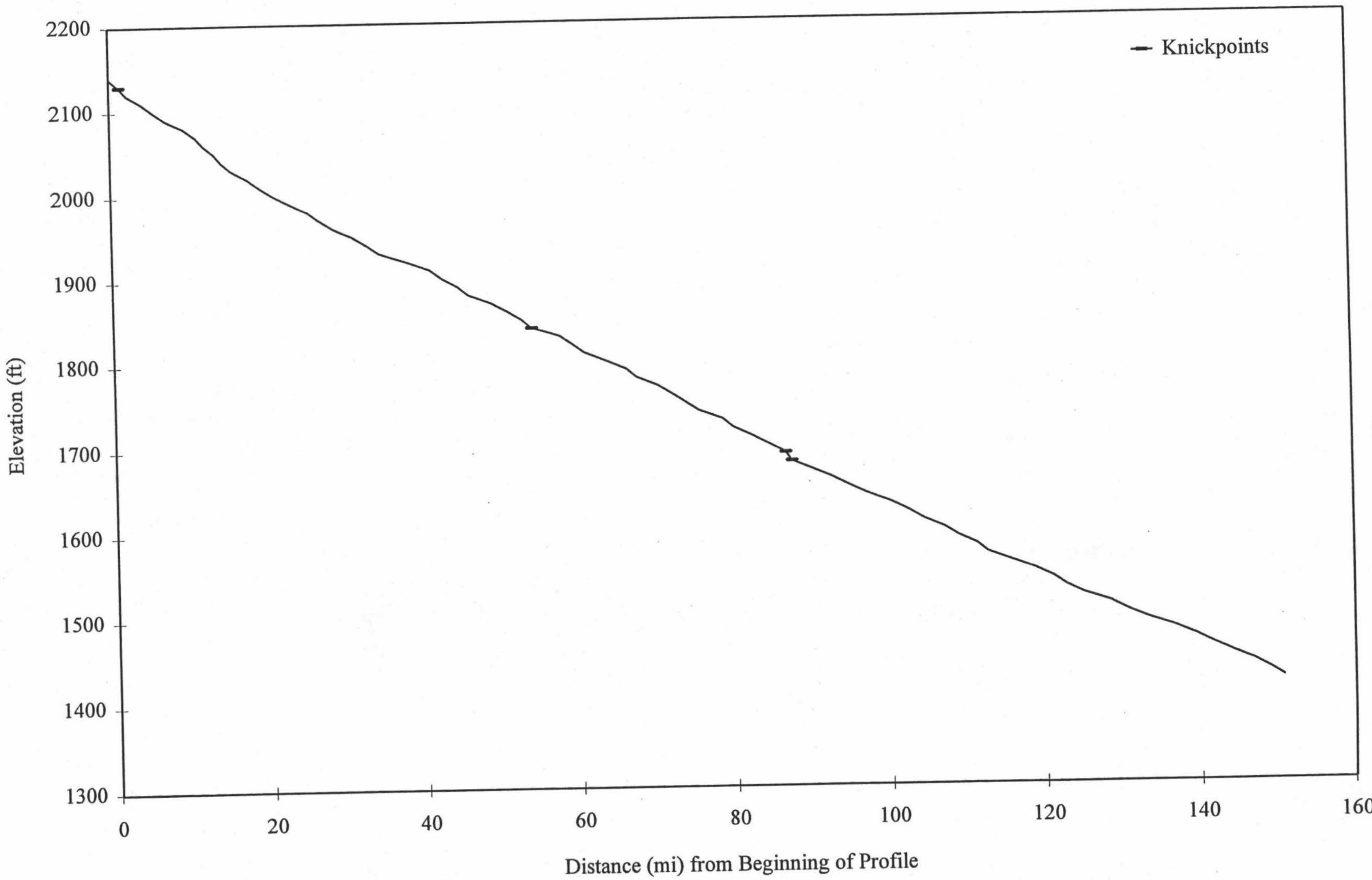


Figure 19. Bad River Profile showing identified knickpoints.(See Figure 15 for knickpoint locations.)

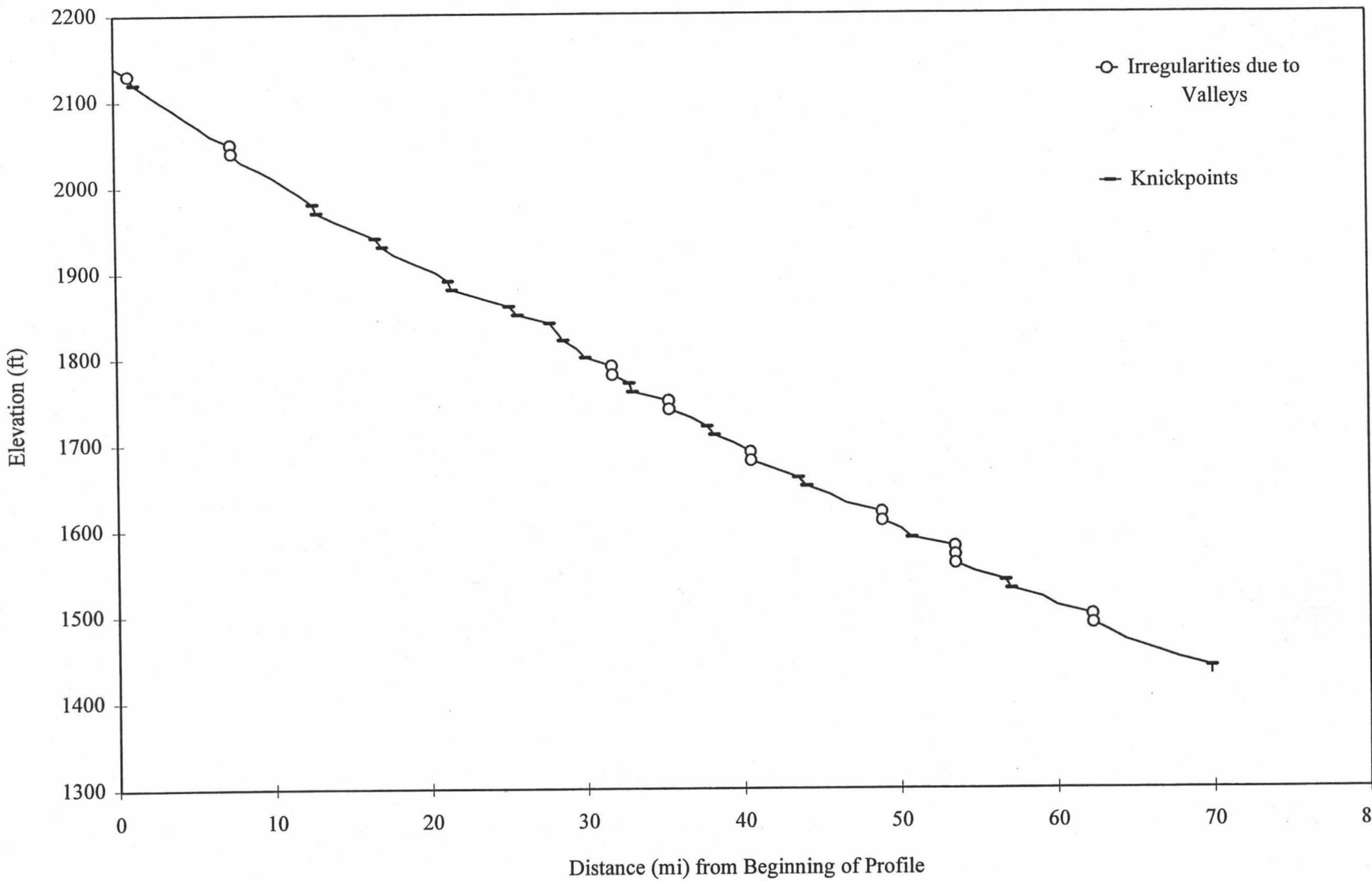


Figure 20. Bad River land surface profile A. (See Figure 16 for valley irregularity and knickpoint locations.)

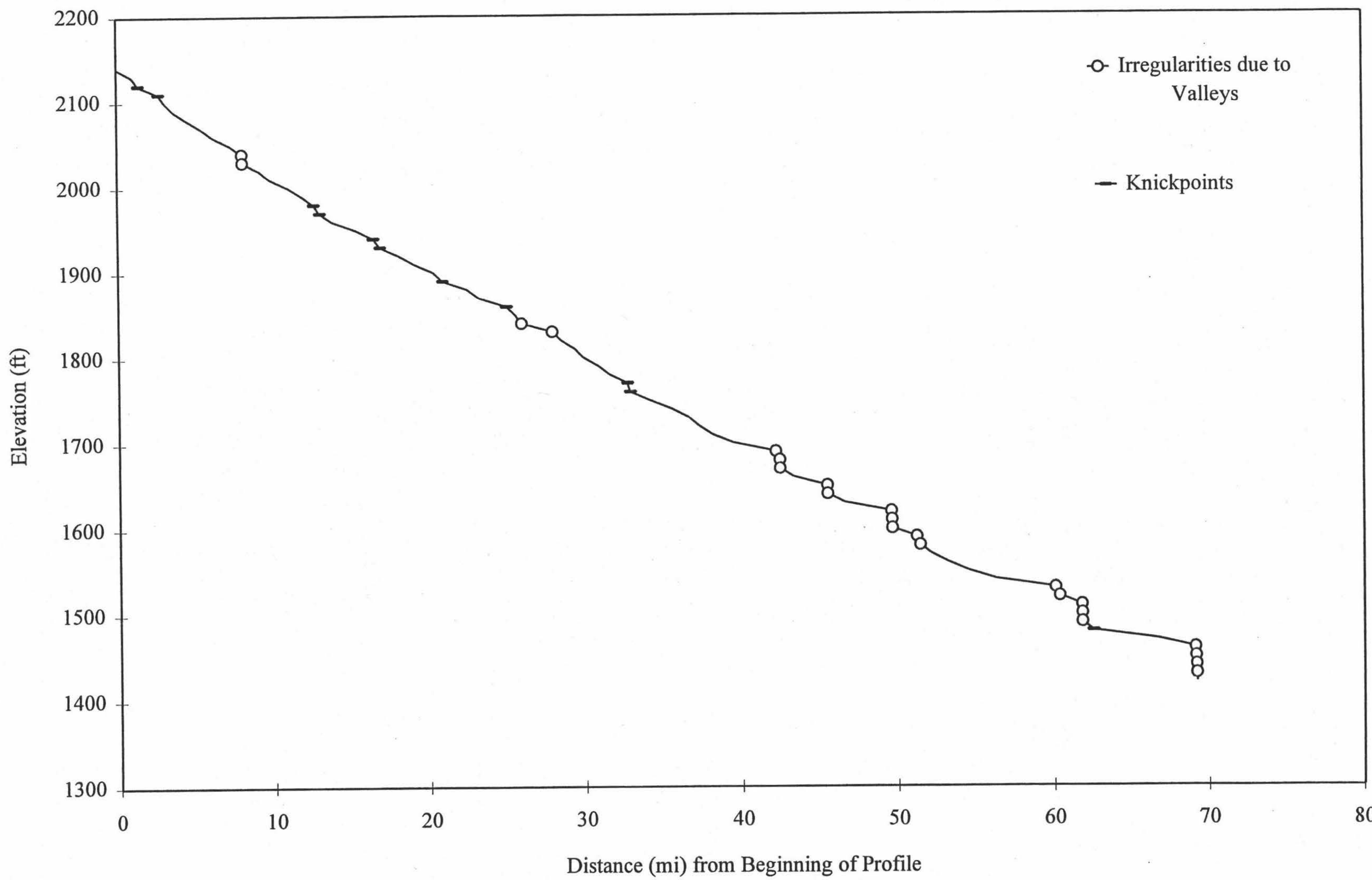


Figure 21. Bad River land surface profile B. (See Figure 17 for valley irregularity and knickpoint locations.)

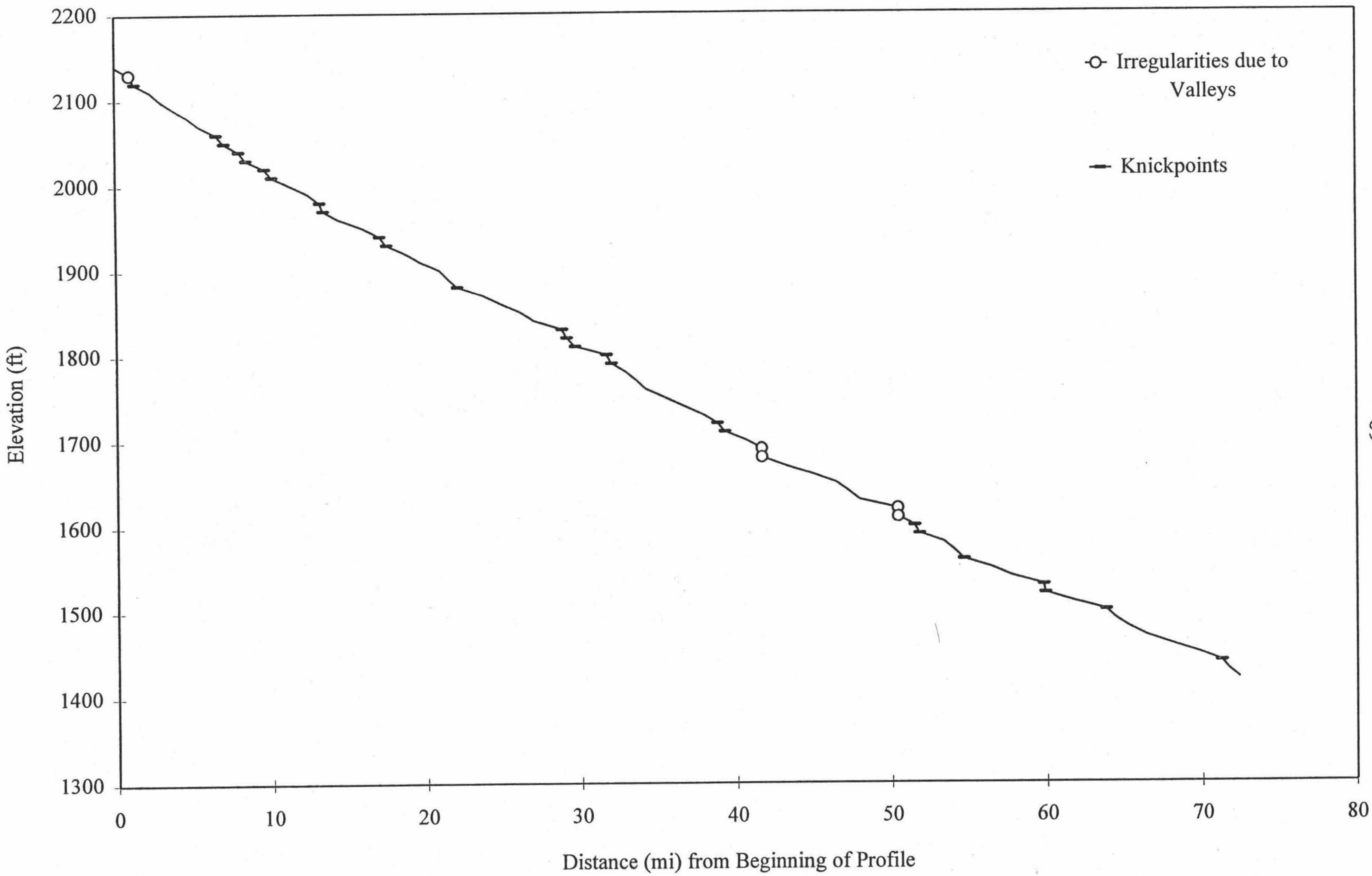


Figure 22. Bad River land surface profile C. (See Figure 18 for valley irregularities and knickpoint locations.)

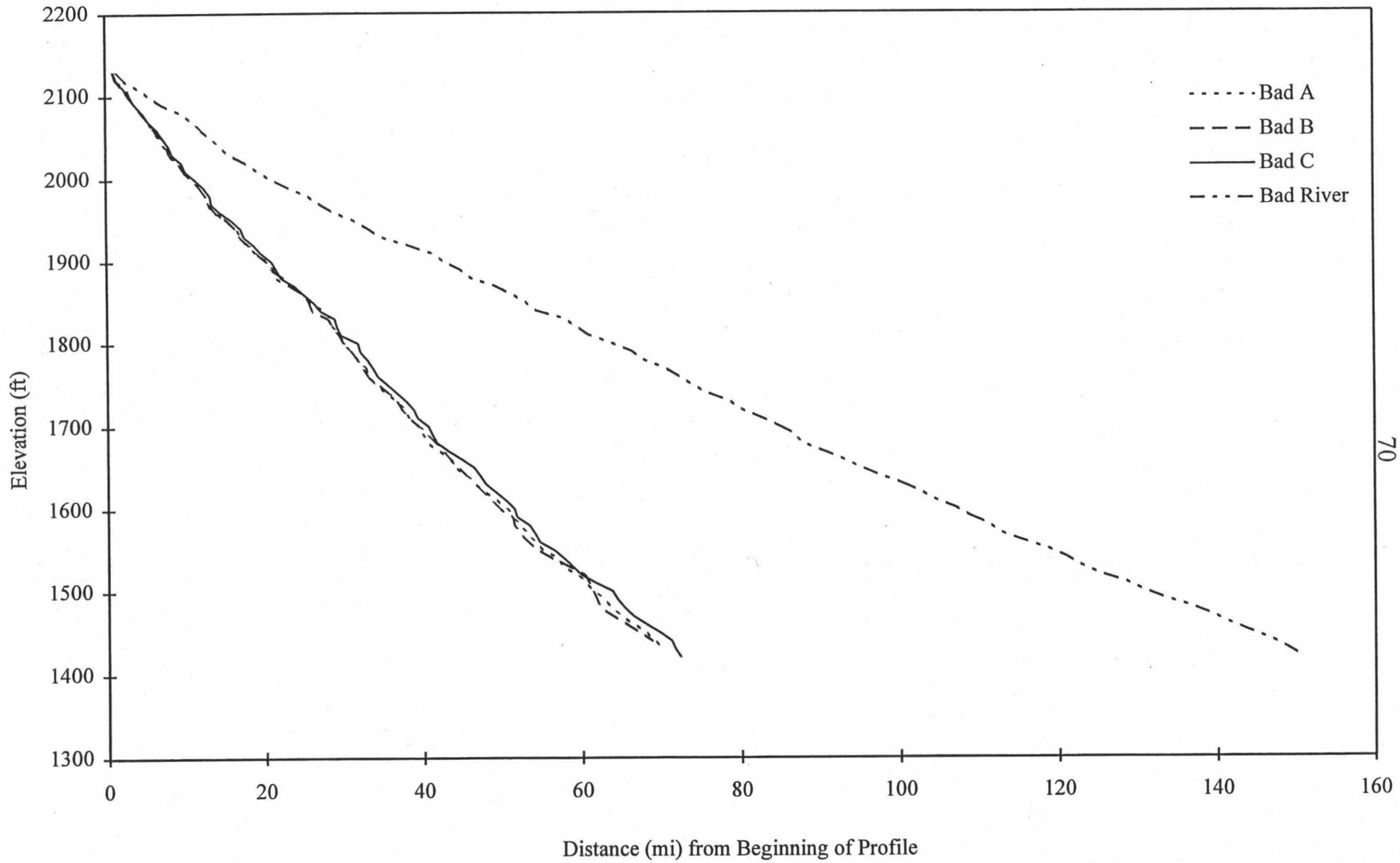


Figure 23. Bad River and land surface profiles.

without the stream profile (Figure 24). Slopes of these profiles are similar and sometimes even cross. It is difficult to differentiate between the land surface profiles near their origin, but this becomes easier downslope. In general, land surface profile C has a more gentle slope than land surface profiles A and B; land surface profiles A and B cross numerous times.

White River

Profiles were constructed for an area along and adjacent to the White River between the elevations of 2100 ft and 1320 ft (Figures 25-28). These profiles are linear to slightly concave (Figures 29-32). Slopes and distances were determined between elevation points for knickpoint identification (Appendix C). Identified knickpoints were compared with lithologic maps in order to determine if any relationship exists between lithologic change and knickpoint location (Figures 25-28).

It was found that only the knickpoint at an elevation of 1330 ft on White River land surface profile B corresponded to a lithologic change, from the Gregory/Sharon Springs Members of the Pierre Shale Formation to the Niobrara Formation (Figures 25-28; Appendix D).

Tributary junctures to the White River were also examined for any relationship to knickpoints identified from the stream profile (Appendix D). However, none of the knickpoints along this profile corresponds with any tributary junctures.

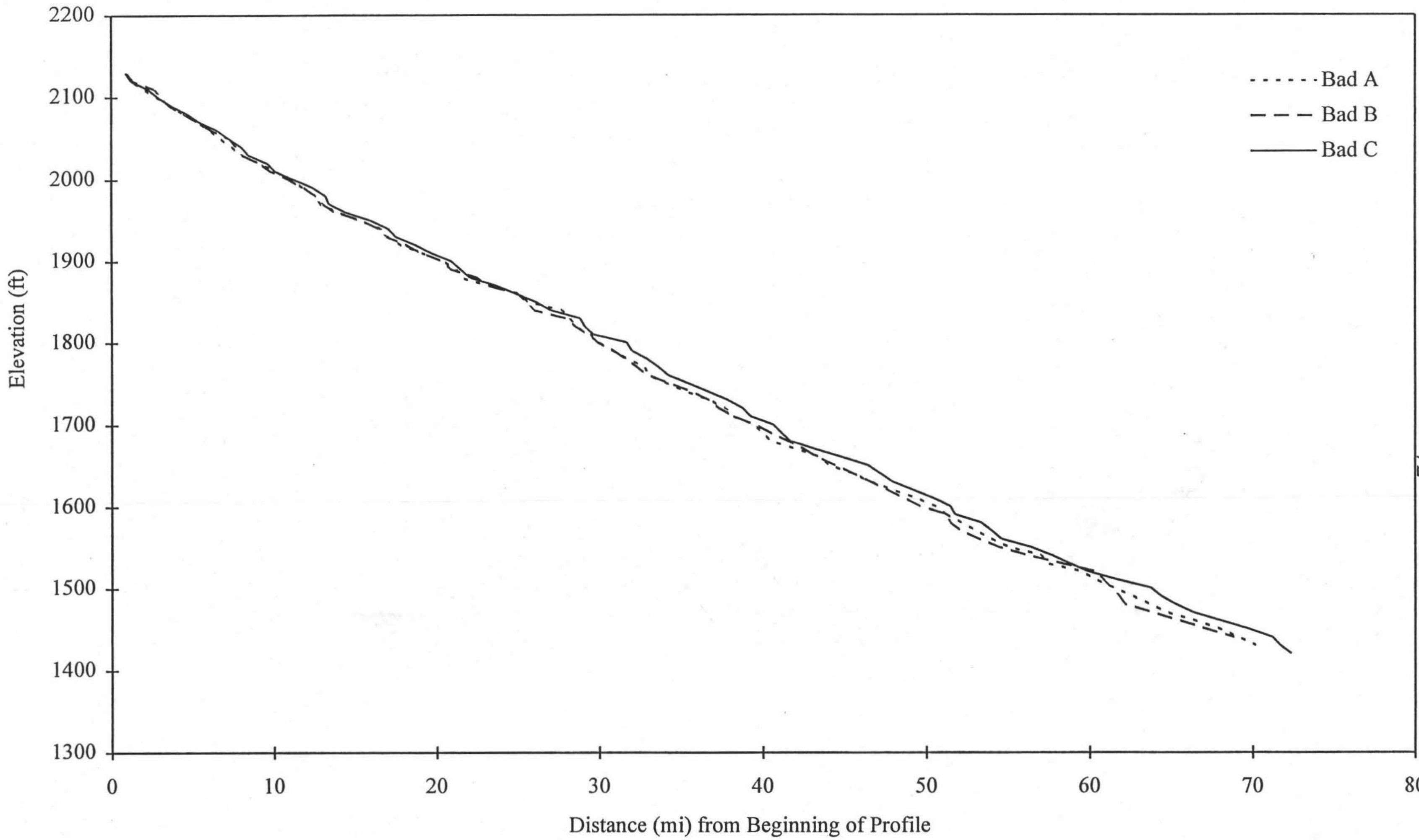


Figure 24. Bad River land surface profiles.

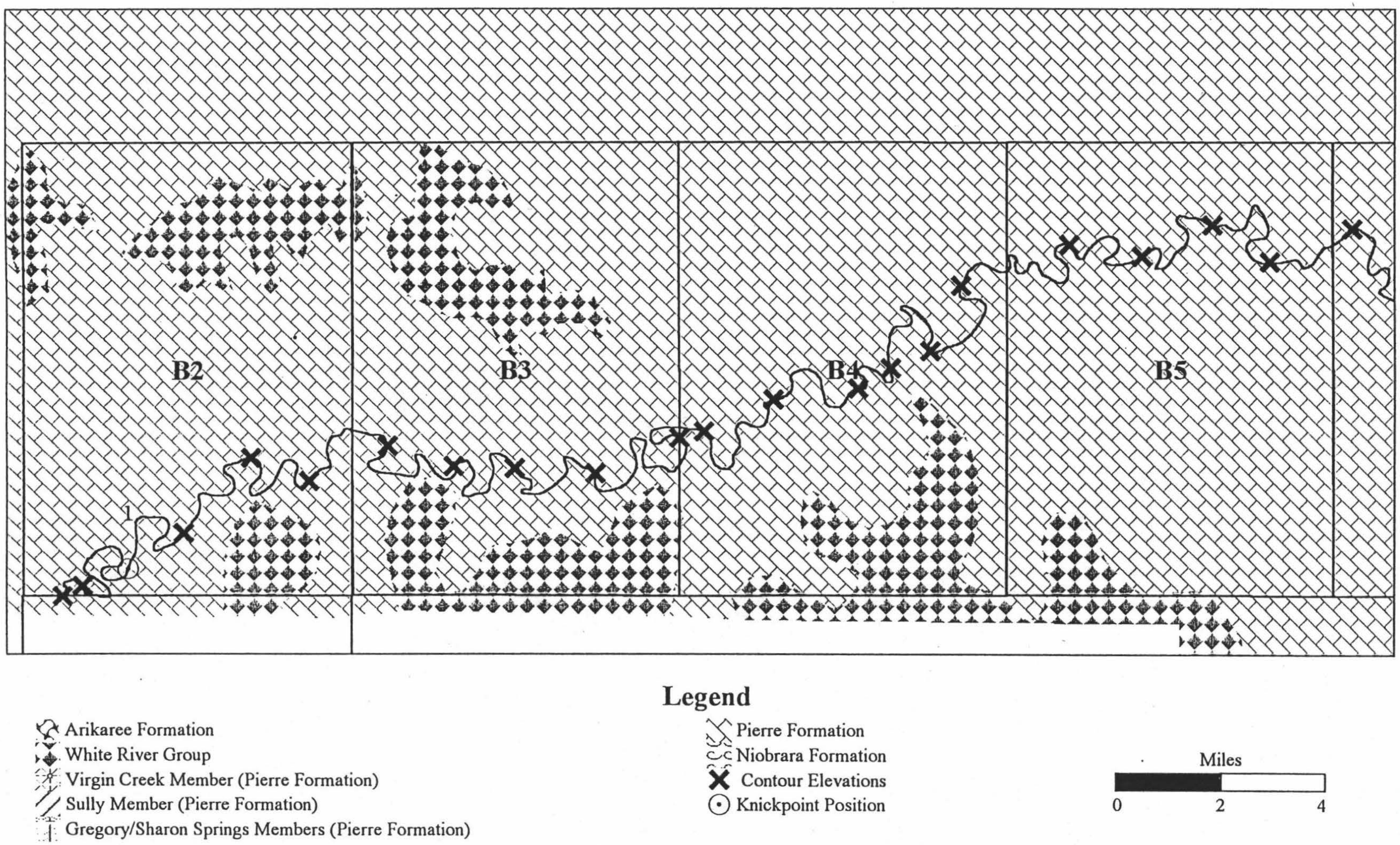


Figure 25. Map showing relationship of geology to elevations and knickpoints along the White River. (From Petsch, 1953) (See Figure 2A for quadrangle locations.)

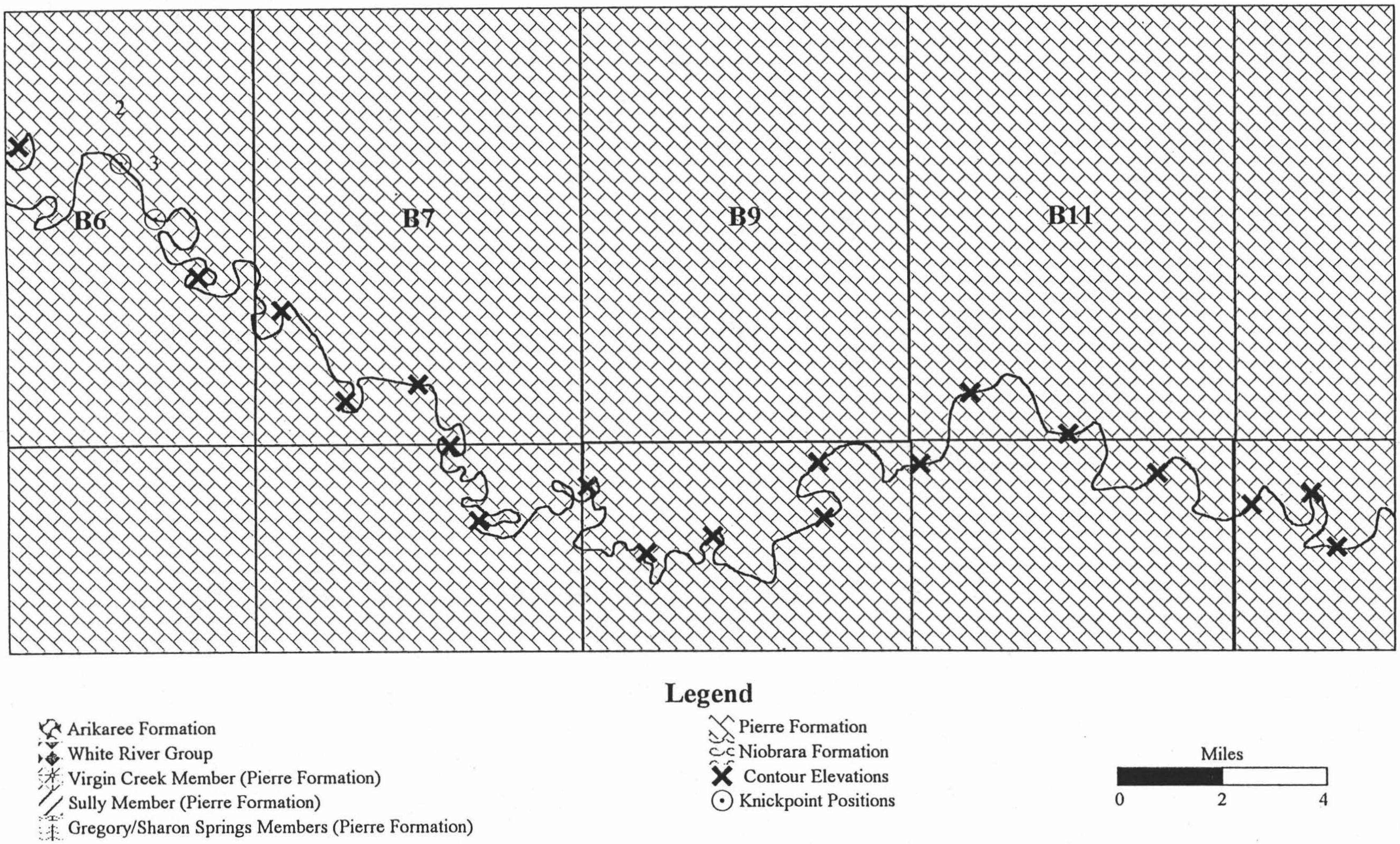


Figure 25. continued.

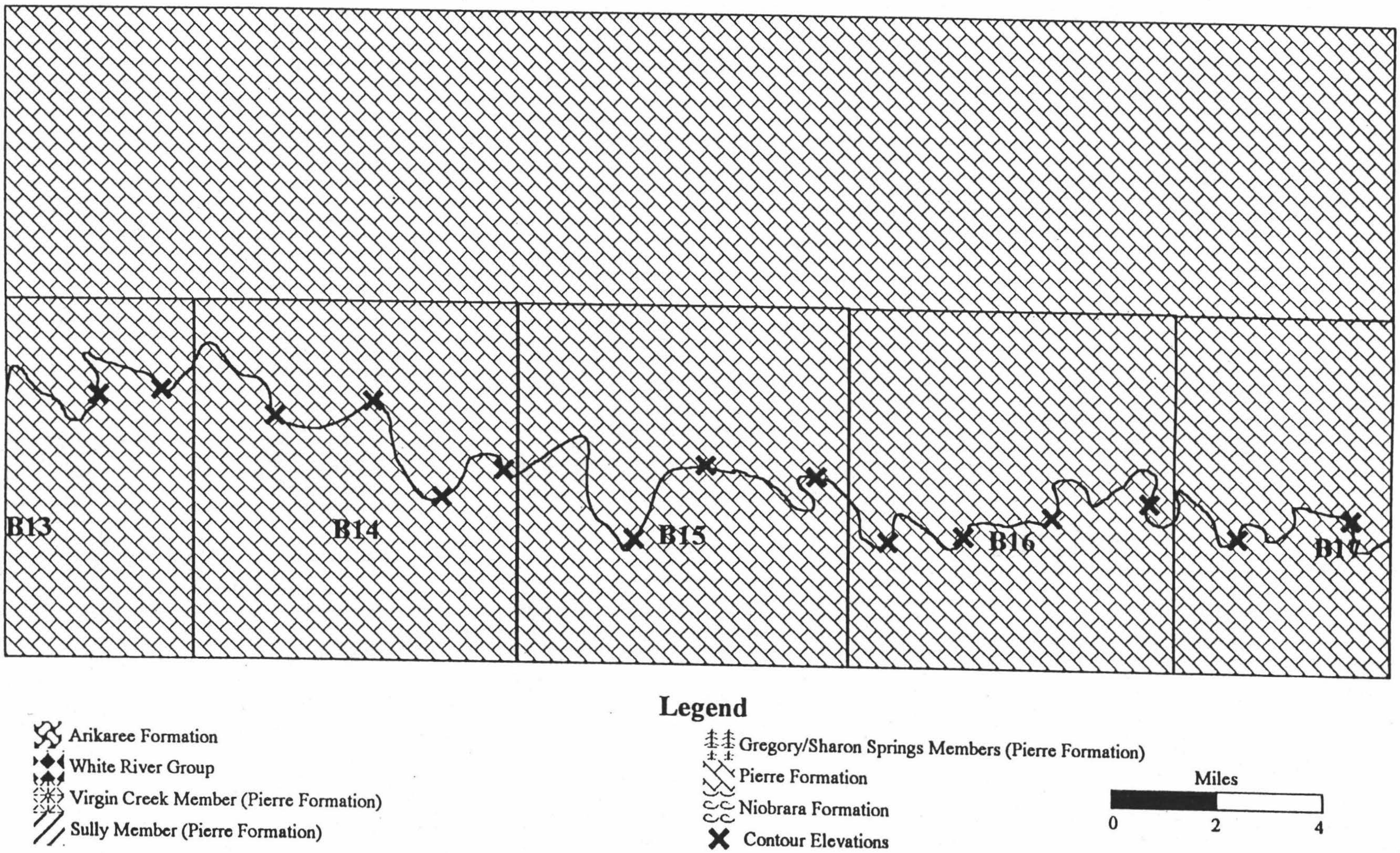


Figure 25. continued.

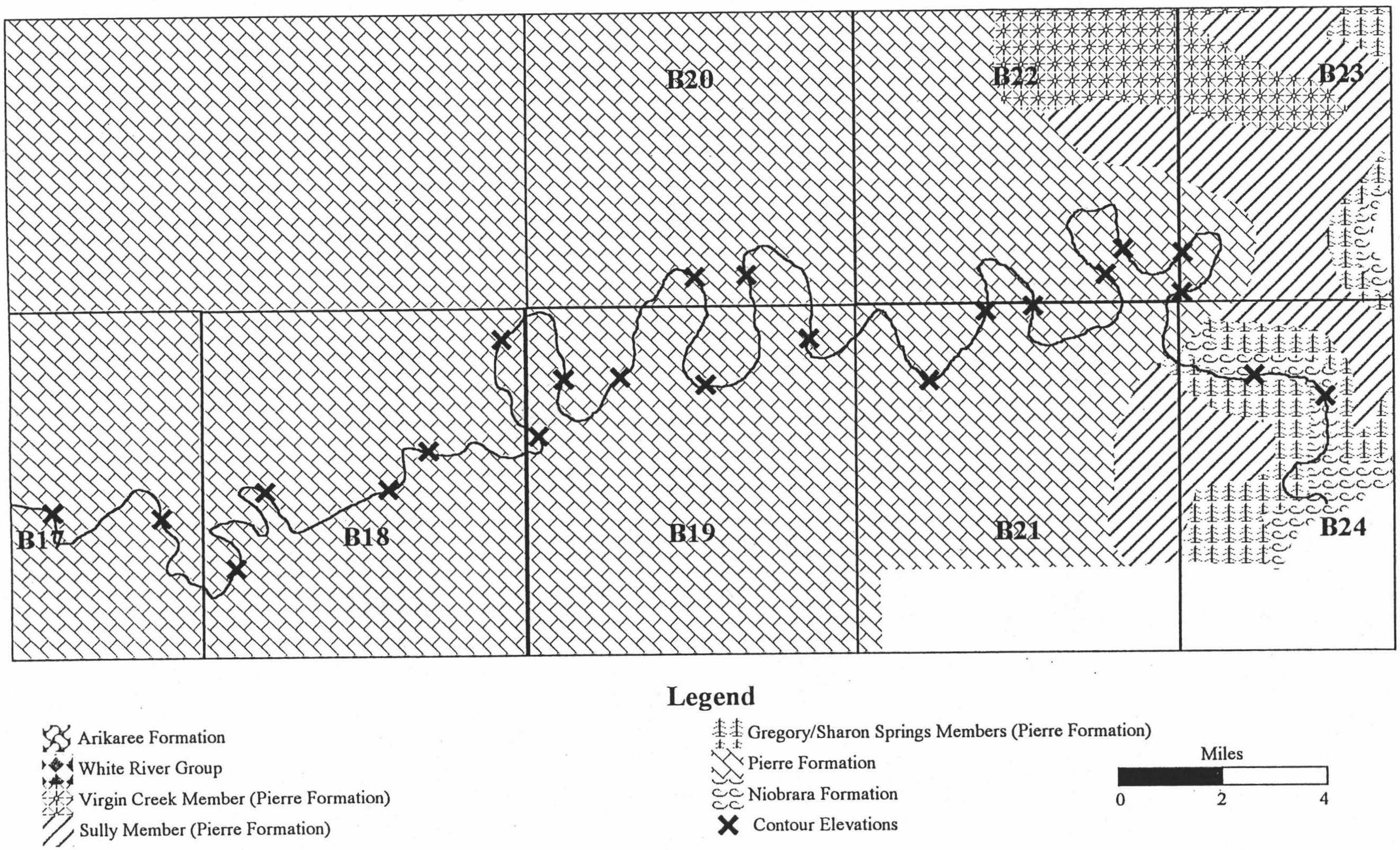


Figure 25. continued.

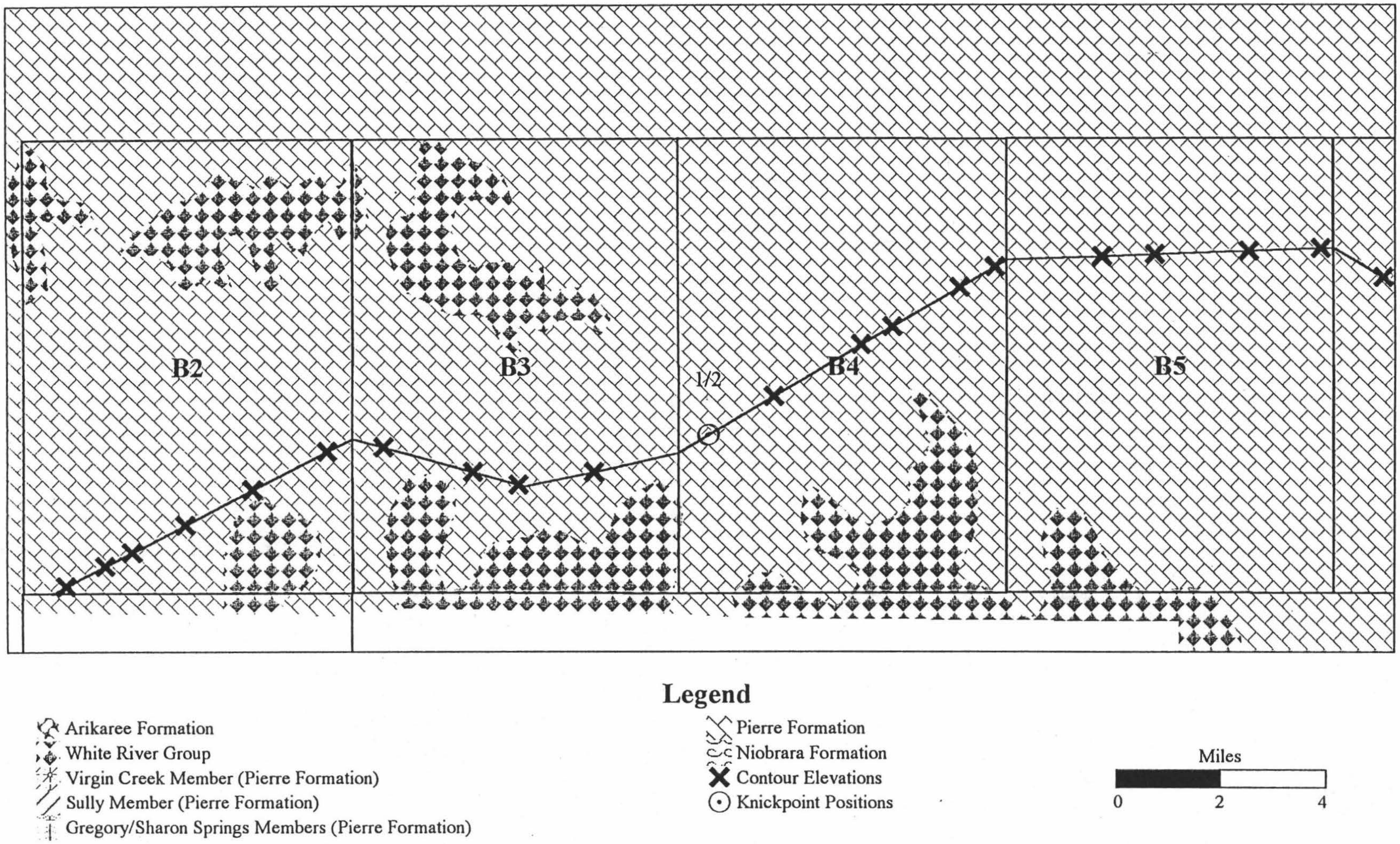


Figure 26. Map showing relationship of geology to elevations, knickpoints, and stream valley irregularities along White River land surface profile A. (From Petsch, 1953) (See Figure 2A for quadrangle locations.)

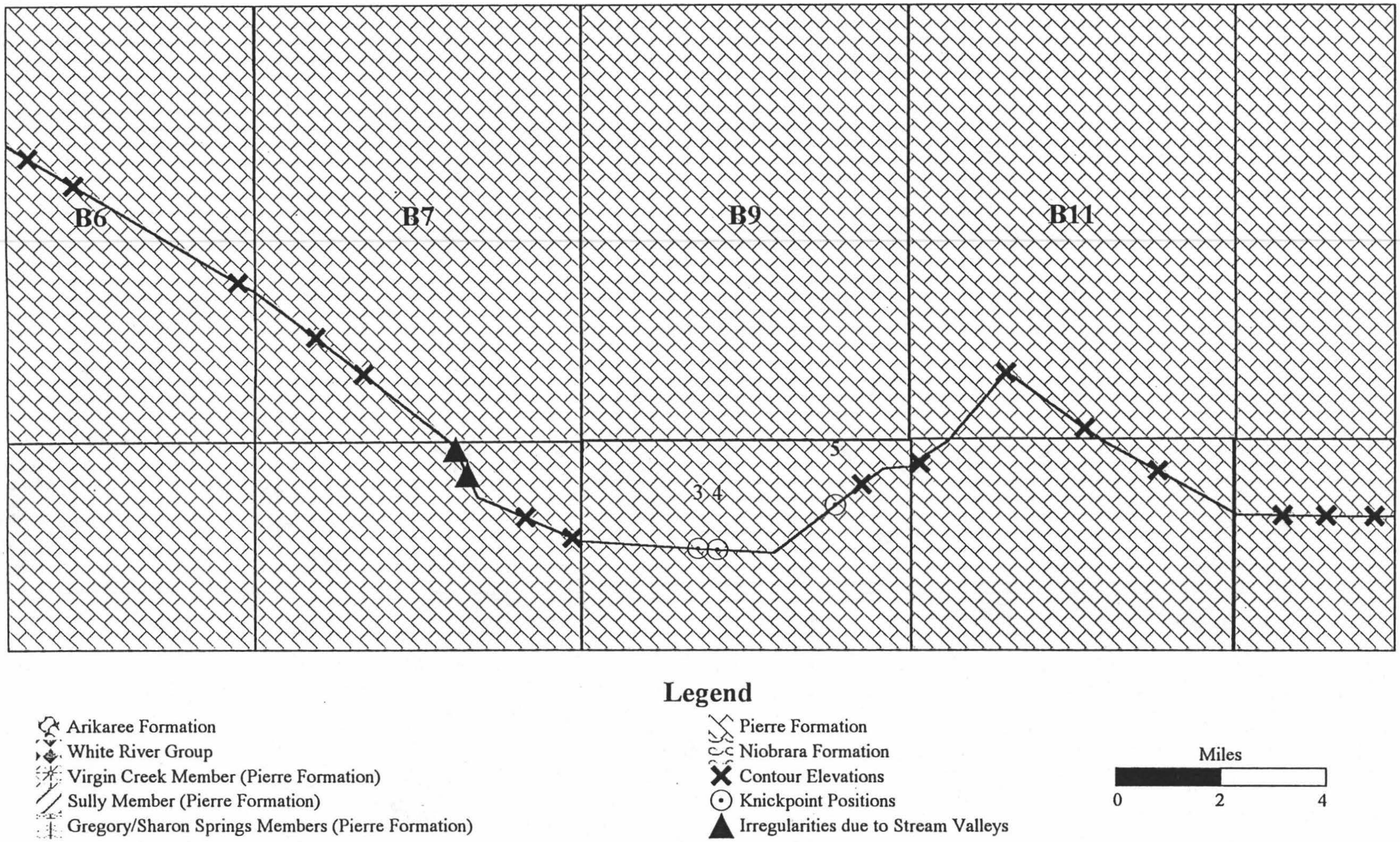


Figure 26. continued.

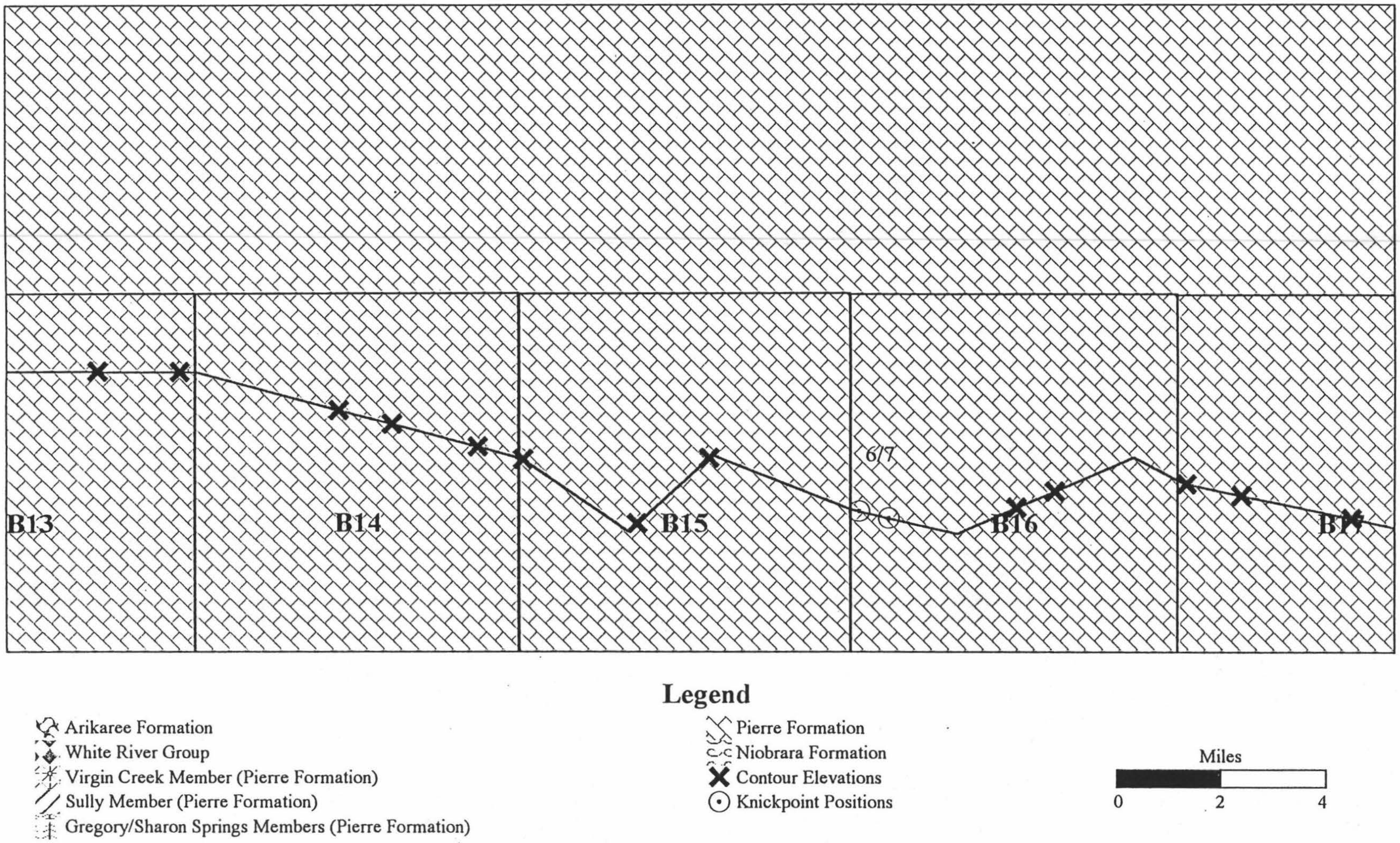


Figure 26. continued.

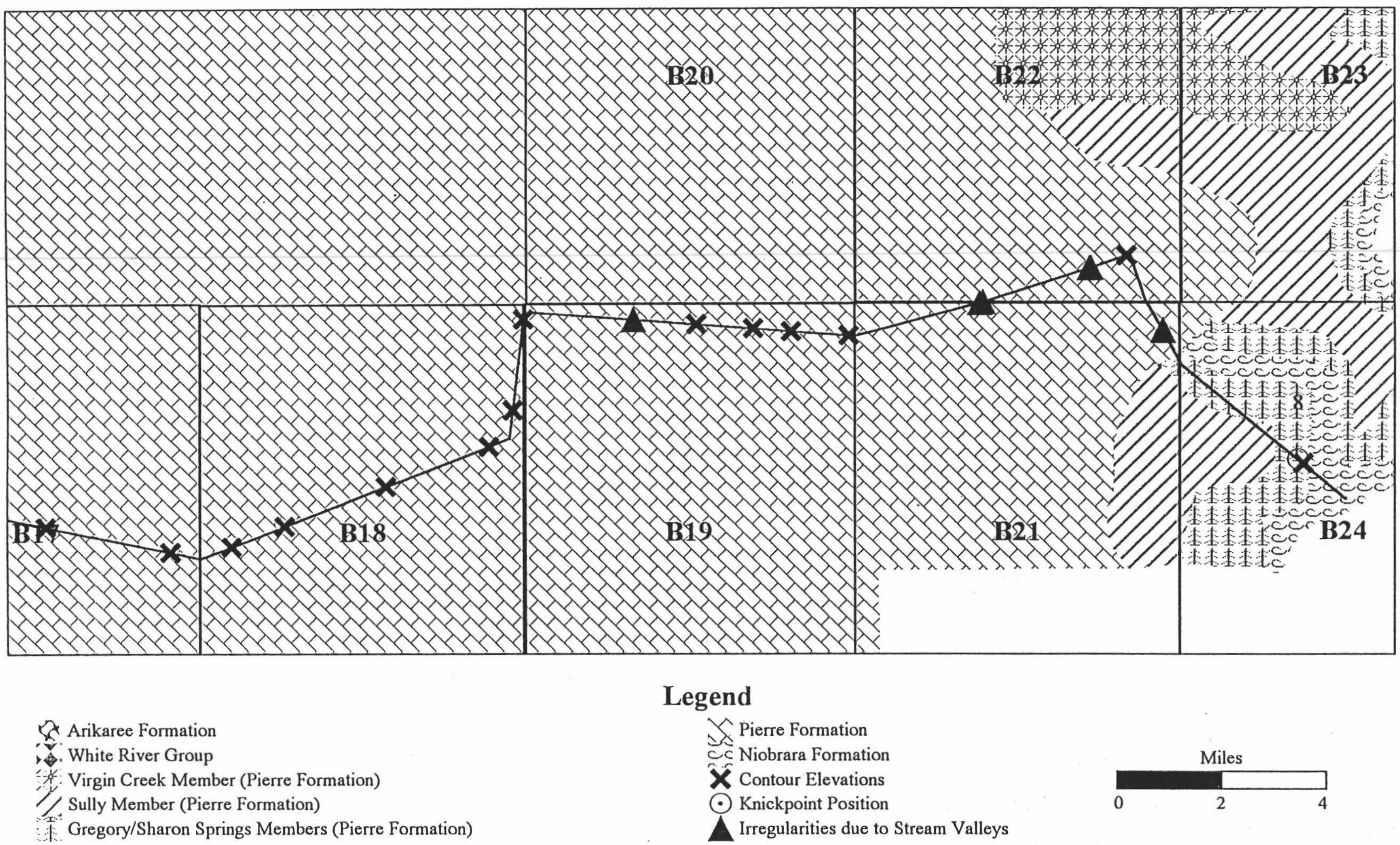


Figure 26. continued.

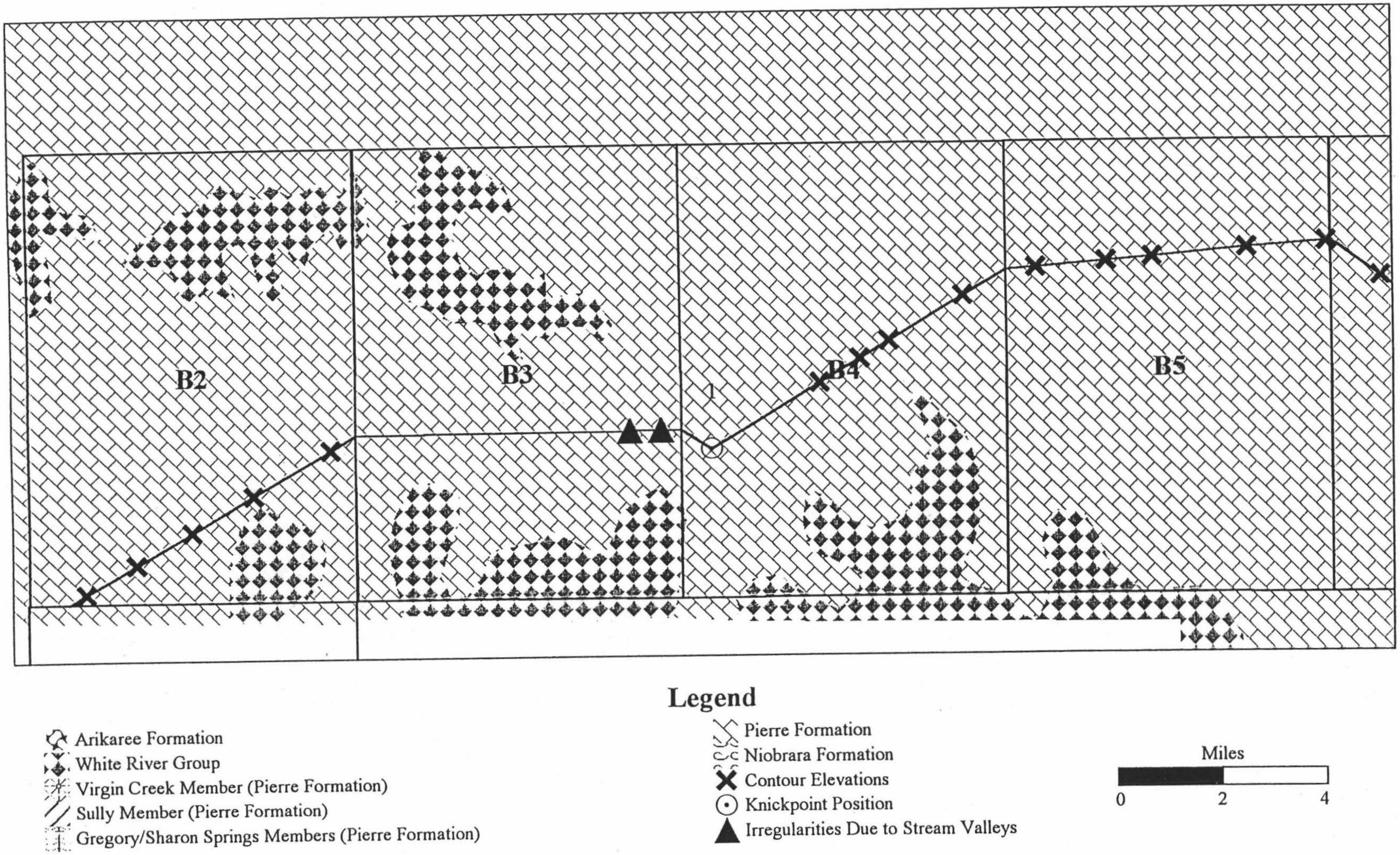
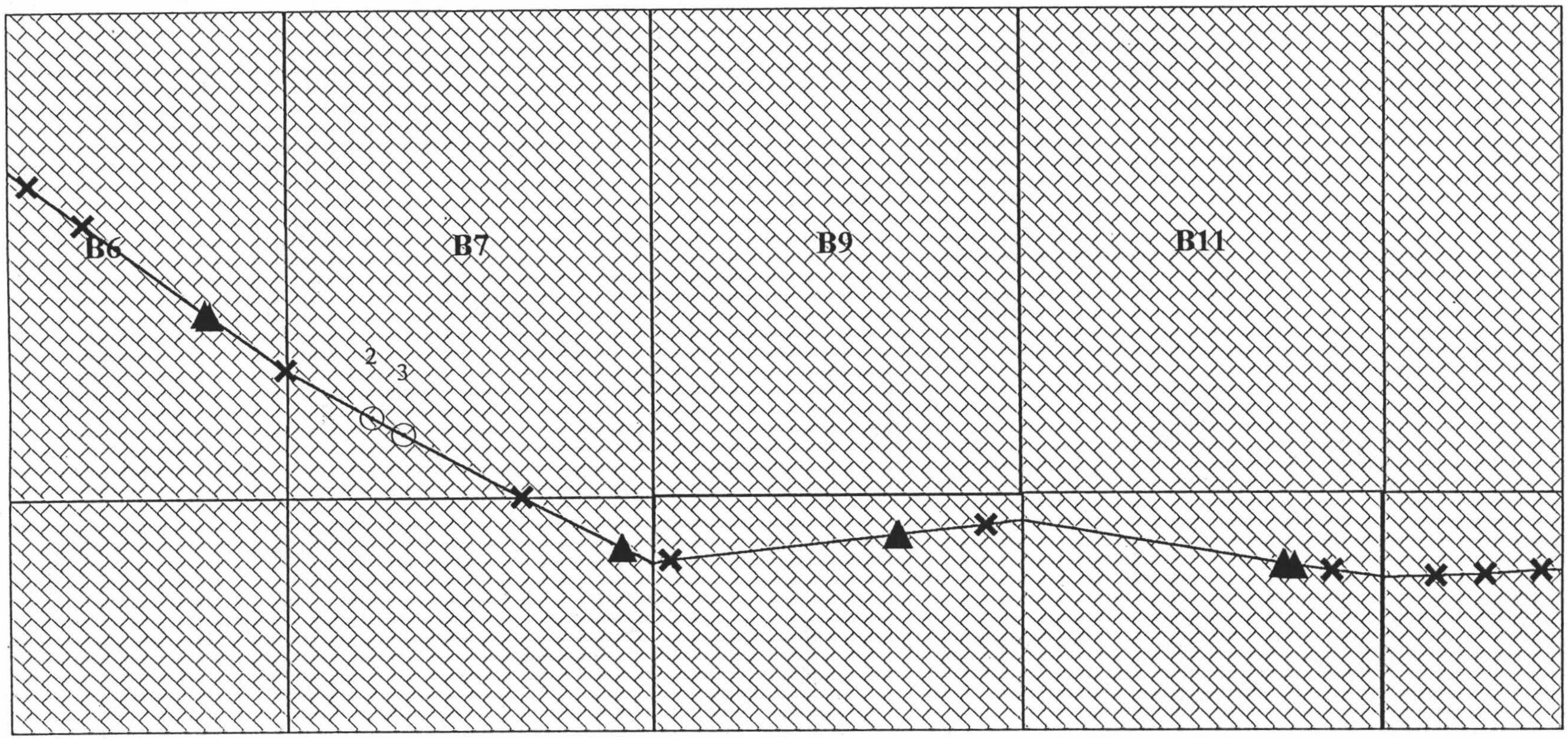


Figure 27. Map showing relationship of geology to elevations, knickpoints, and stream valley irregularities along White River land surface profile B. (From Petsch, 1953) (See Figure 2A for quadrangle locations.)



Legend

- Arikaree Formation
- White River Group
- Virgin Creek Member (Pierre Formation)
- Sully Member (Pierre Formation)
- Gregory/Sharon Springs Members (Pierre Formation)
- Pierre Formation
- Niobrara Formation
- Contour Elevations
- Knickpoint Positions
- Irregularities Due to Stream Valleys

Miles

0 2 4

Figure 27. continued.

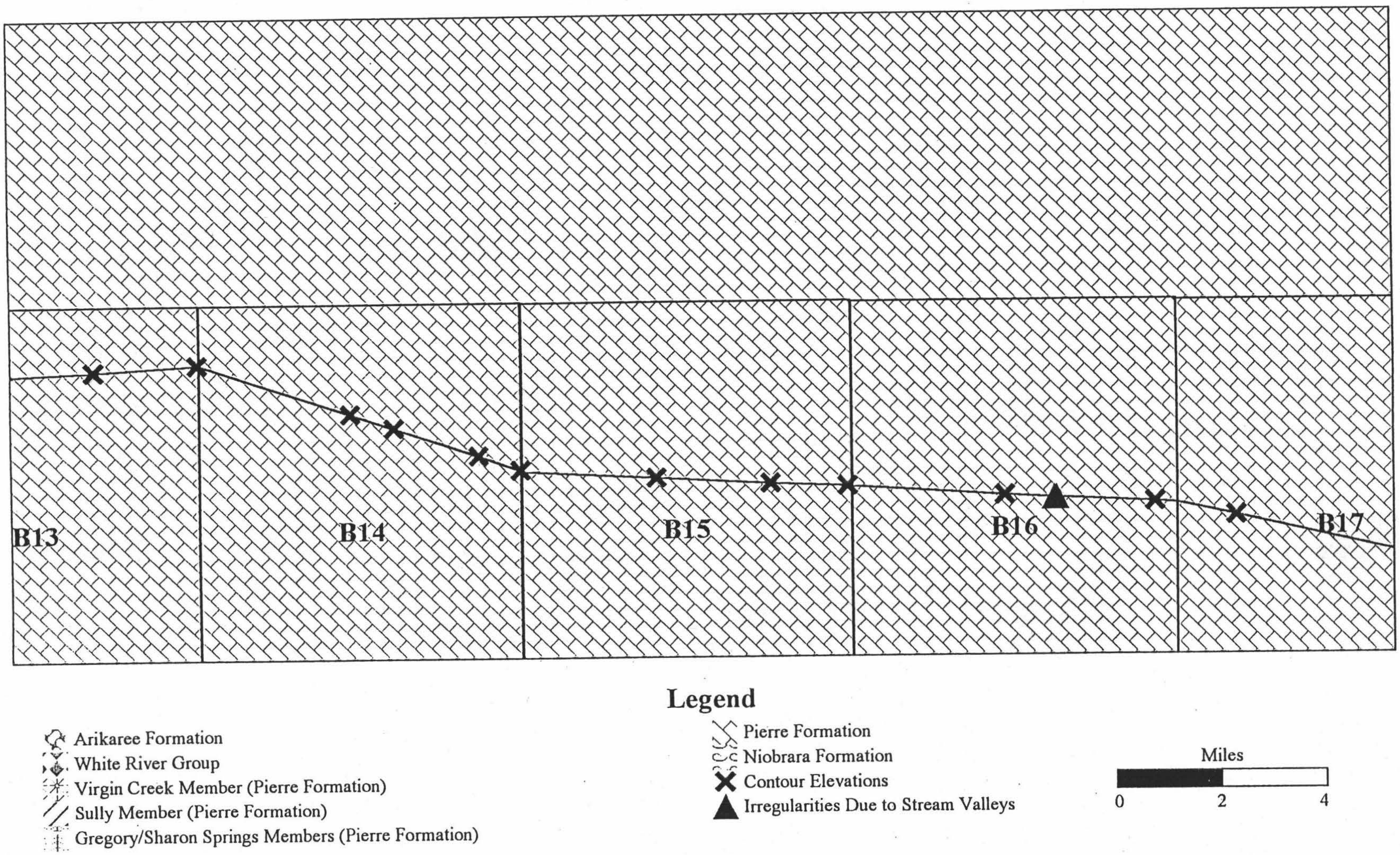


Figure 27. continued.

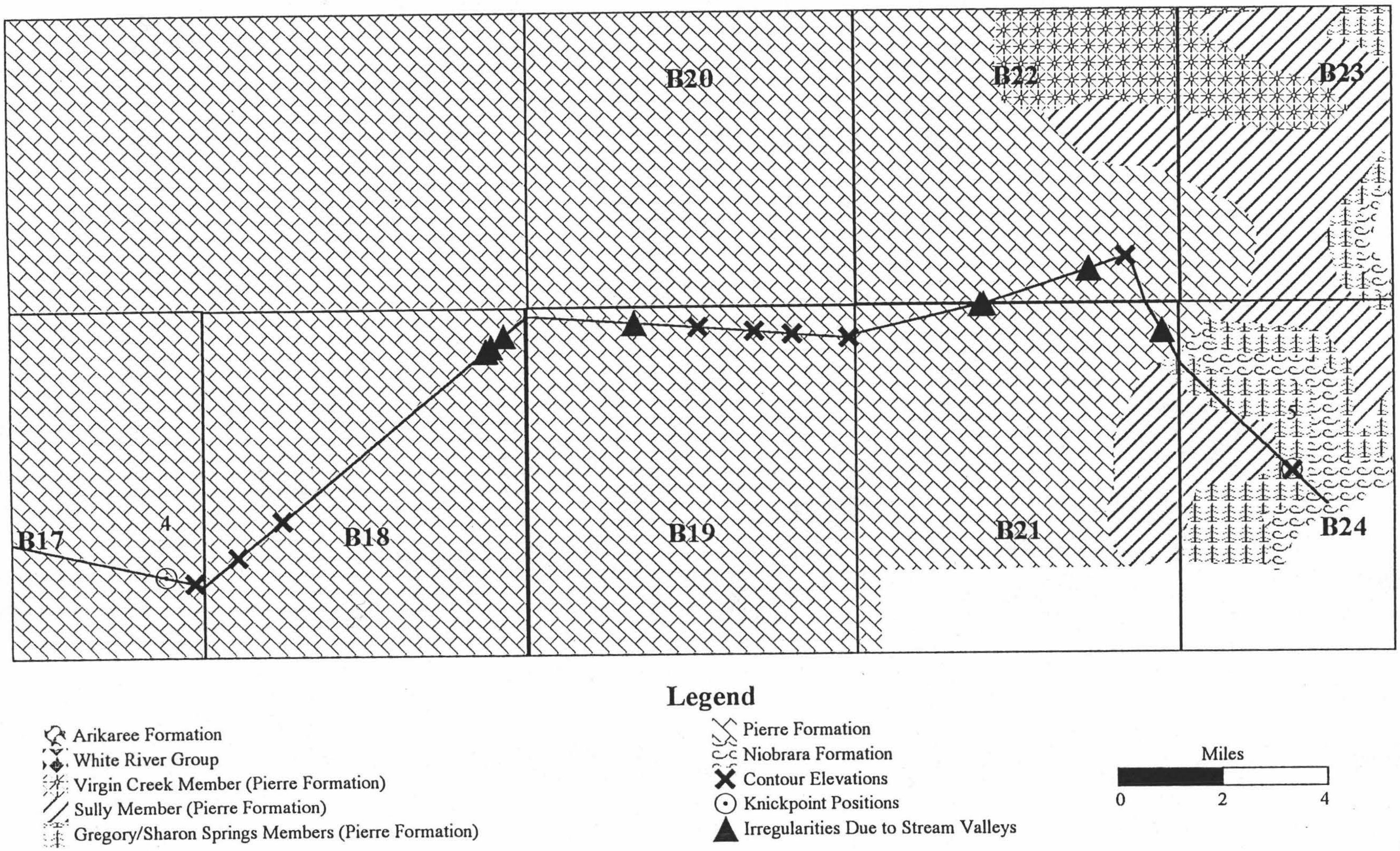


Figure 27. continued.

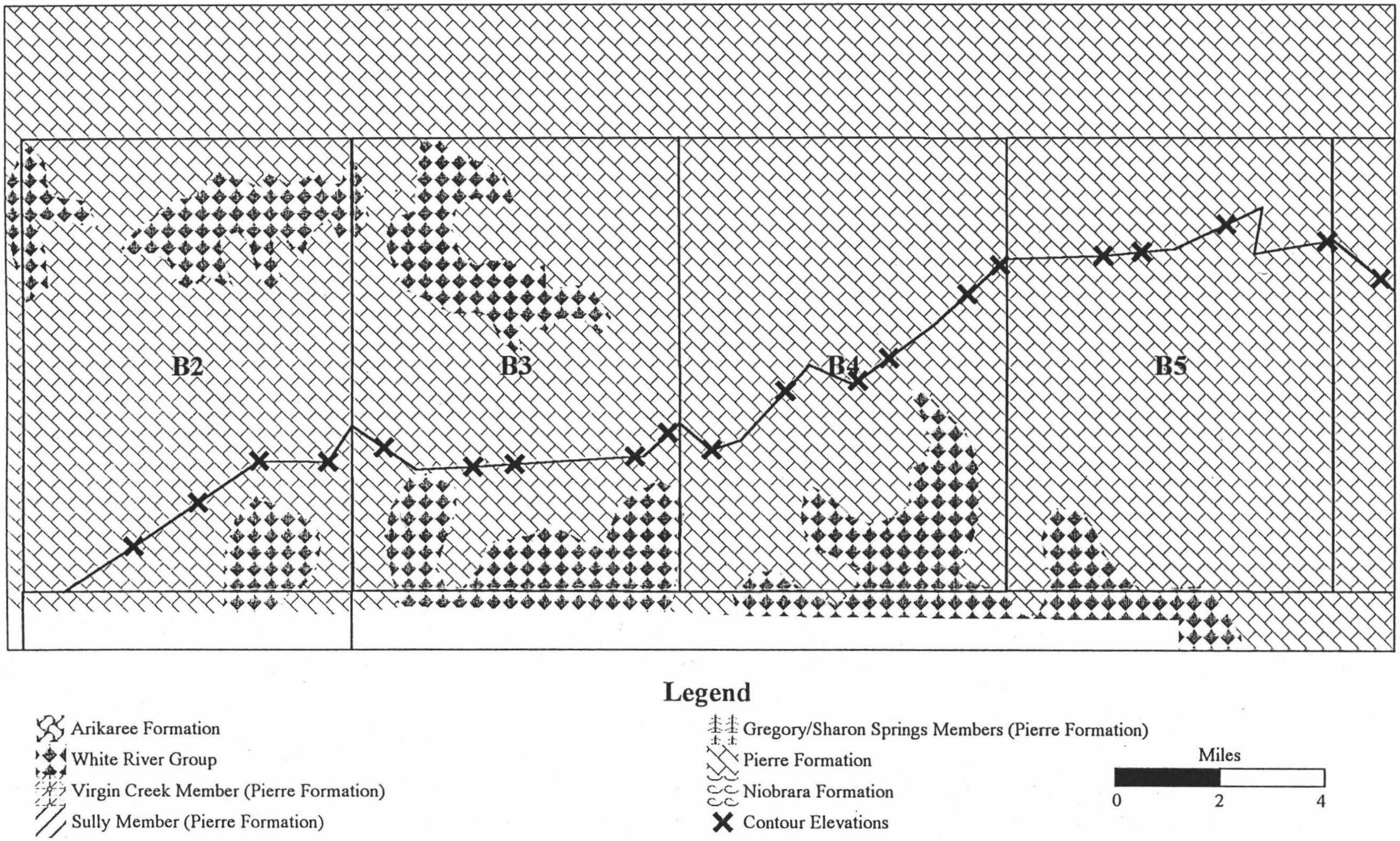


Figure 28. Map showing relationship of geology to elevations knickpoints, and stream profile irregularities along White River land surface profile C. (From Petsch, 1953) (See Figure 2A for quadrangle locations.)

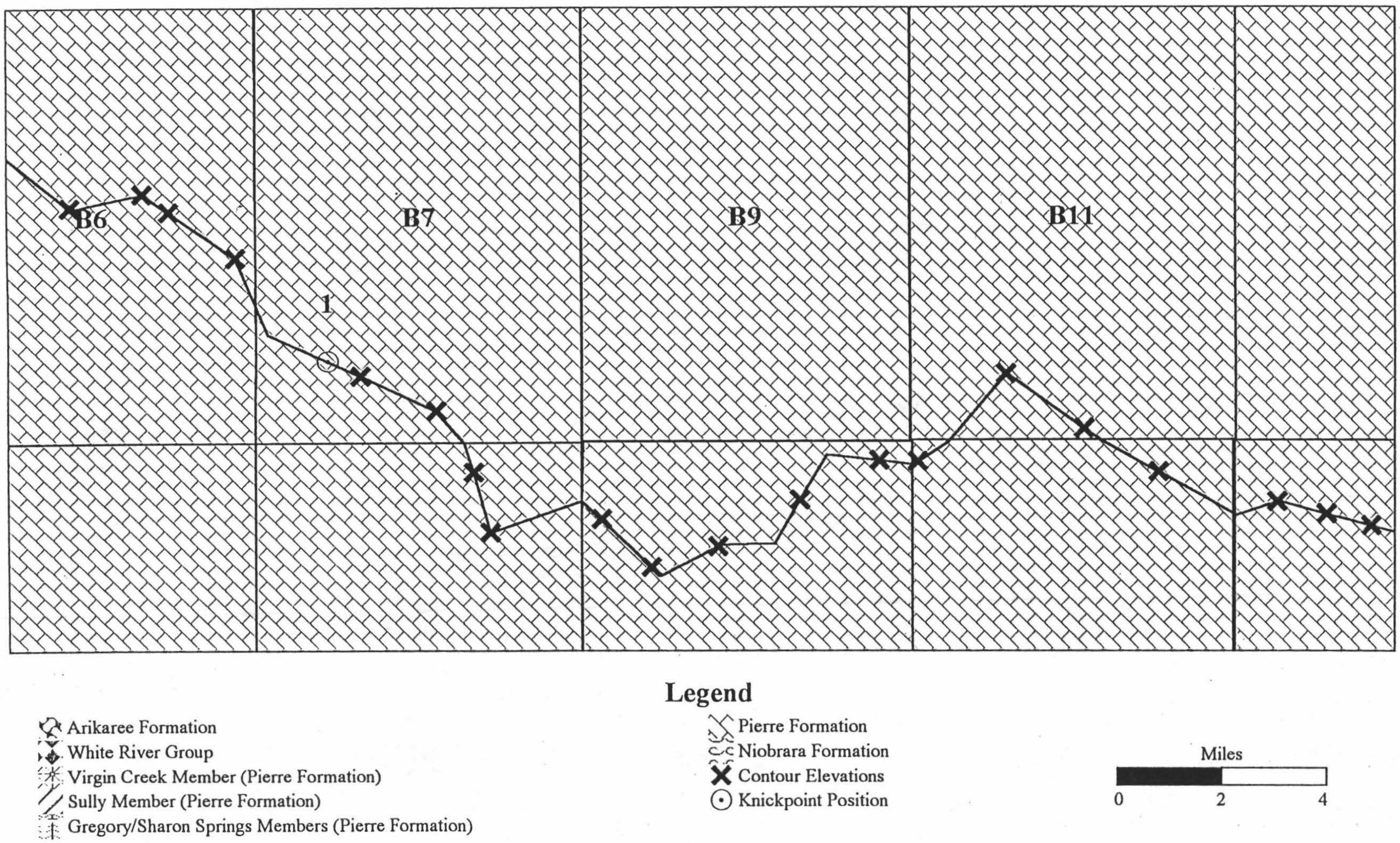


Figure 28. continued.

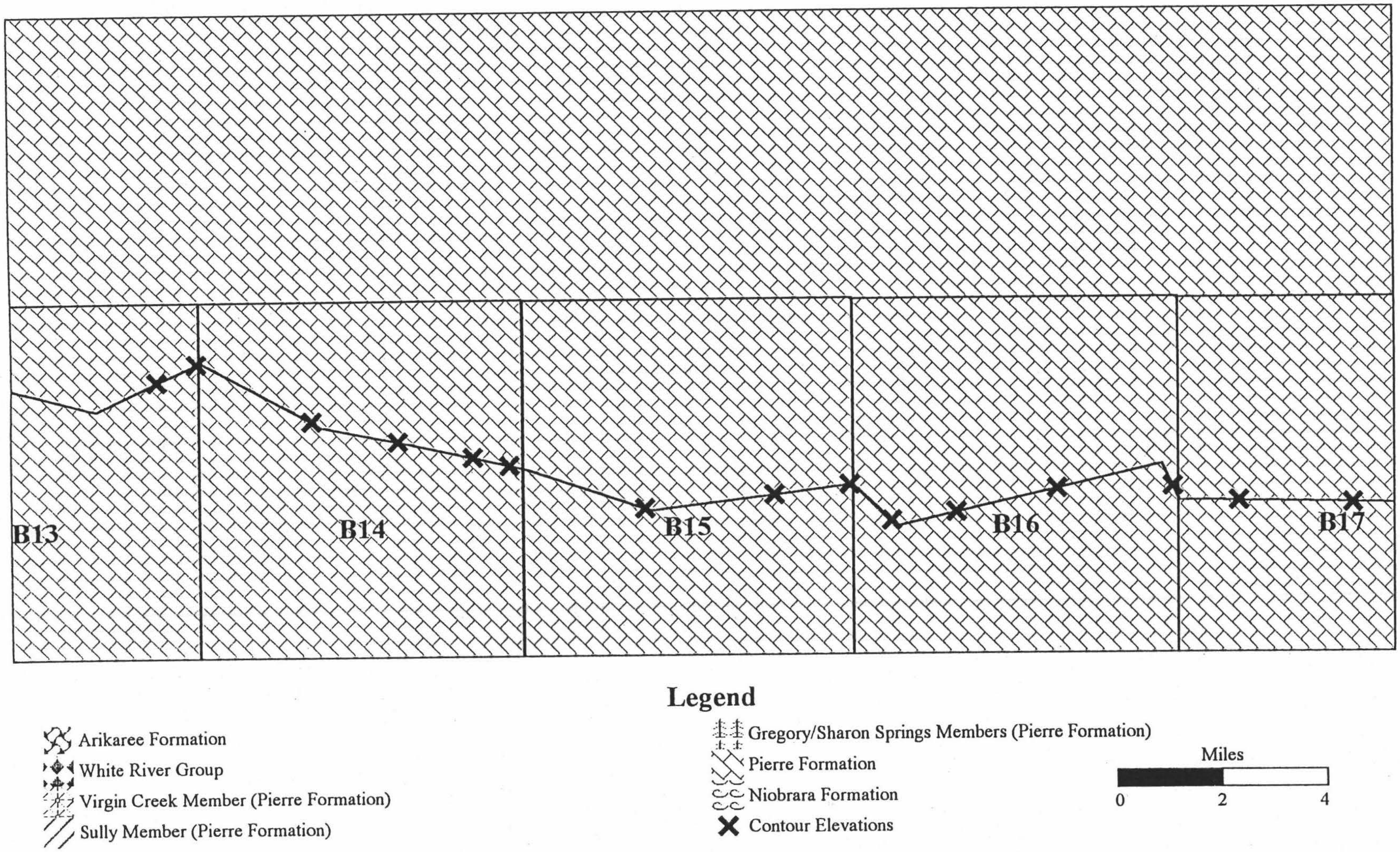


Figure 28. continued.

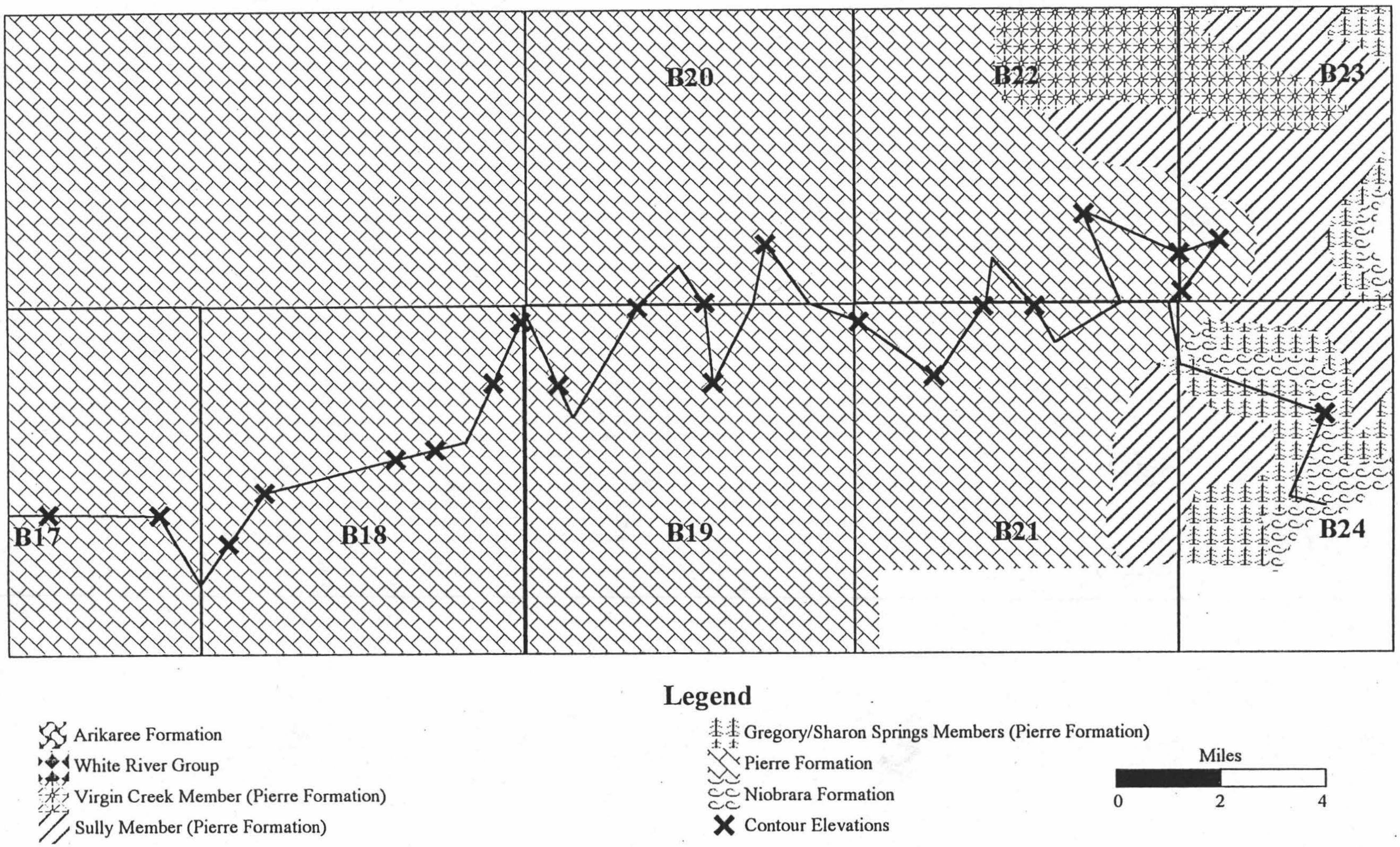


Figure 28. continued.

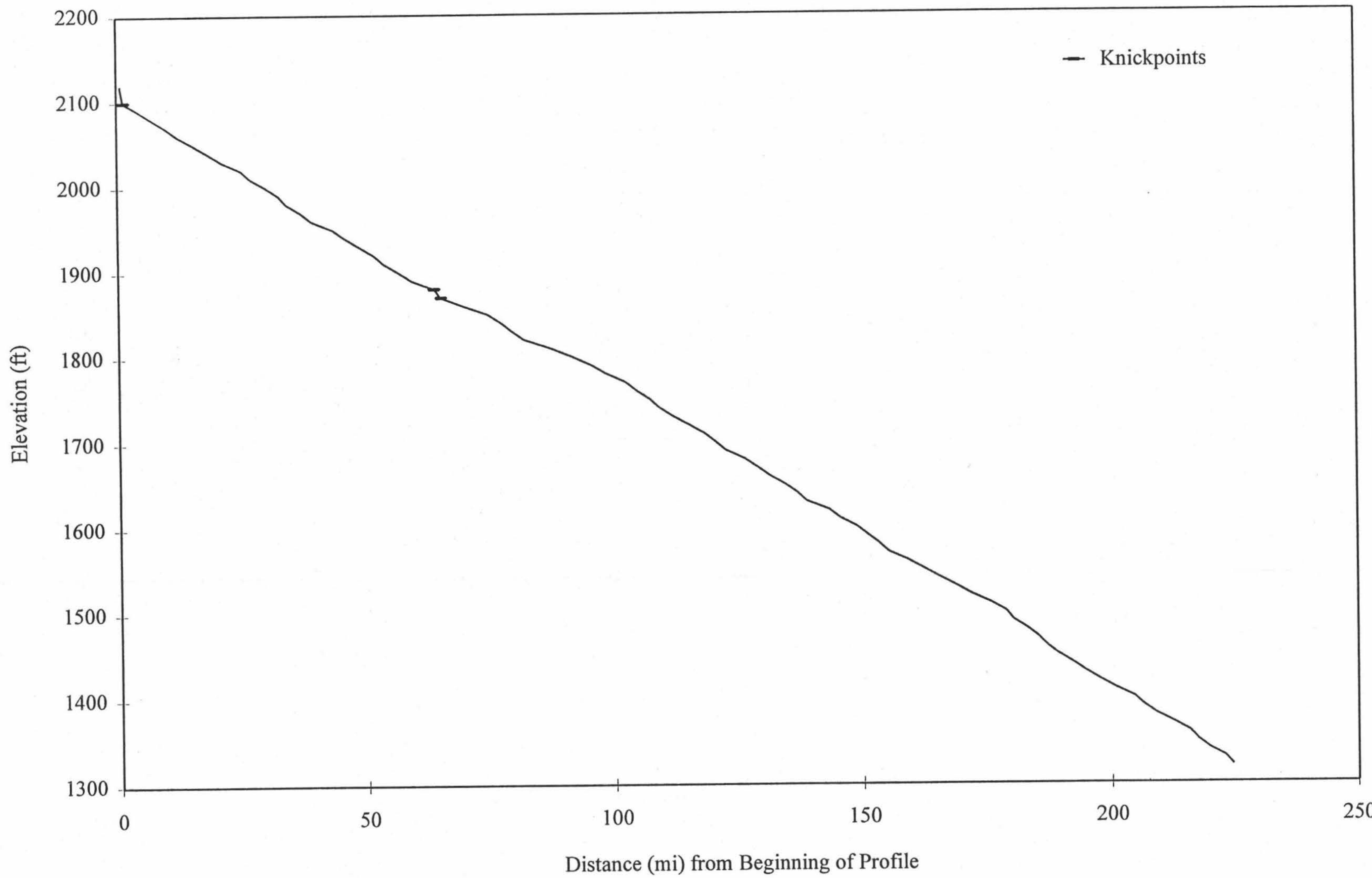


Figure 29. White River profile. (See Figure 25 for knickpoint locations.)

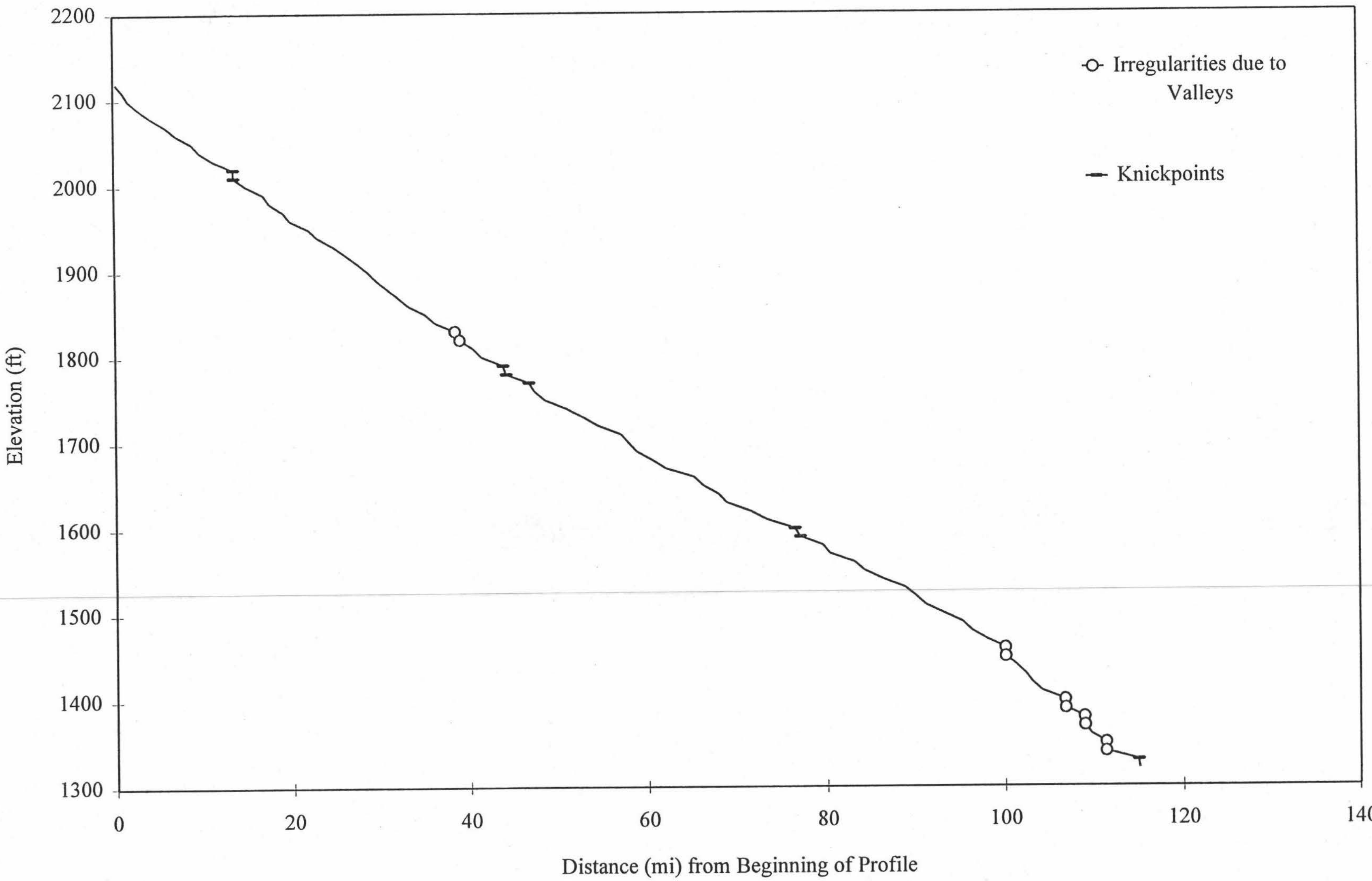


Figure 30. White River land surface profile A. (See Figure 26 for valley irregularity and knickpoint locations.)

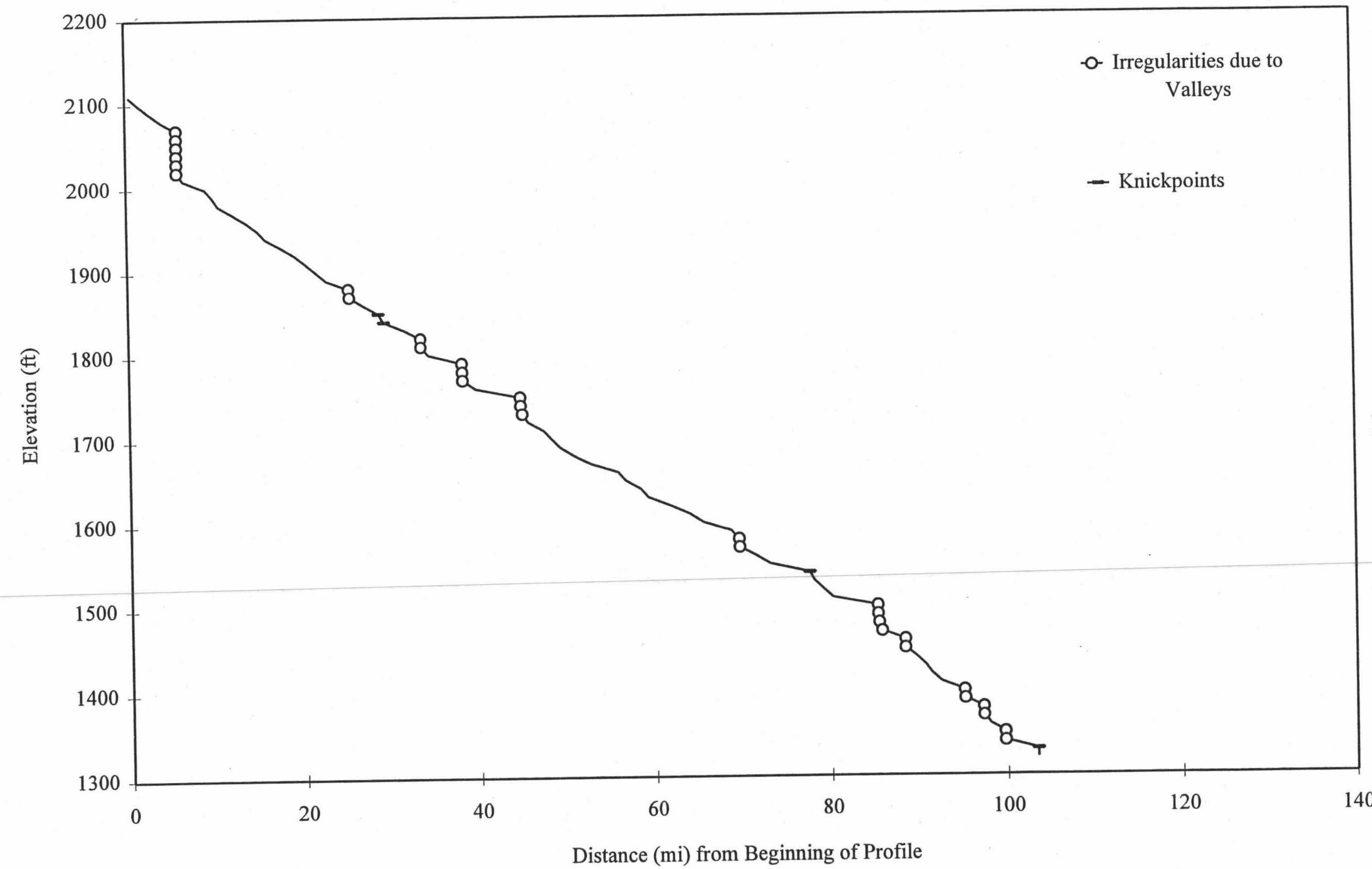


Figure 31. White River land surface profile B. (See Figure 27 for valley irregularity and knickpoint locations.)

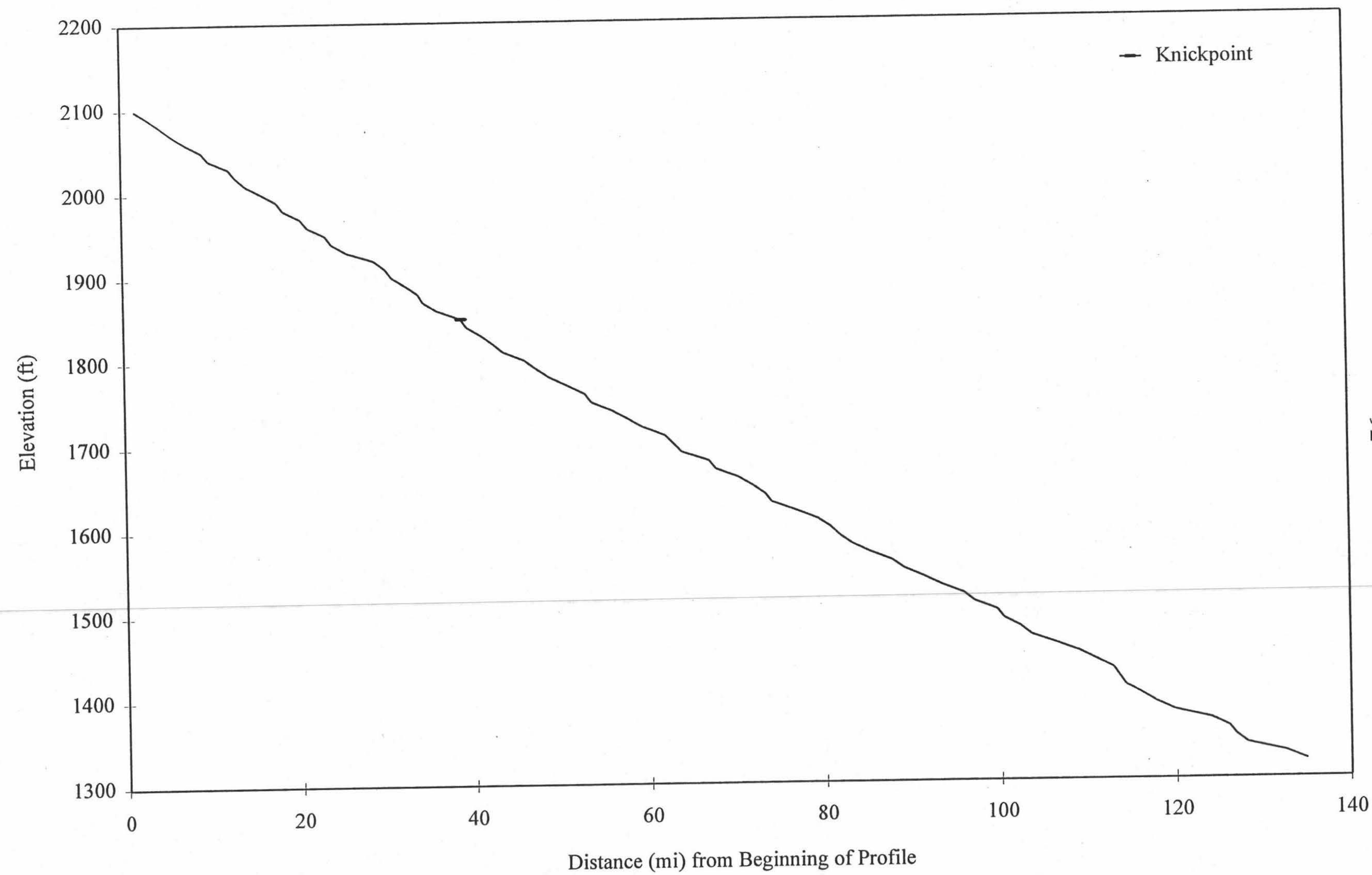


Figure 32. White River land surface profile C. (See Figure 28 for knickpoint location.)

An equation of a trendline for the reach of White River land surface profile A above 1460 ft has been calculated (Table 1). At the end of the profile the difference between the actual elevation of the profile and the calculated elevation of the trendline is 59.1 ft. The equation of a trendline for a section of White River land surface profile B above an elevation of 1540 ft has also been calculated (Table 1). The elevation of the trendline is 43.68 ft above the actual elevation at the end of the profile.

The only knickpoint common among profiles was at an elevation of 1850 ft on White River Land Surface profiles B and C (Table 2).

When all profiles were plotted together the White River profile has a much more gentle gradient than the land surface profiles (Figure 33). A plot of only the land surface profiles shows that land surface profiles A and B are steeper than land surface profile C (Figure 34). This graph also shows land surface profiles B and C crossing several times, much like in other river areas.

Keya Paha River

Profiles were also constructed along and adjacent to the Keya Paha River between the elevations of 2370 ft and 1640 ft (Figures 35-38). These profiles, much like the others, show a linear to slightly concave shape (Figures 39-42). Slopes and distances were determined between elevation points for knickpoint identification (Appendix C).

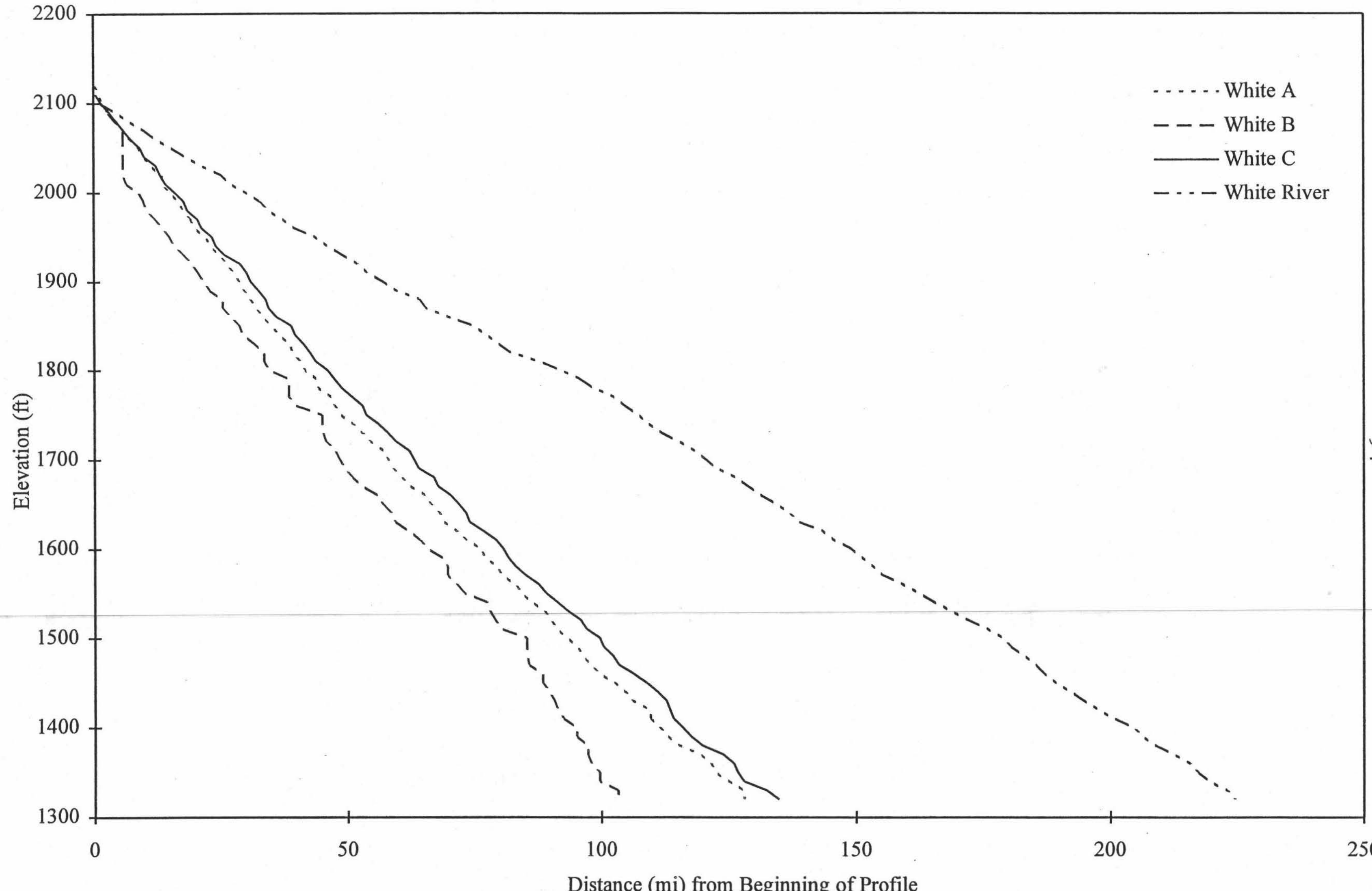


Figure 33. White River and land surface profiles.

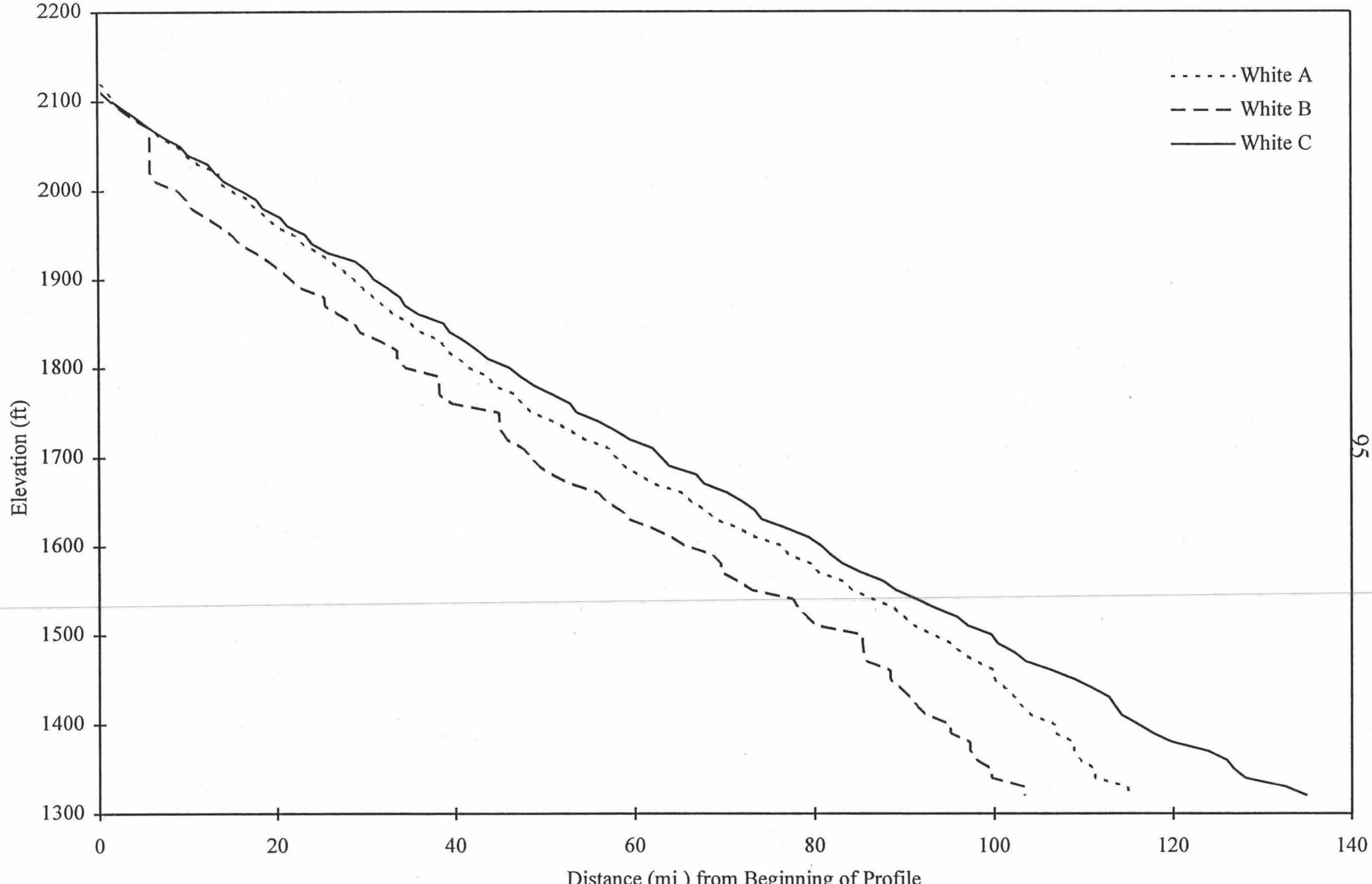


Figure 34. White River land surface profiles.

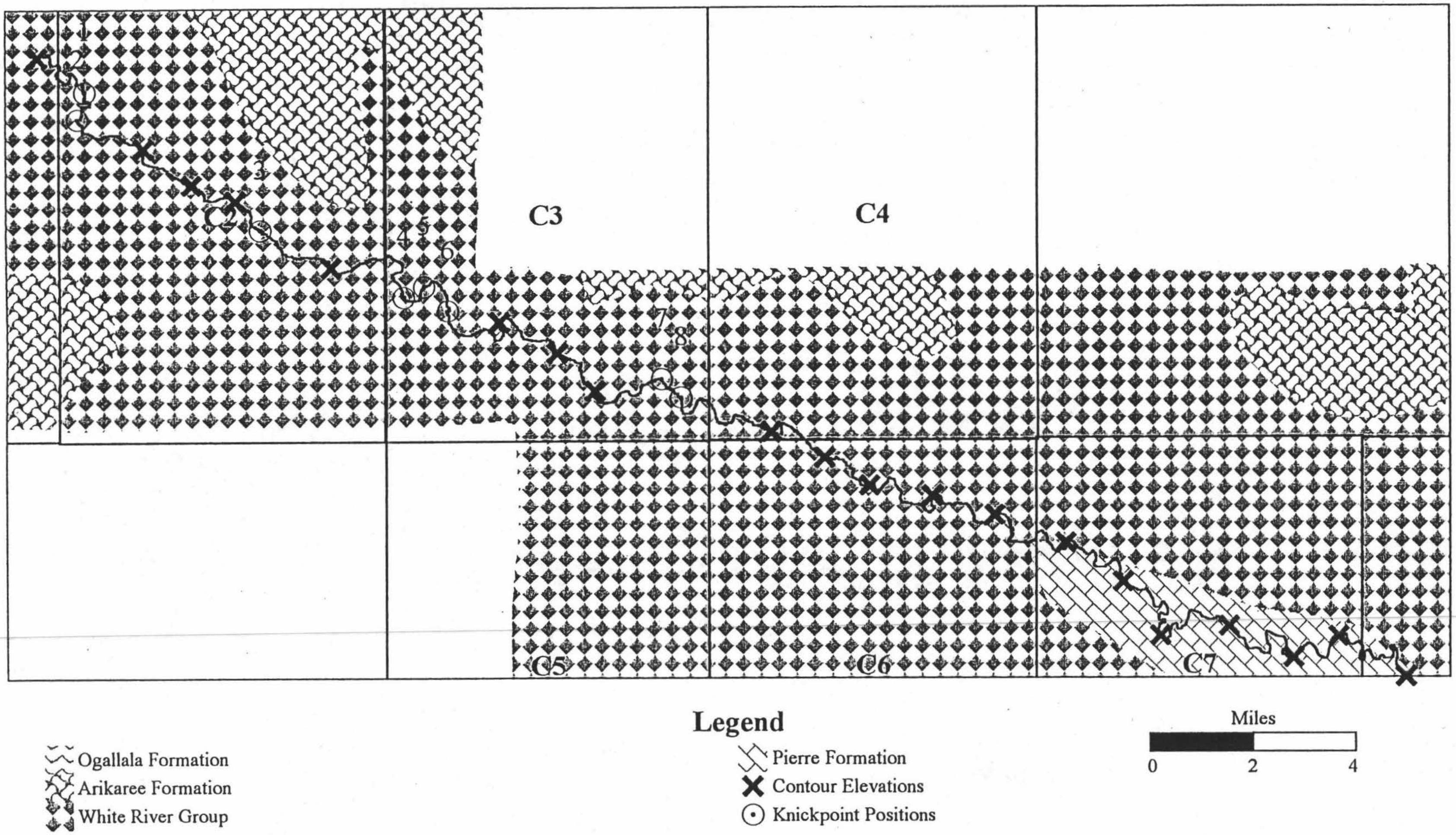


Figure 35. Map showing relationship of geology to elevations and knickpoints along Keya Paha River. (From Petsch, 1953; Burchett, 1969) (See Figure 2A for quadrangle locations.)

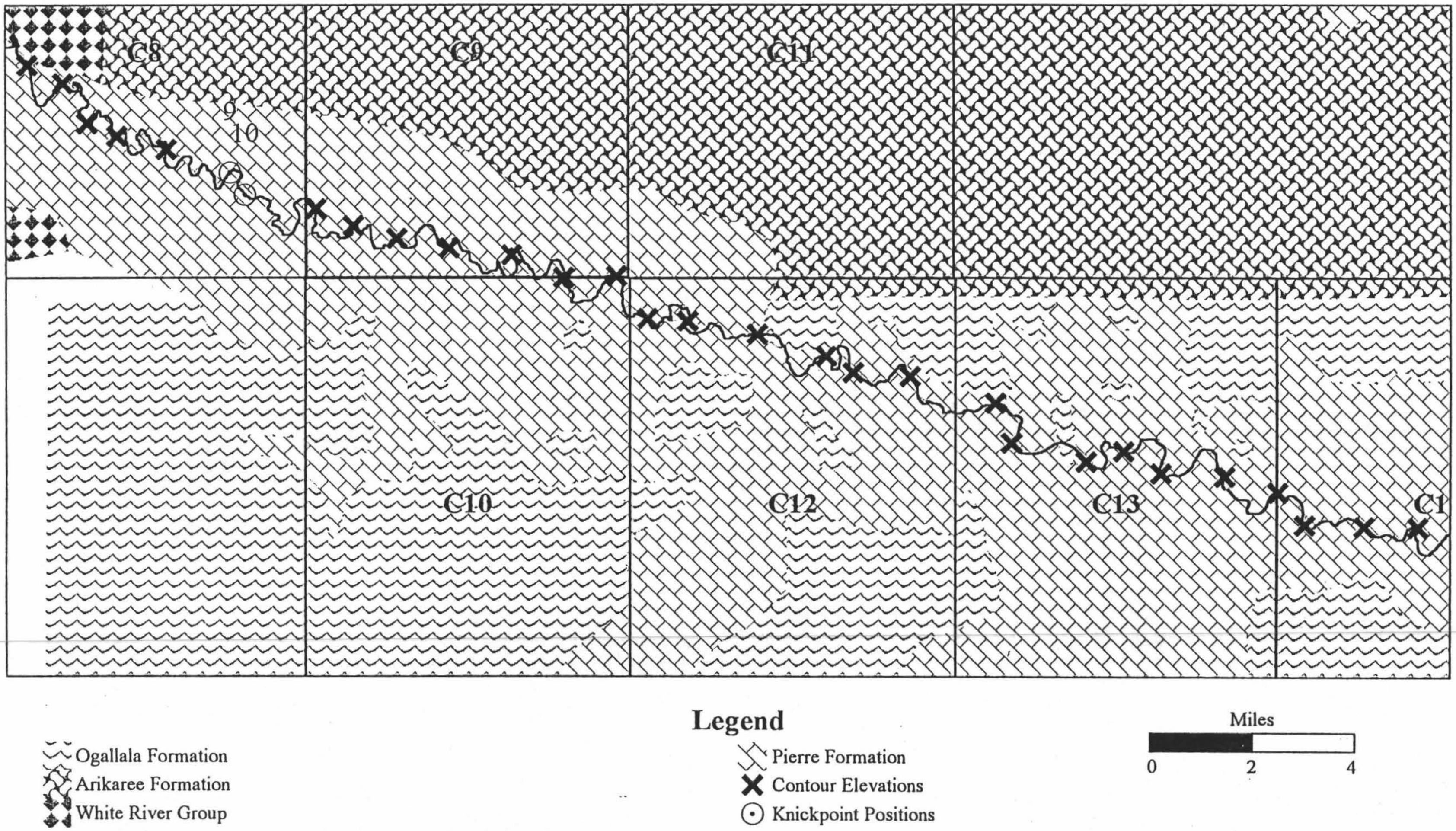


Figure 35. continued.

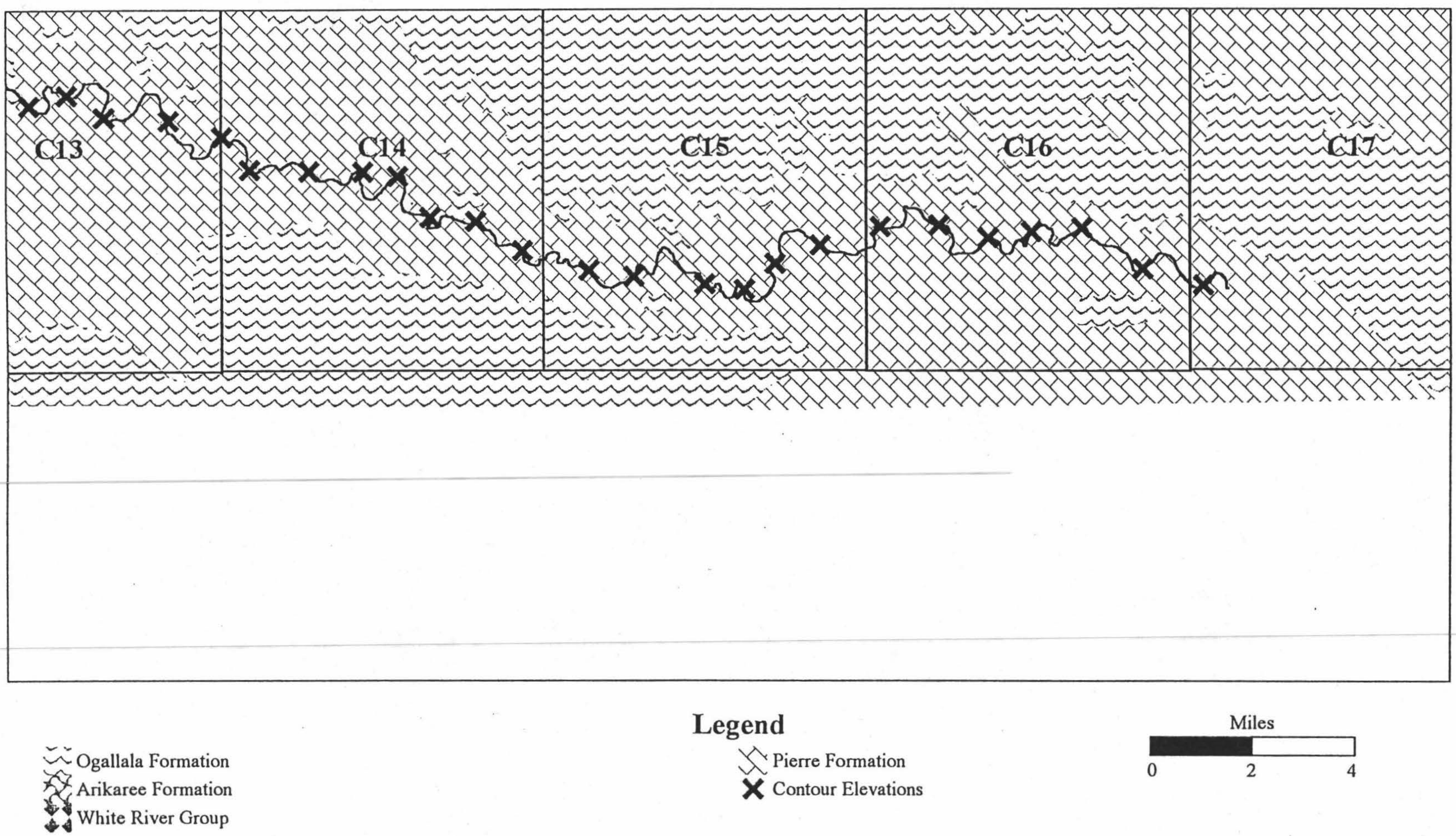


Figure 35. continued.

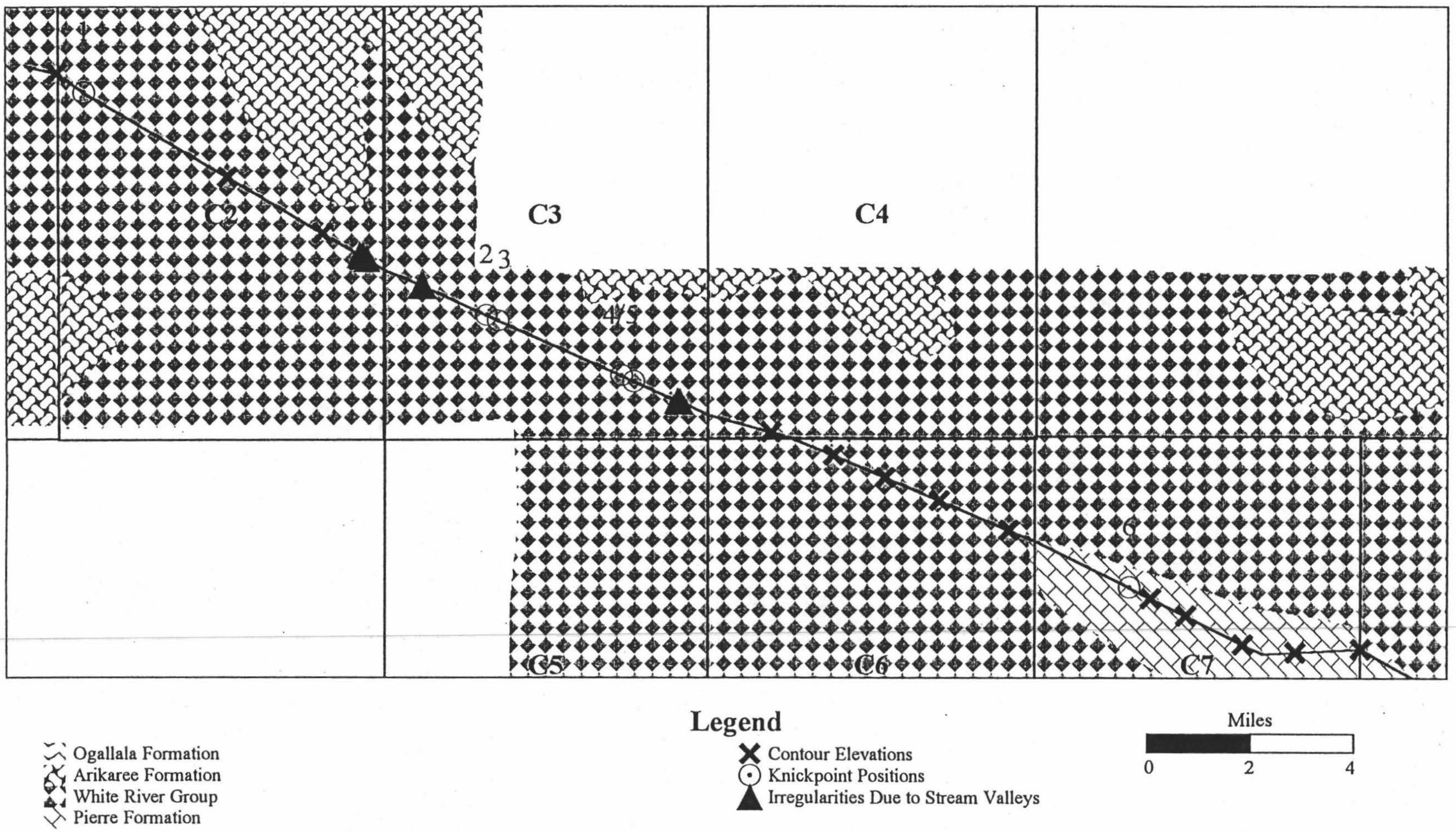


Figure 36. Map showing relationship of geology to elevations, knickpoints, and stream valley irregularities along Keya Paha River land surface profile A. (From Petsch, 1953; Burchett, 1969) (See Figure 2A for quadrangle locations.)

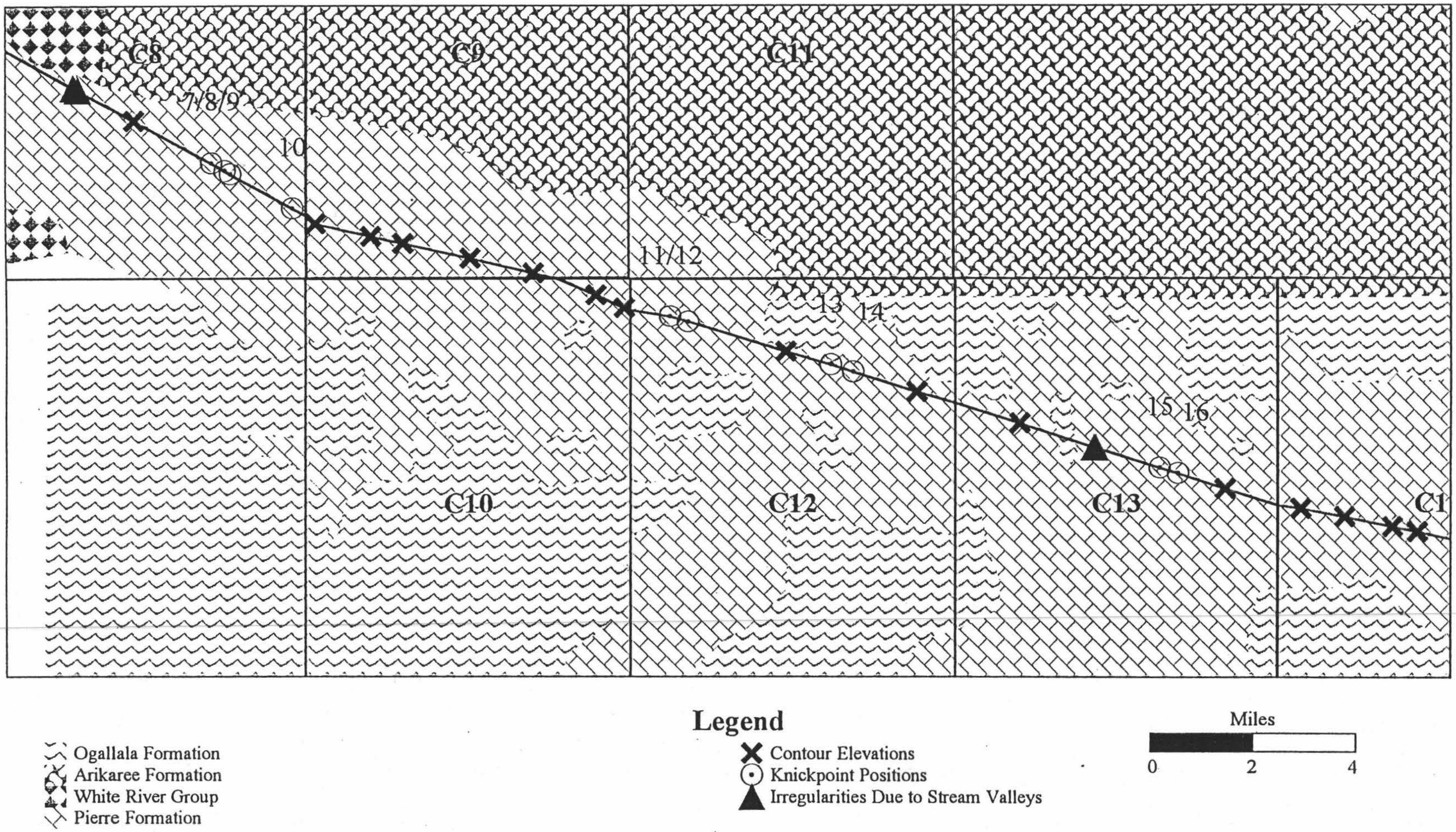


Figure 36. continued.

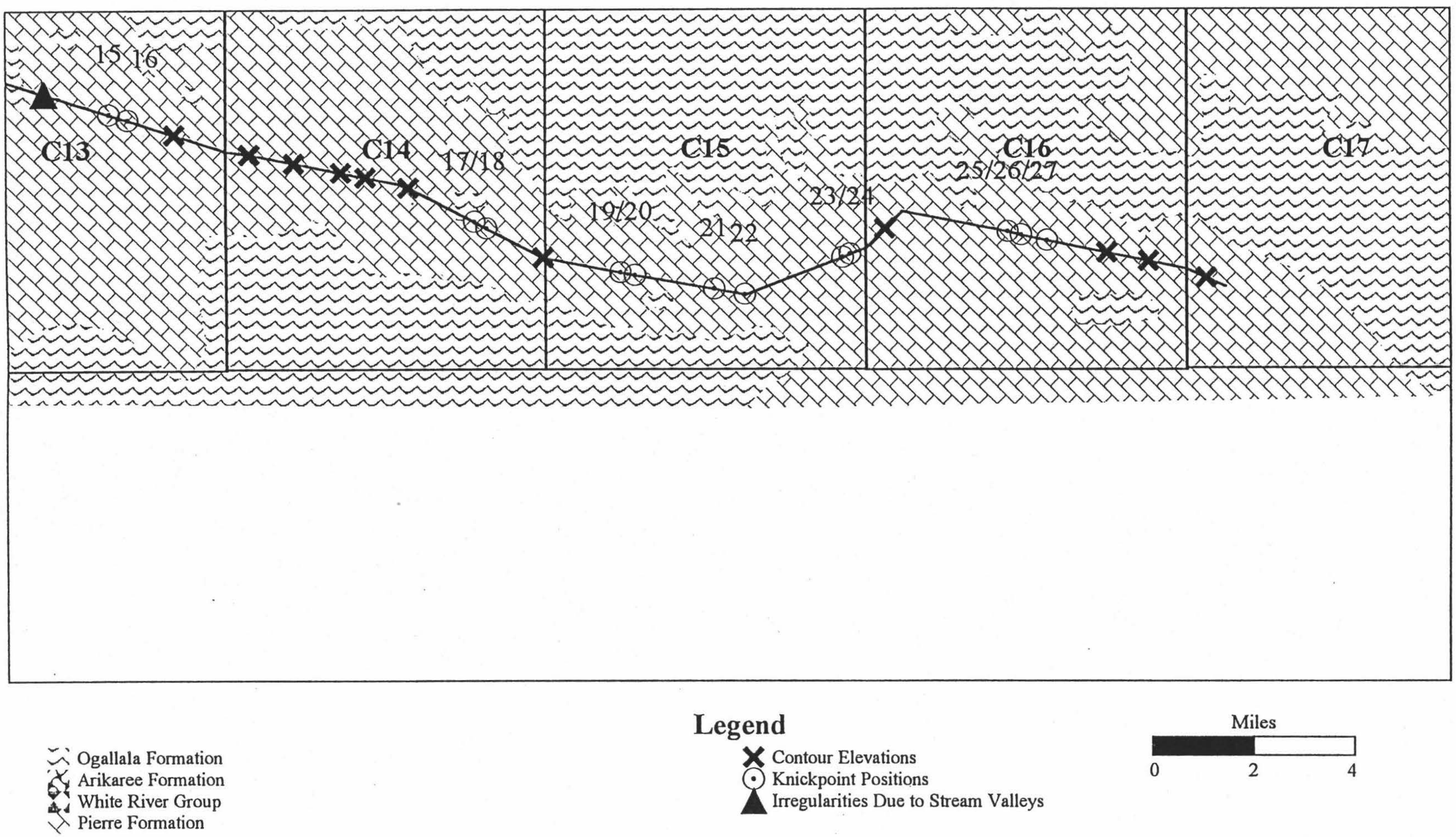


Figure 36. continued.

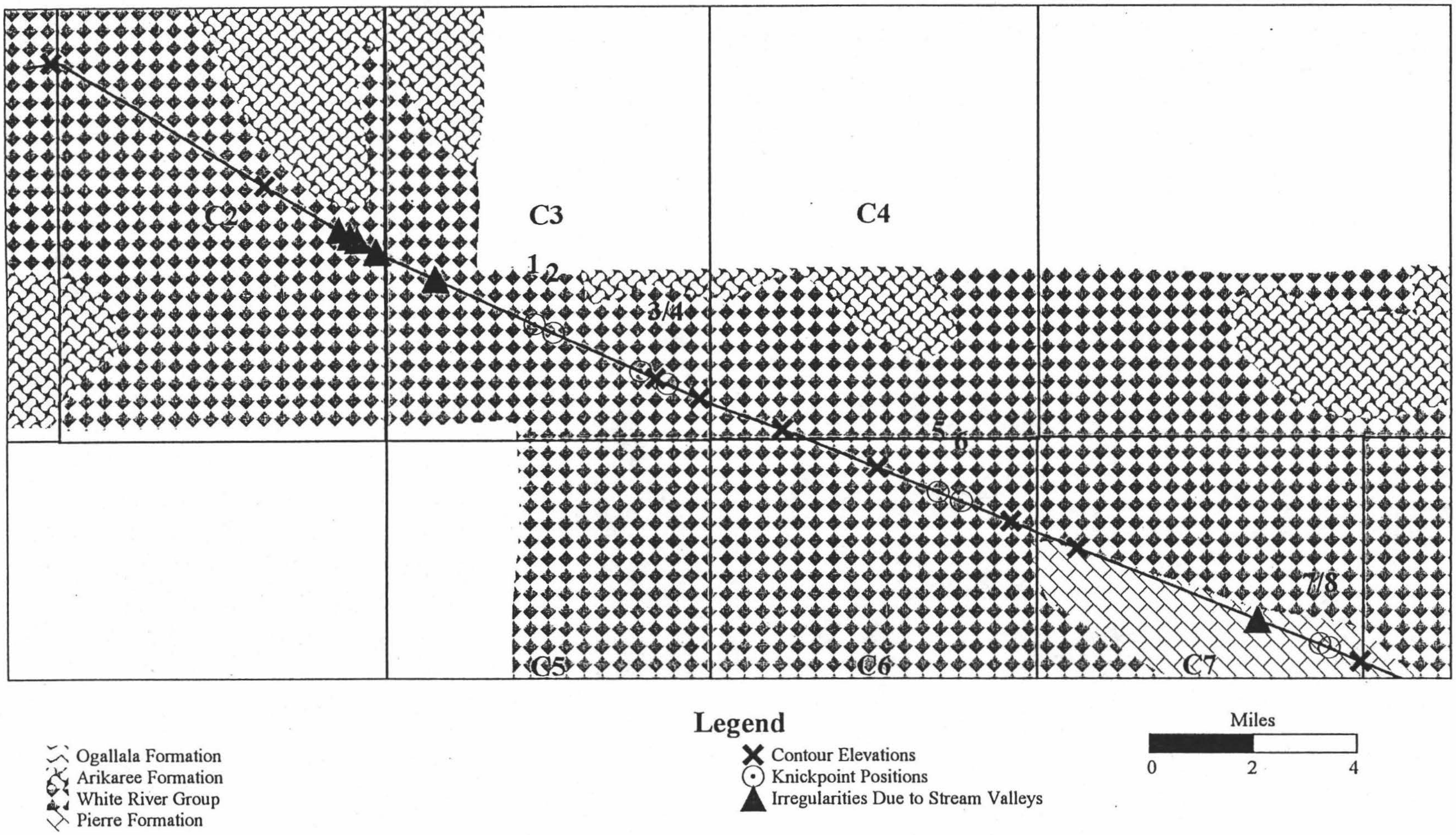


Figure 37. Map showing relationship of geology to elevations, knickpoints, and stream valley irregularities along Keya Paha River land surface profile B. (From Petsch, 1953; Burchett, 1969) (See Figure 2A for quadrangle locations.)

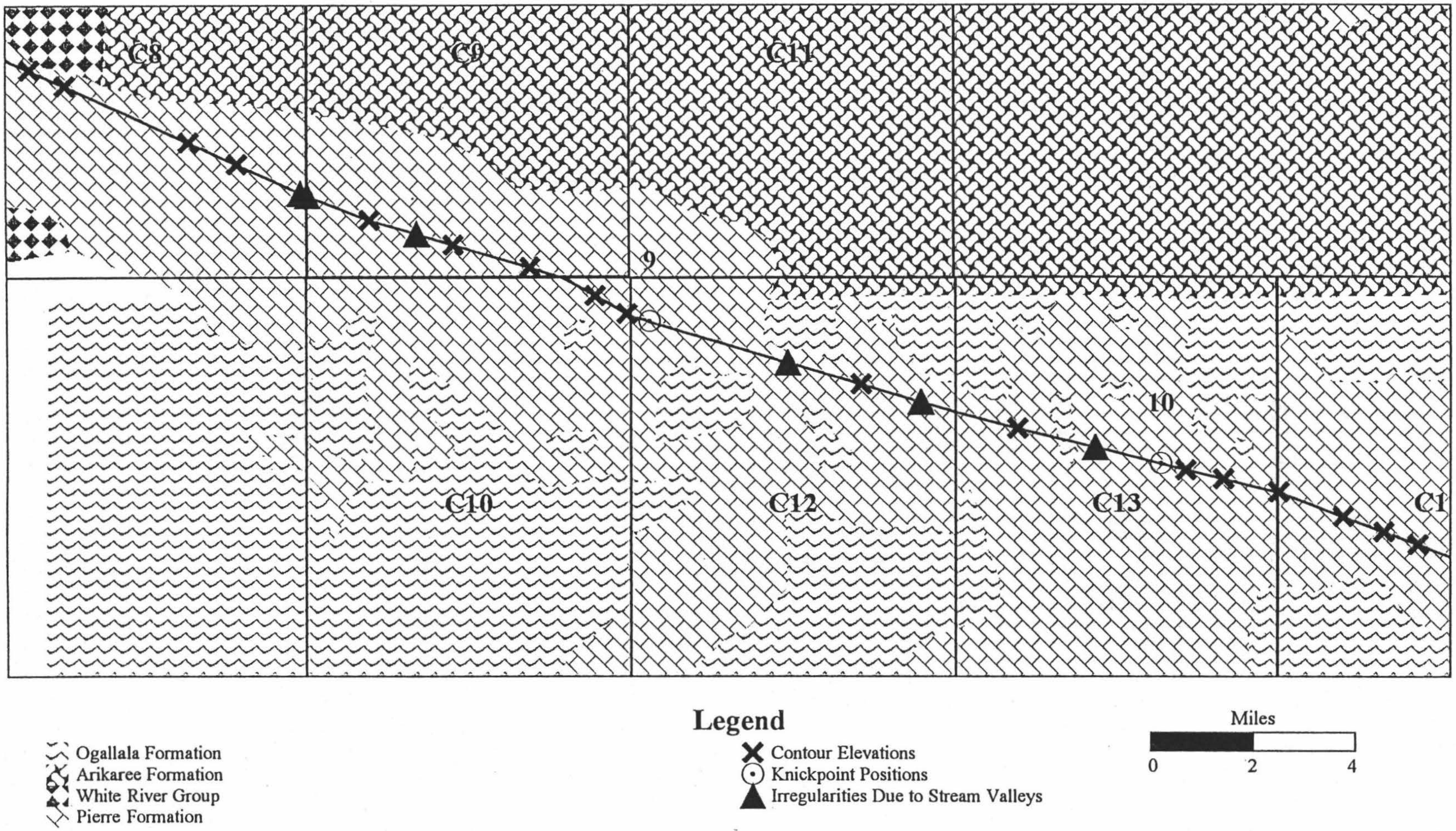


Figure 37. continued.

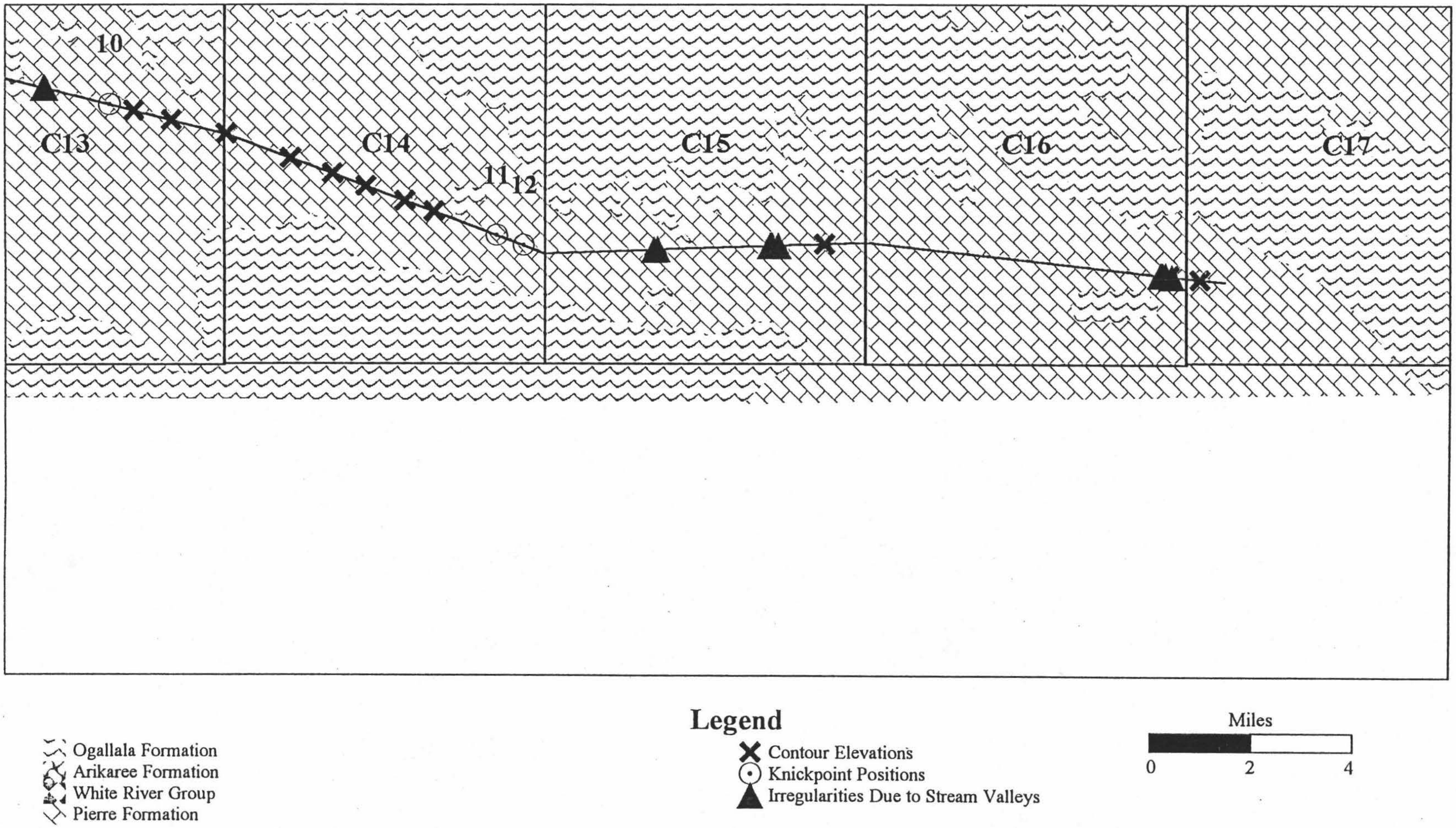


Figure 37. continued.

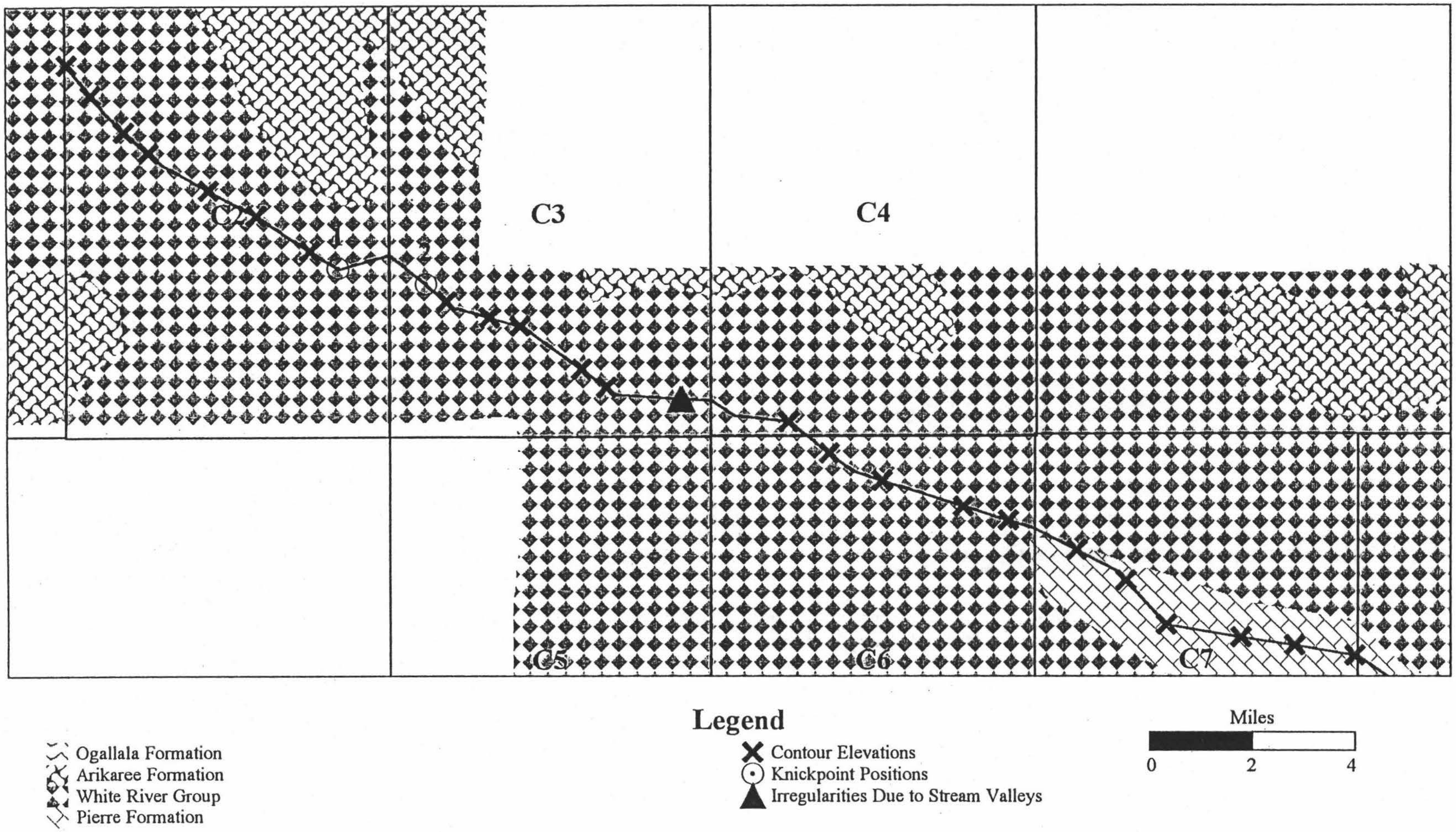


Figure 38. Map showing relationship of geology to elevations, knickpoints and stream profile irregularities along Keya Paha River land surface profile C. (From Petsch, 1953; Burchett, 1969) (See Figure 2A for quadrangle locations.)

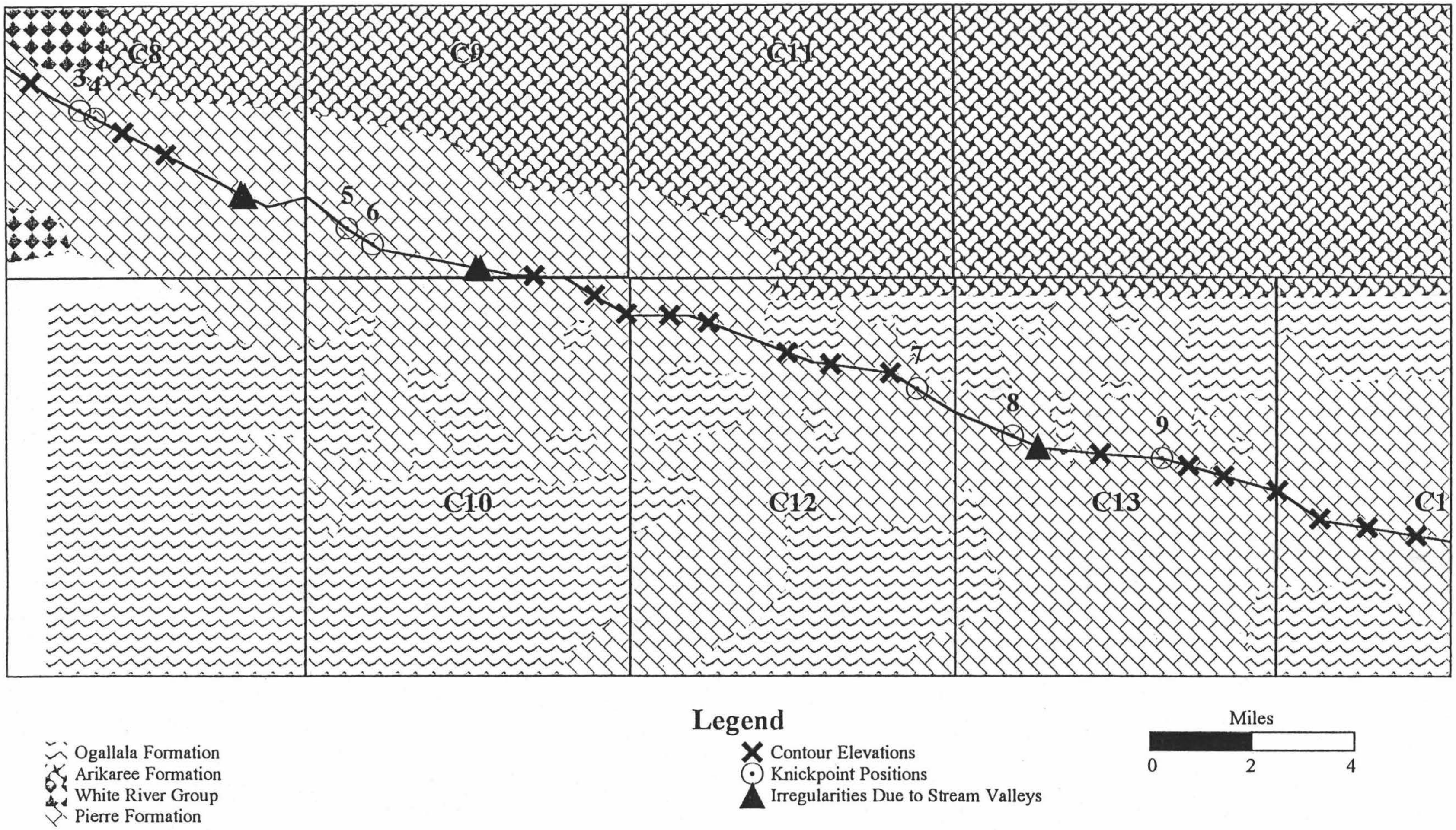


Figure 38. continued.

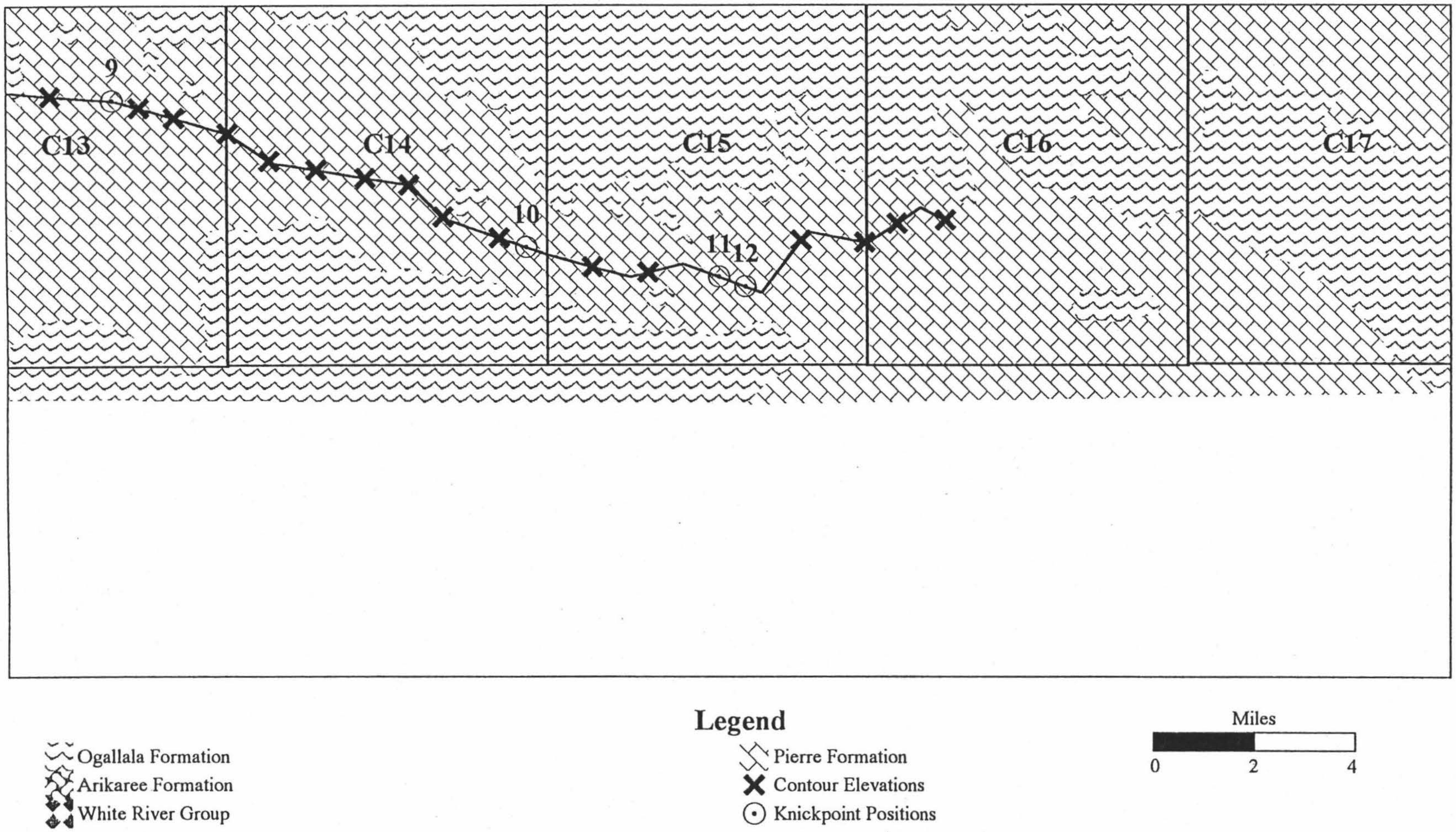


Figure 38. continued.

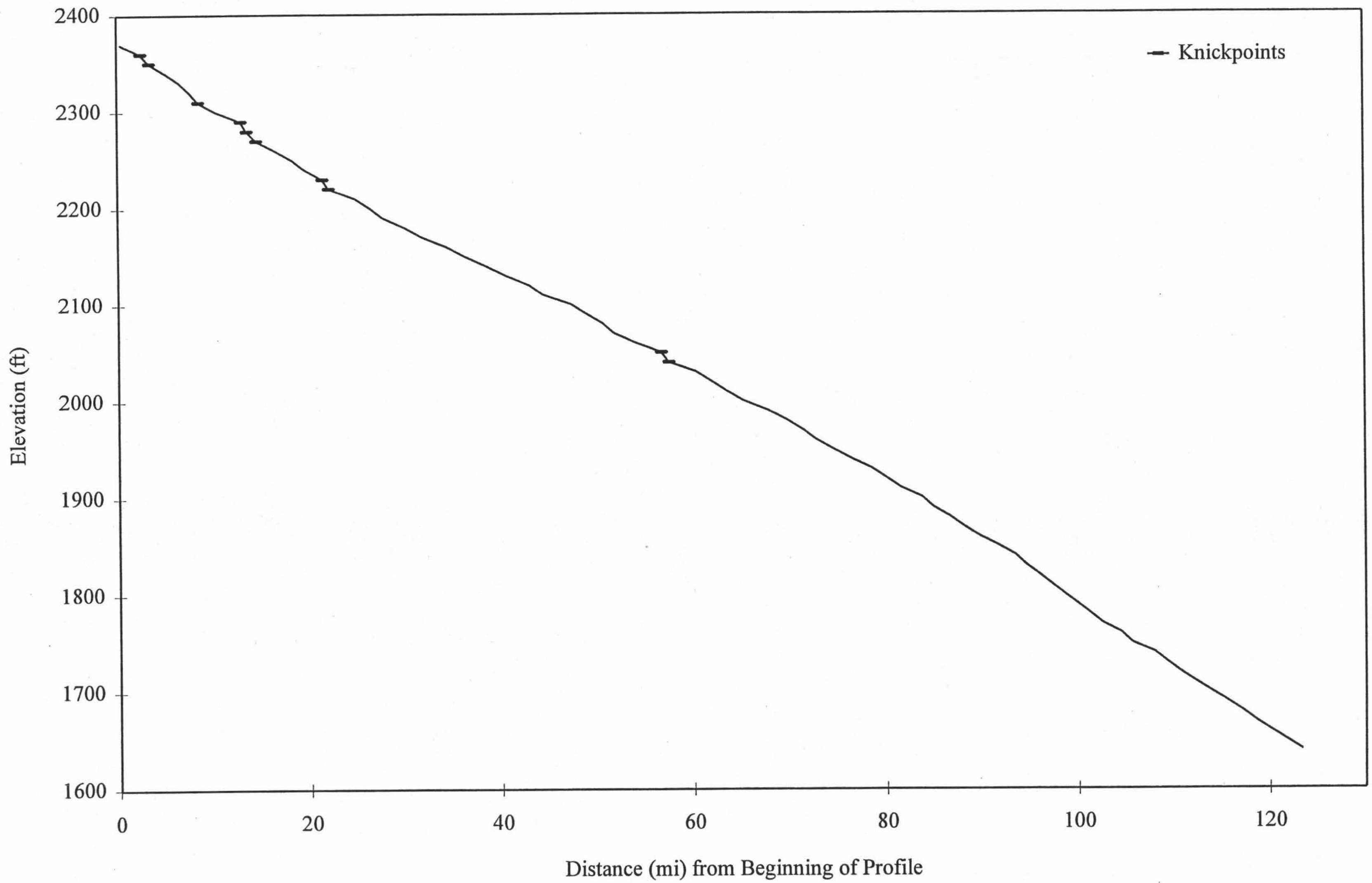


Figure 39. Keya Paha River profile. (See Figure 35 for knickpoint locations.)

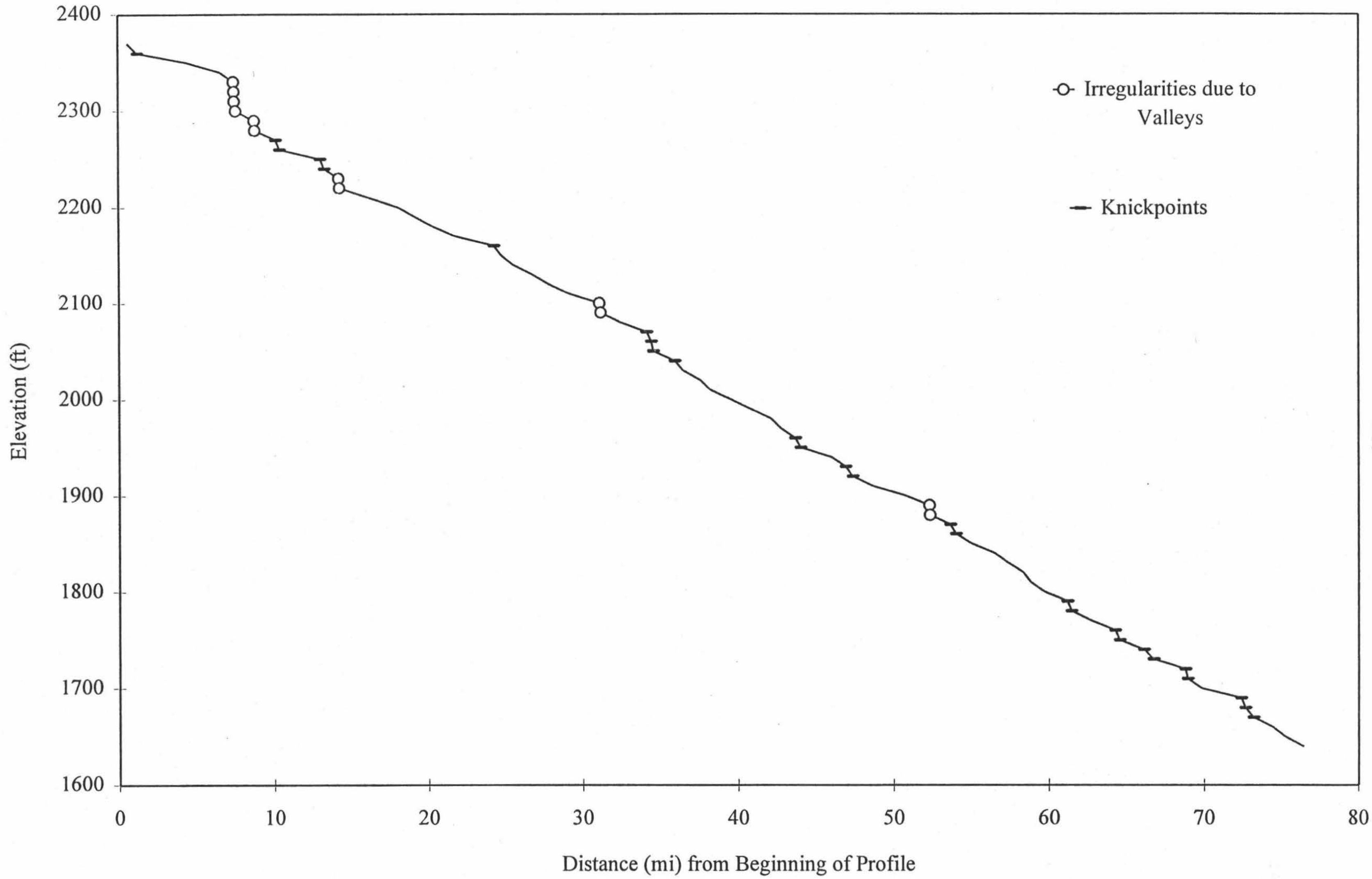


Figure 40. Keya Paha River land surface profile A. (See Figure 36 for valley irregularity and knickpoint locations.)

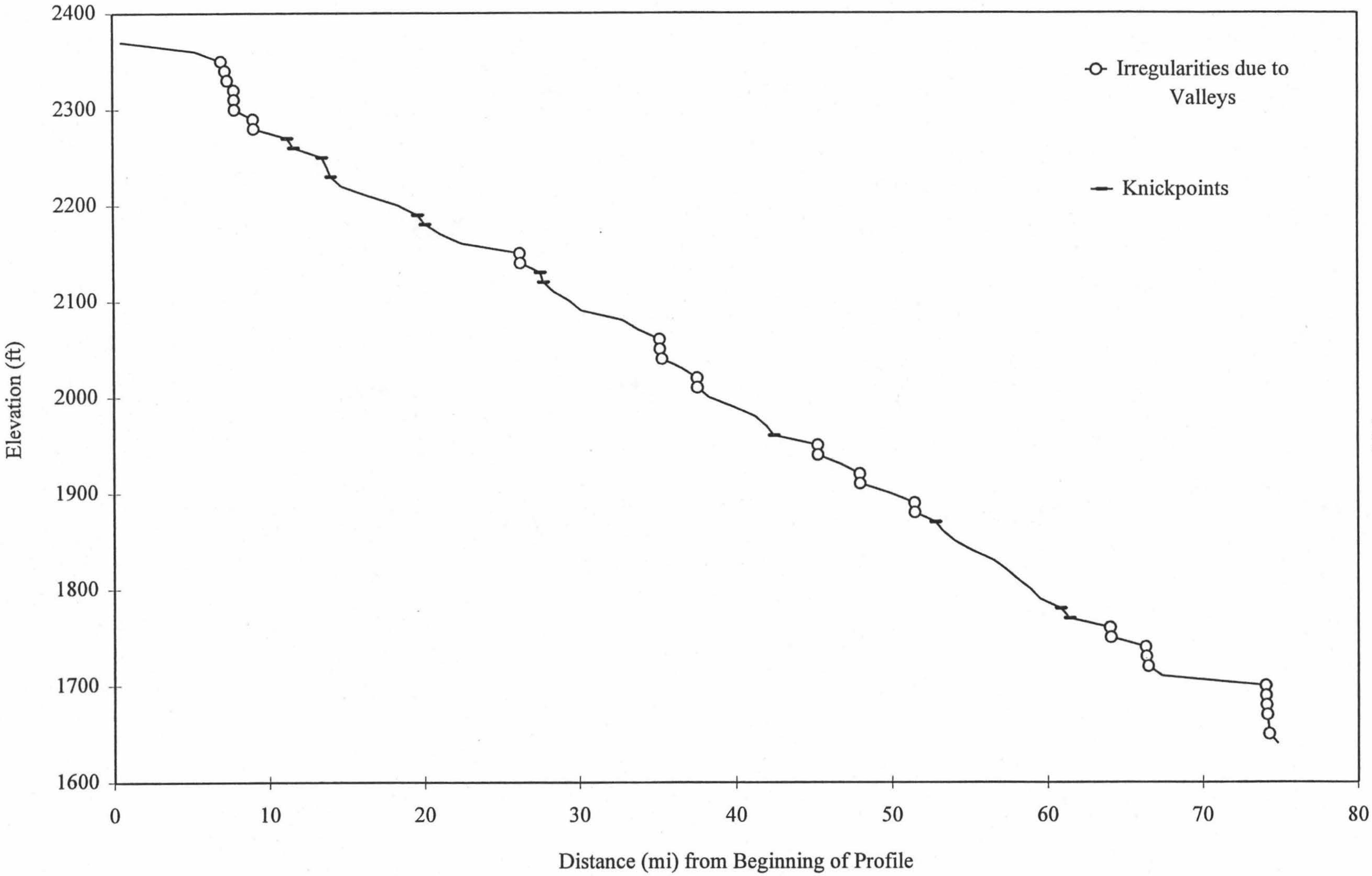


Figure 41. Keya Paha River land surface profile B. (See Figure 37 for valley irregularitiy and knickpoint locations.)

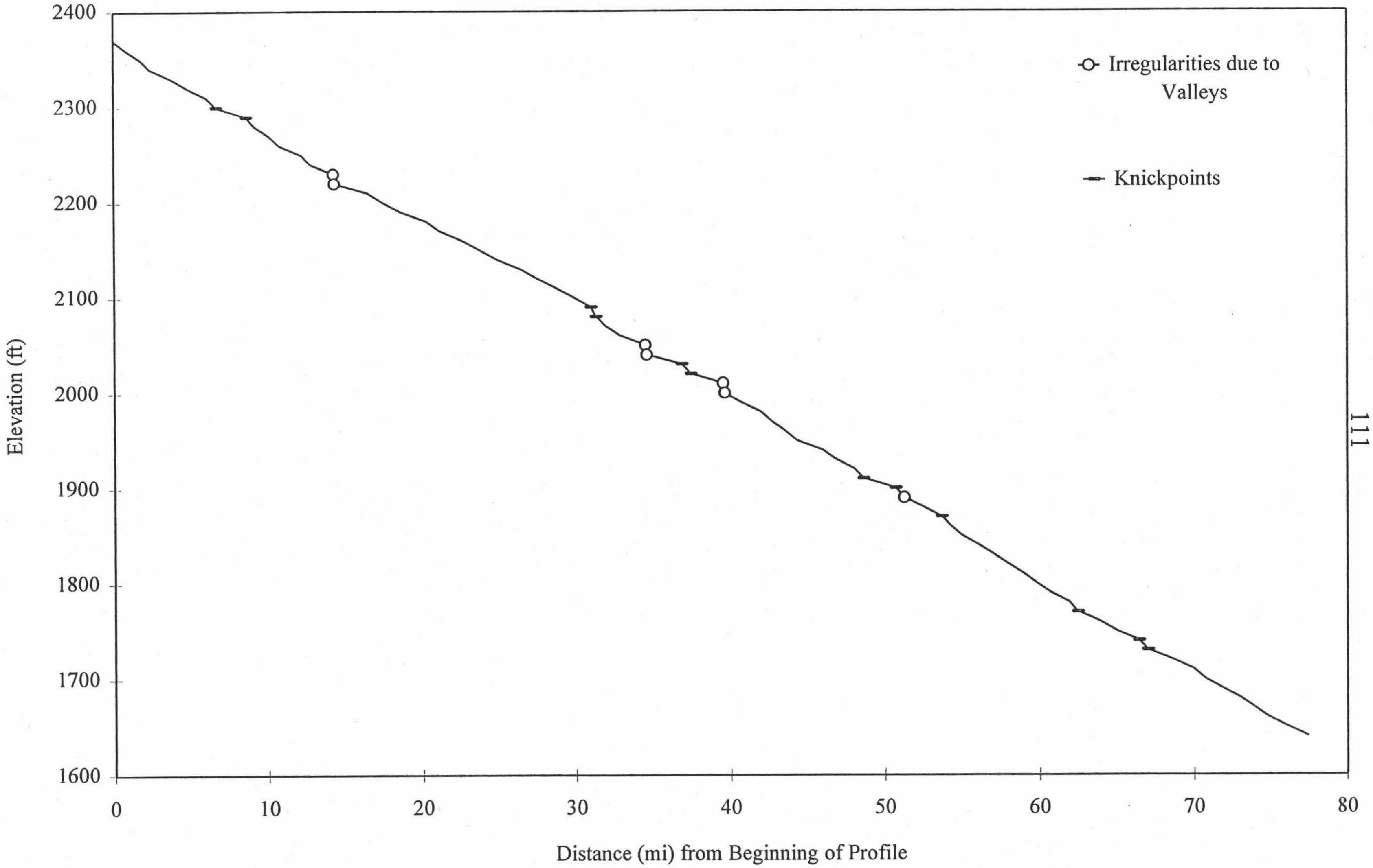


Figure 42. Keya Paha River land surface profile C (See Figure 38 for valley irregularity and knickpoint locations.)

No knickpoints appear to be related to changes in lithology (Figures 35-38) Appendix D). However, knickpoints number one, two, three, five, nine and ten appear to relate to tributary junctures along the Keya Paha River profile (Figure 35; Appendix D).

A trendline was calculated for the reach of Keya Paha Land Surface Profile A above 2160 ft (Table 1). The difference in elevation as calculated from the trendline and the actual elevation is 61.75 ft at the end of the profile. A trendline for the reach of Keya Paha land surface profile C above 2090 ft is approximately 94 ft higher than the actual elevation at the end of the profile (Table 1).

The evaluation of common knickpoint elevations showed that many are common to the several profiles (Table 2).

All the profiles from this area plotted together show the land surface profiles to be much steeper than the Keya Paha River profile (Figure 43). When all the land surface profiles are plotted together they appear similar in slope (Figure 44). Land surface profiles from the Keya Paha area are much more similar in slope than are land surface profiles from other areas.

Ponca Creek

Profiles were constructed for an area along and adjacent to Ponca Creek between the elevations of 2370 ft and 1640 ft (Figures 45-48). These profiles show a linear to slightly convex shape (Figures 49-52). Slopes and distances have been determined between elevation points for knickpoint identification (Appendix C).

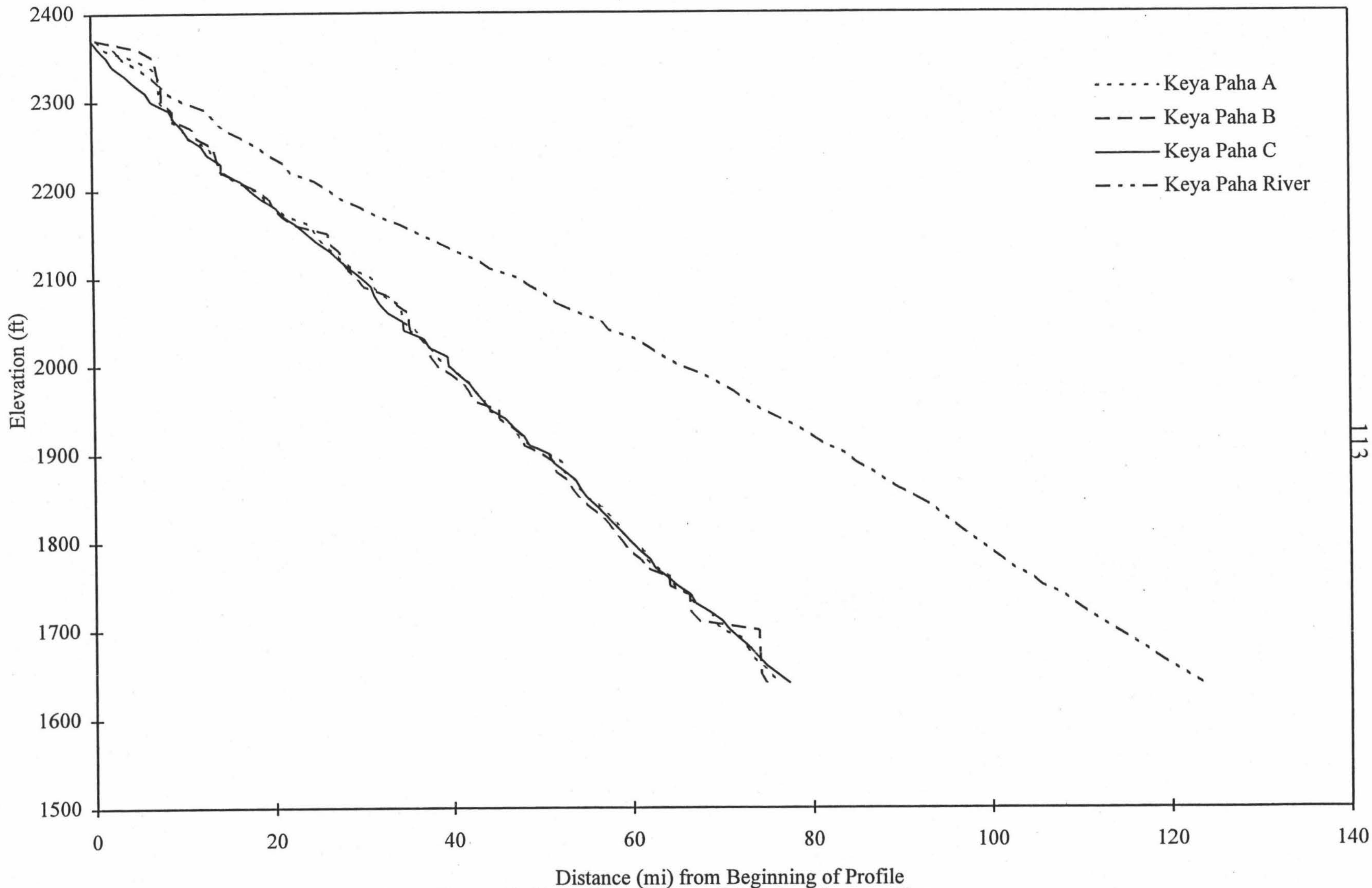


Figure 43. Keya Paha River and land surface profiles.

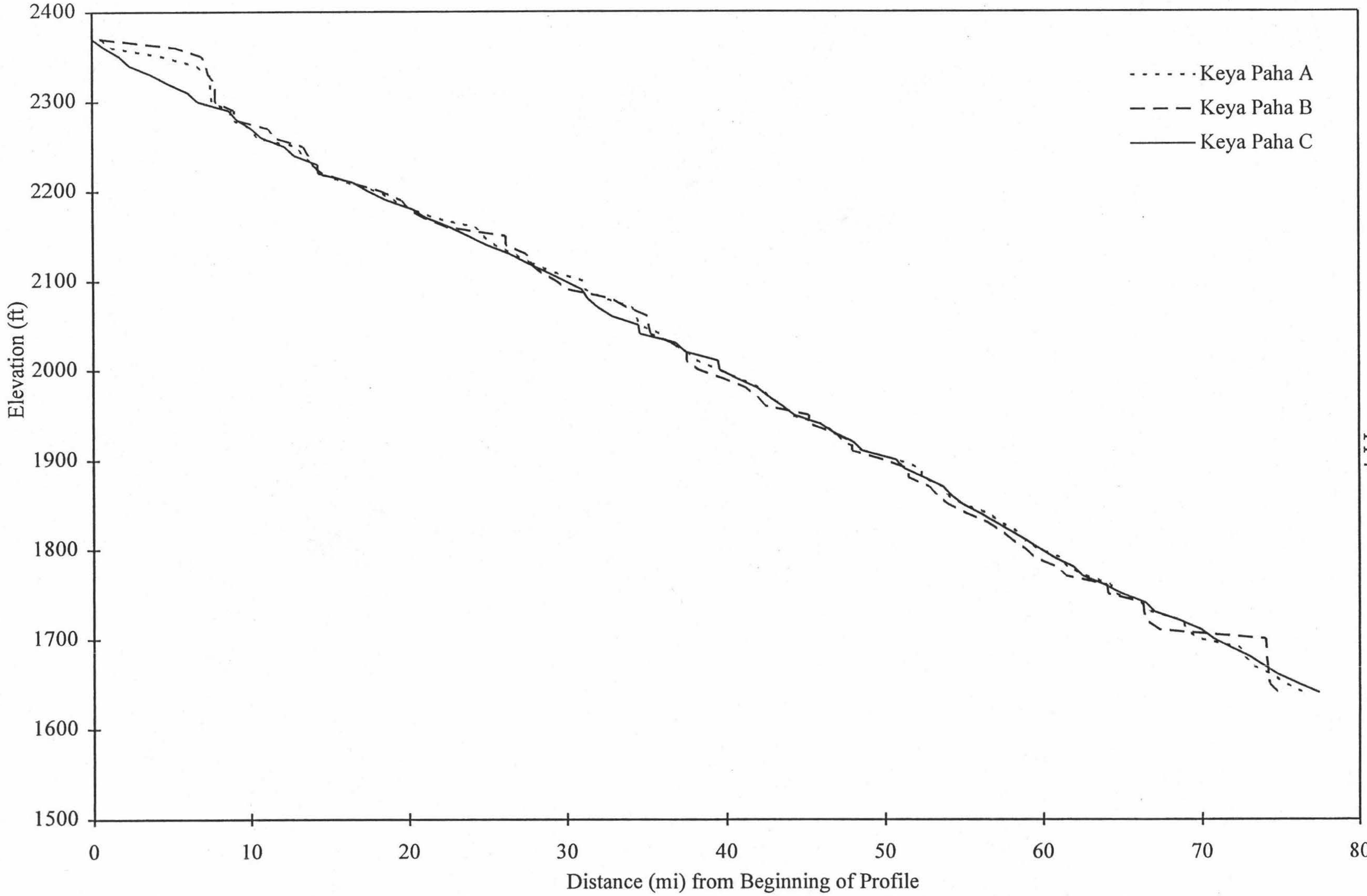


Figure 44. Keya Paha River land surface profiles.

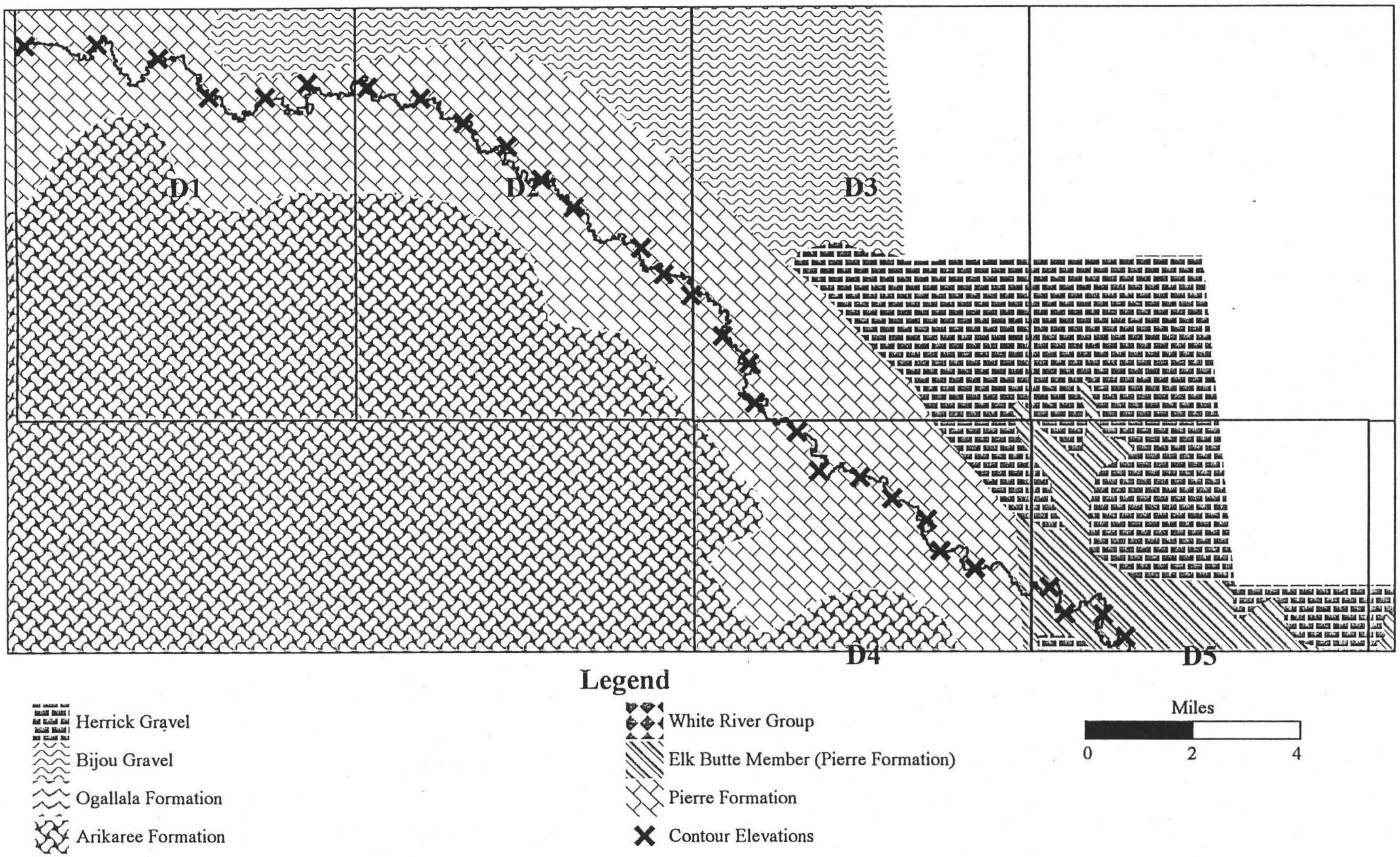


Figure 45. Map showing relationship of geology to elevations and knickpoints along Ponca Creek profile. (From Petsch, 1953; Burchett, 1969) (See Figure 2A for quadrangle locations.)

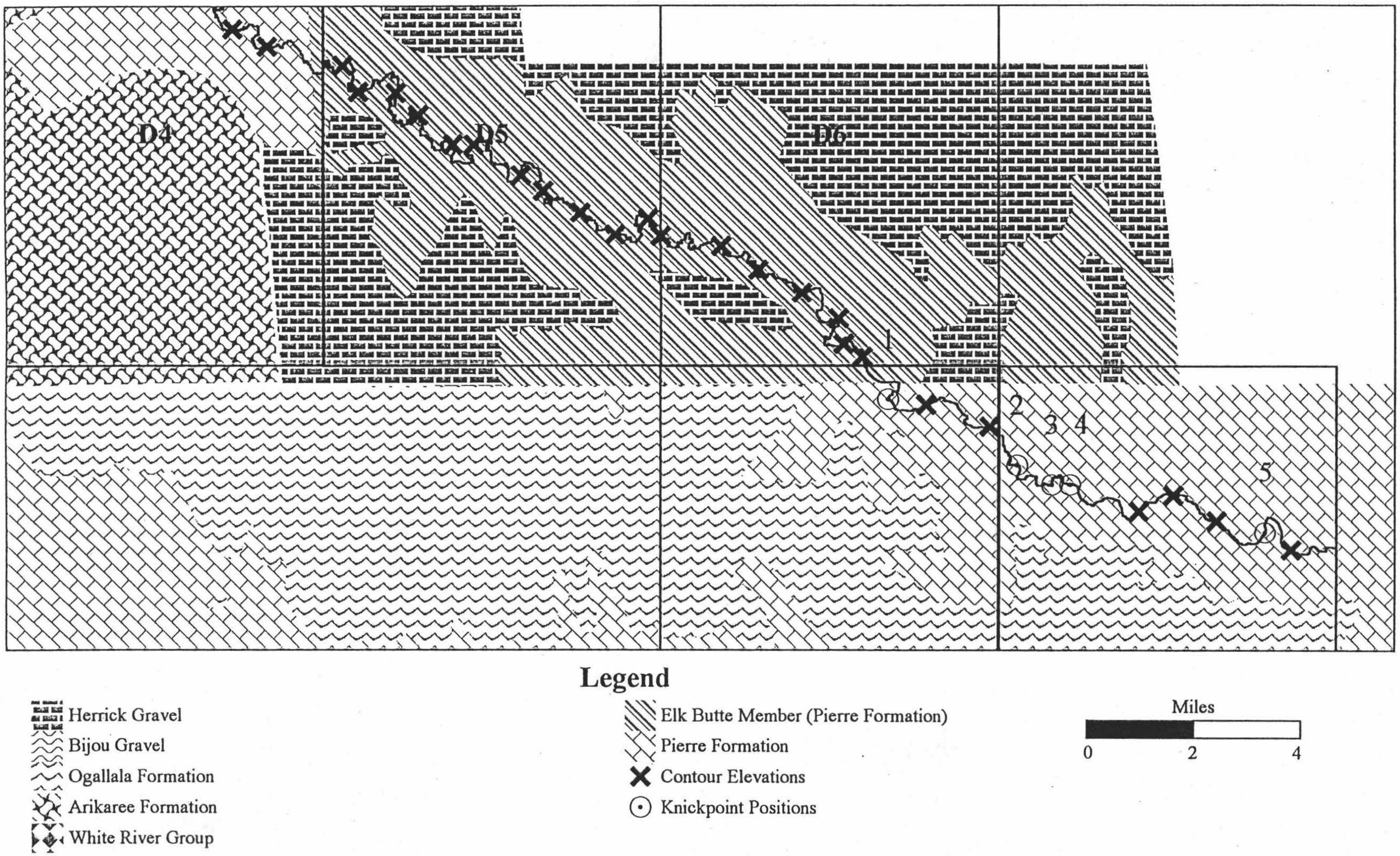


Figure 45. continued.

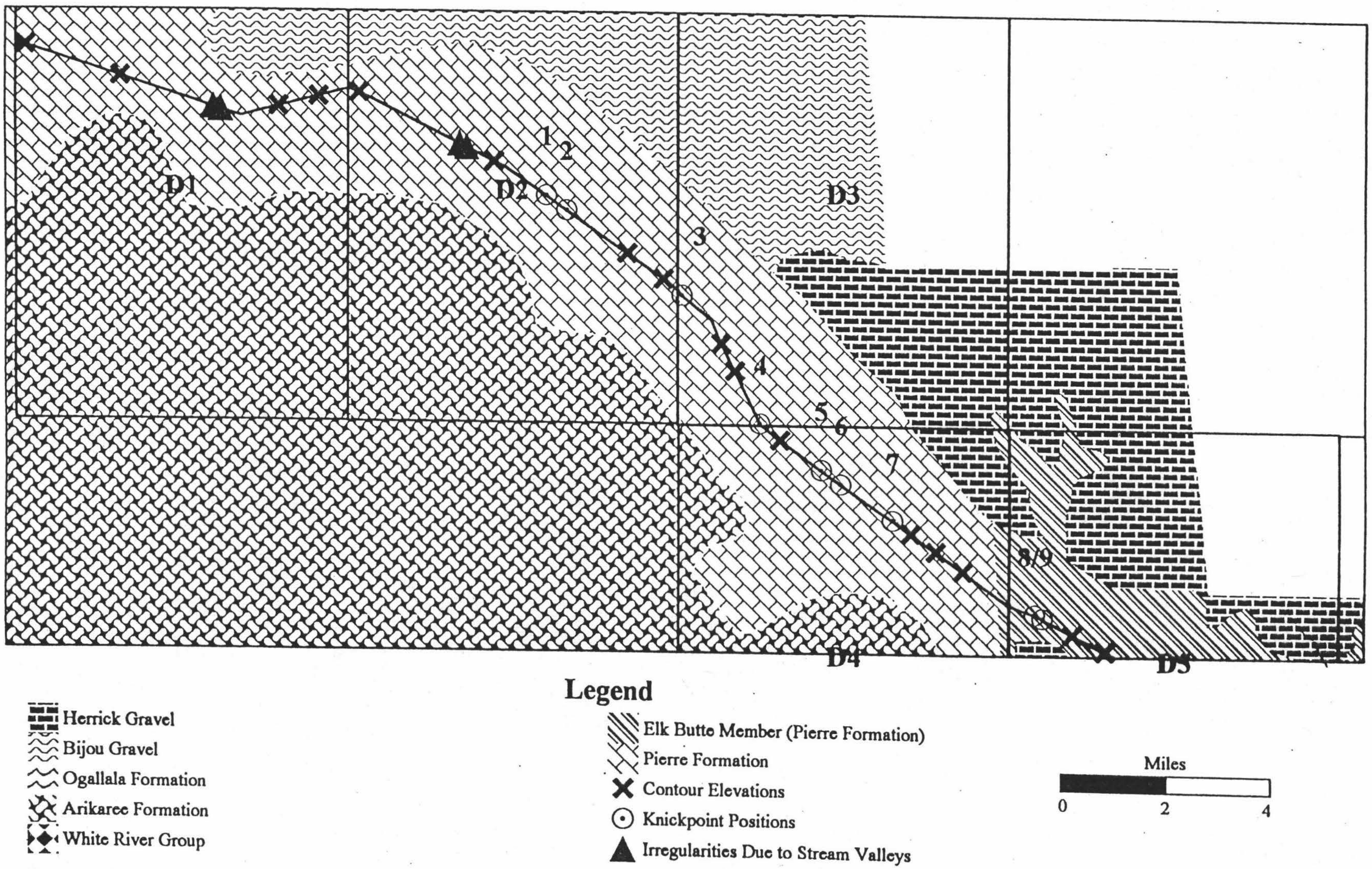


Figure 46. Map showing relationship of geology to elevations knickpoints and stream valley irregularities along Ponca Creek land surface profile A. (From Petsch, 1953; Burchett, 1969) (See Figure 2A for quadrangle locations.)

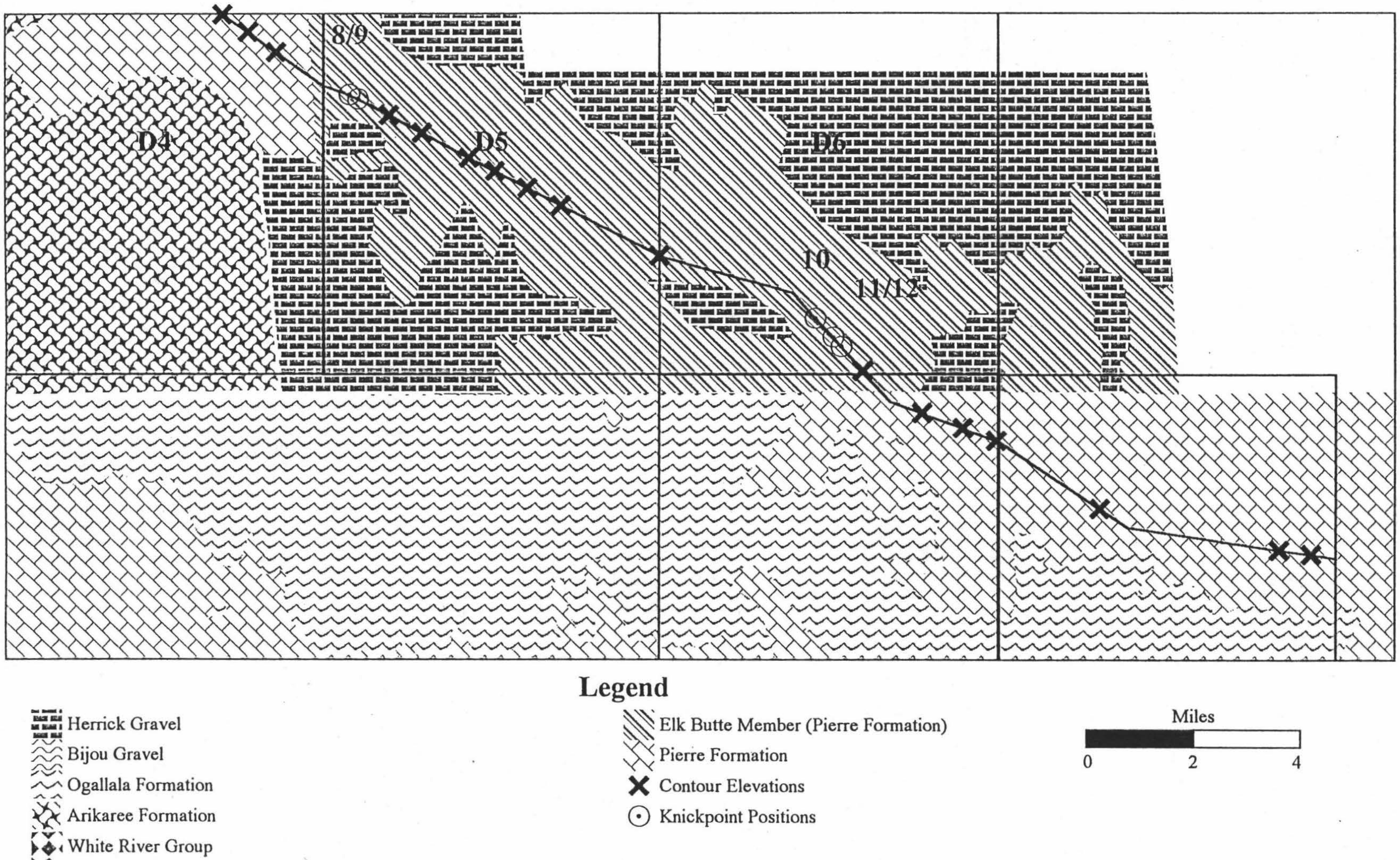


Figure 46. continued.

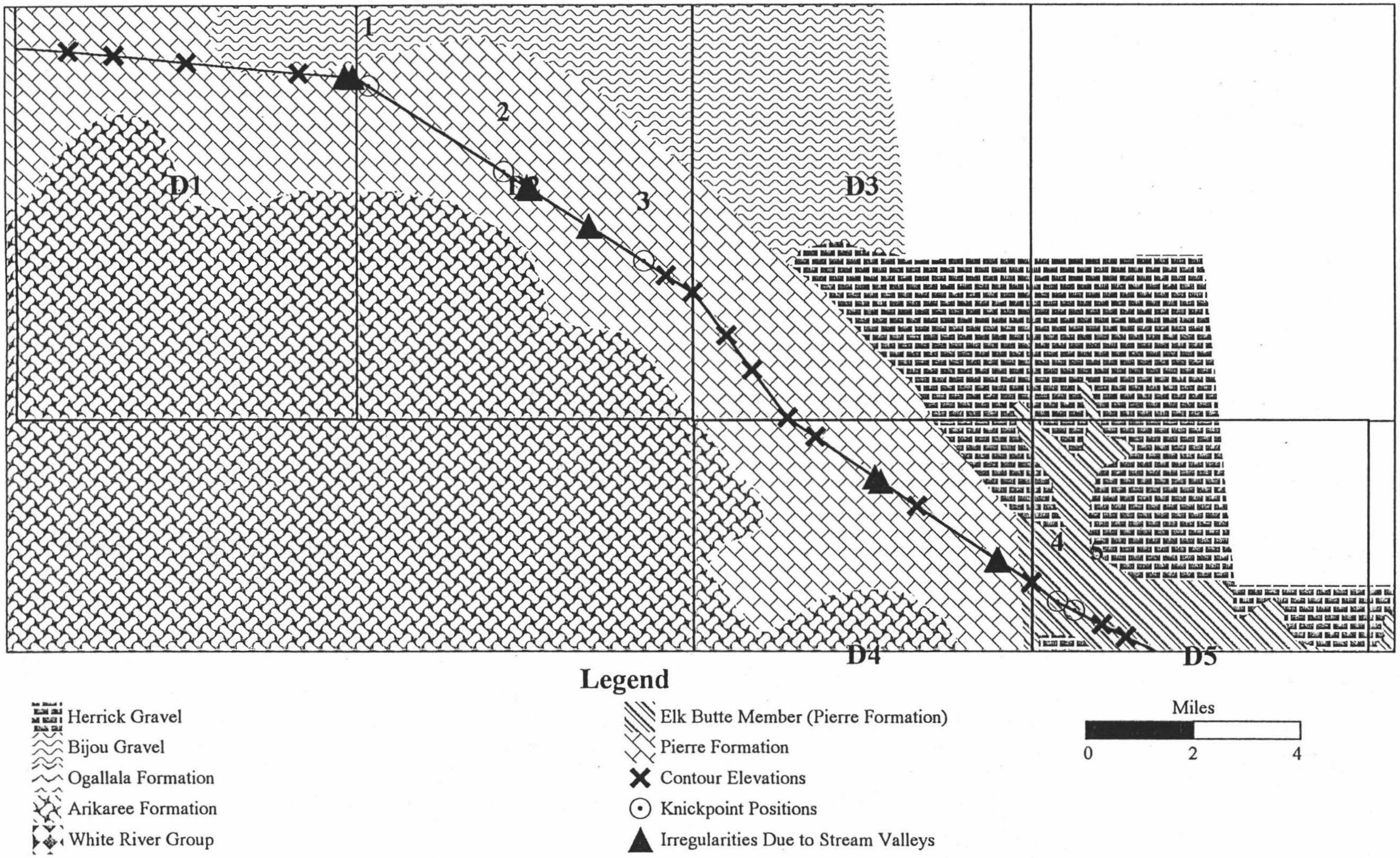


Figure 47. Map showing relationship of geology to elevations, knickpoints, and stream valley irregularities along Ponca Creek land surface profile B. (From Petsch, 1953; Burchett, 1969) (See Figure 2A for quadrangle locations.)

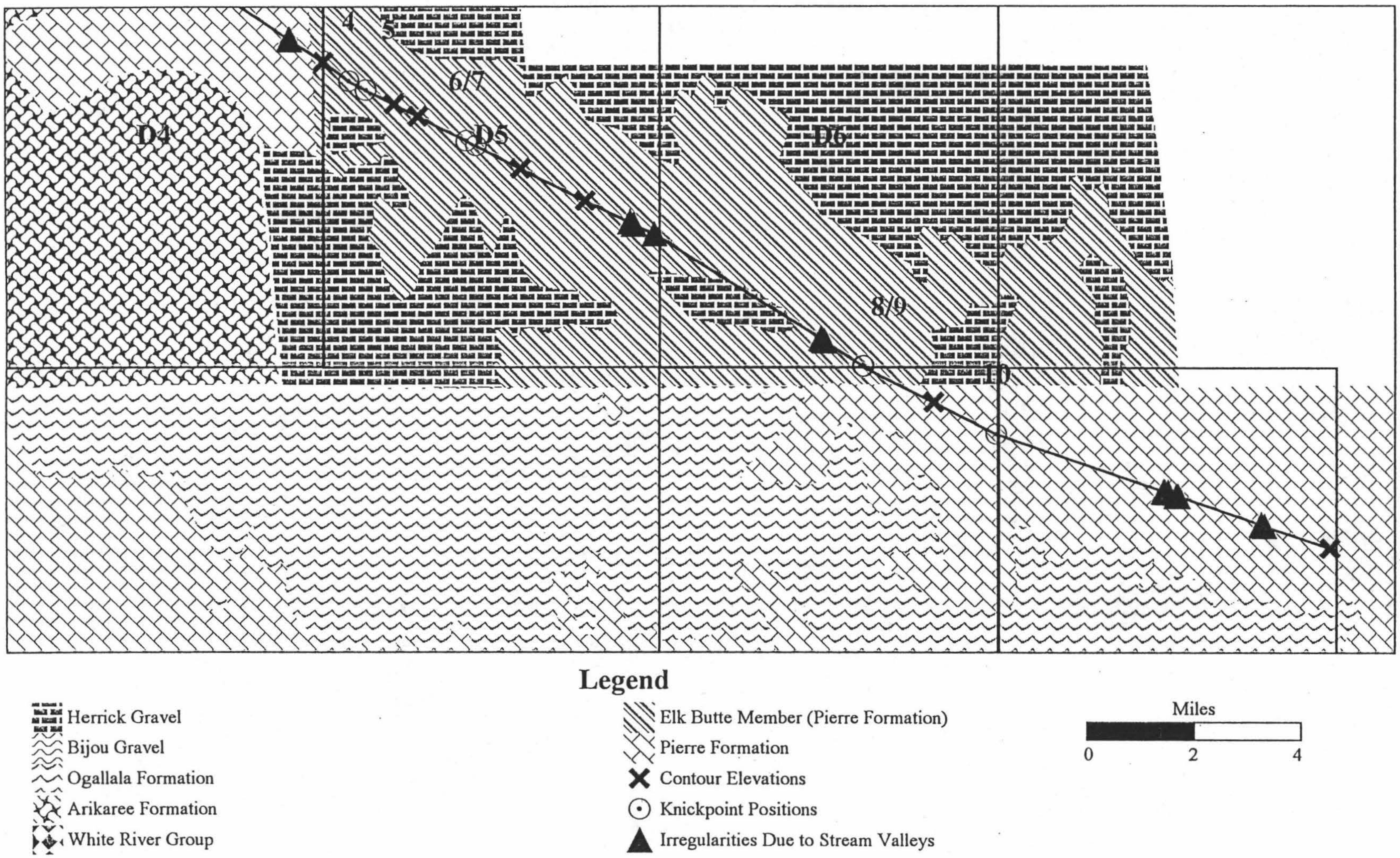


Figure 47. continued.

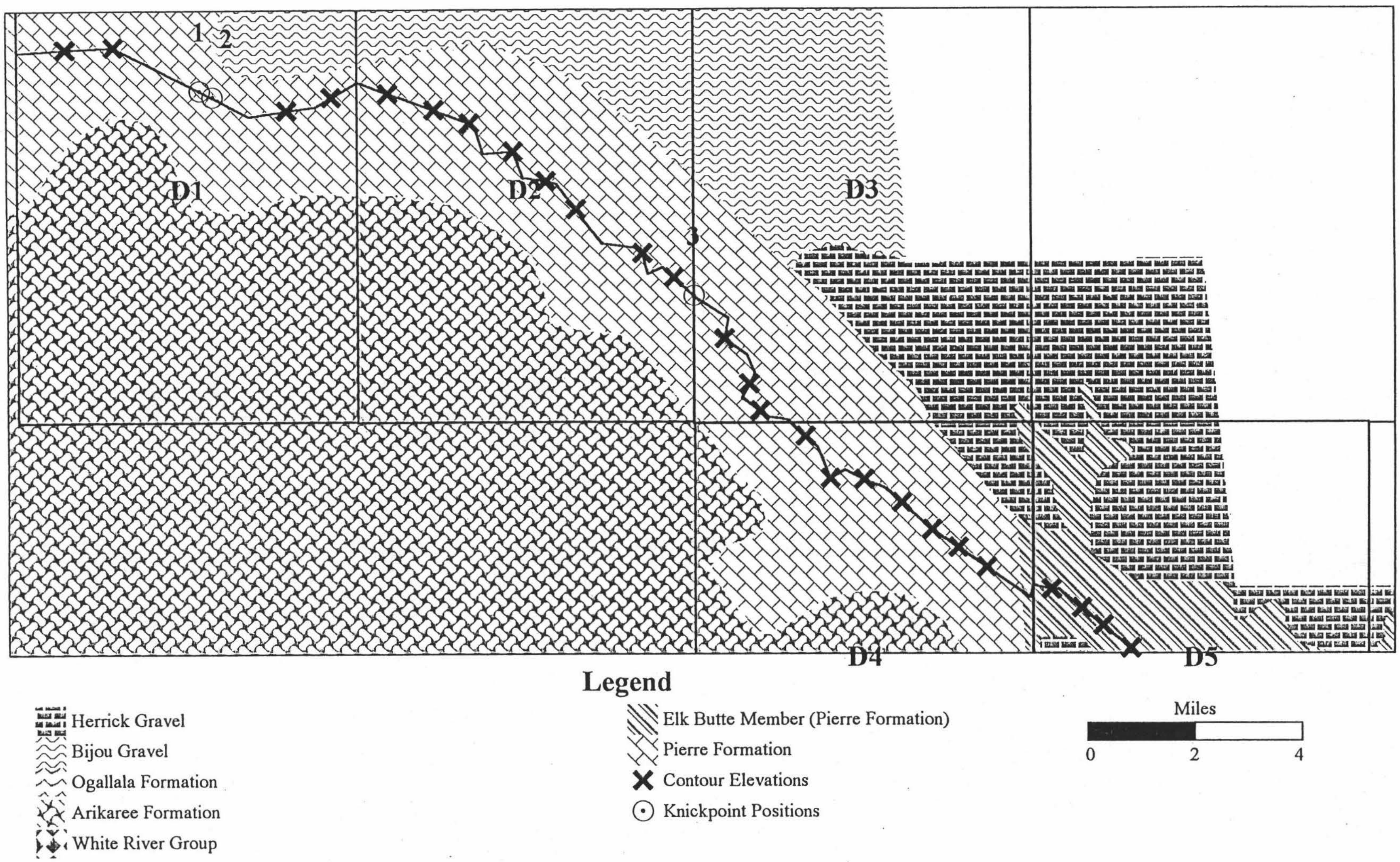


Figure 48. Map showing relationship of geology to elevations, knickpoints, and stream valley irregularities along Ponca Creek land surface profile C. (From Petsch, 1953; Burchett, 1969) (See Figure 2A for quadrangle locations.)

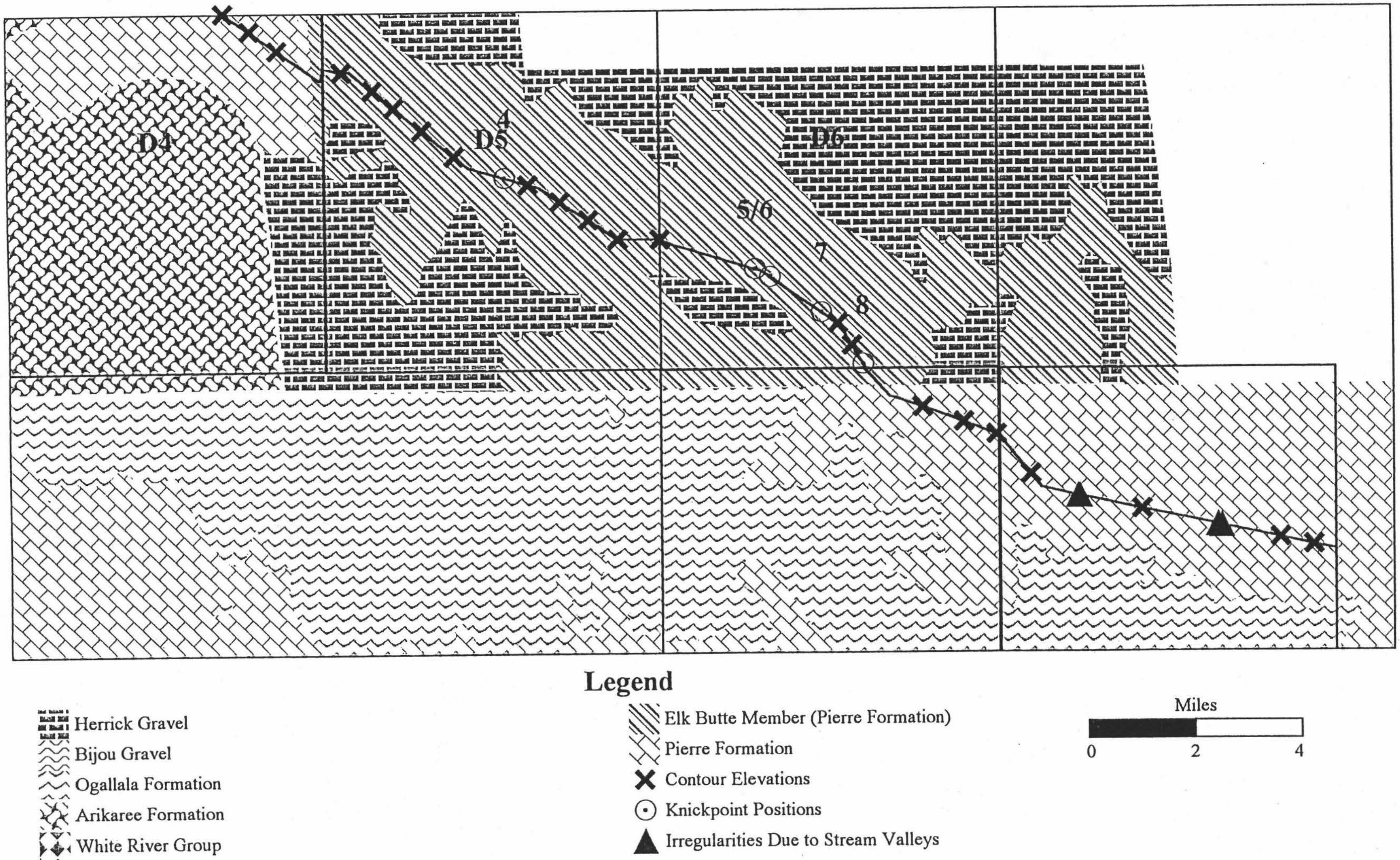


Figure 48. continued.

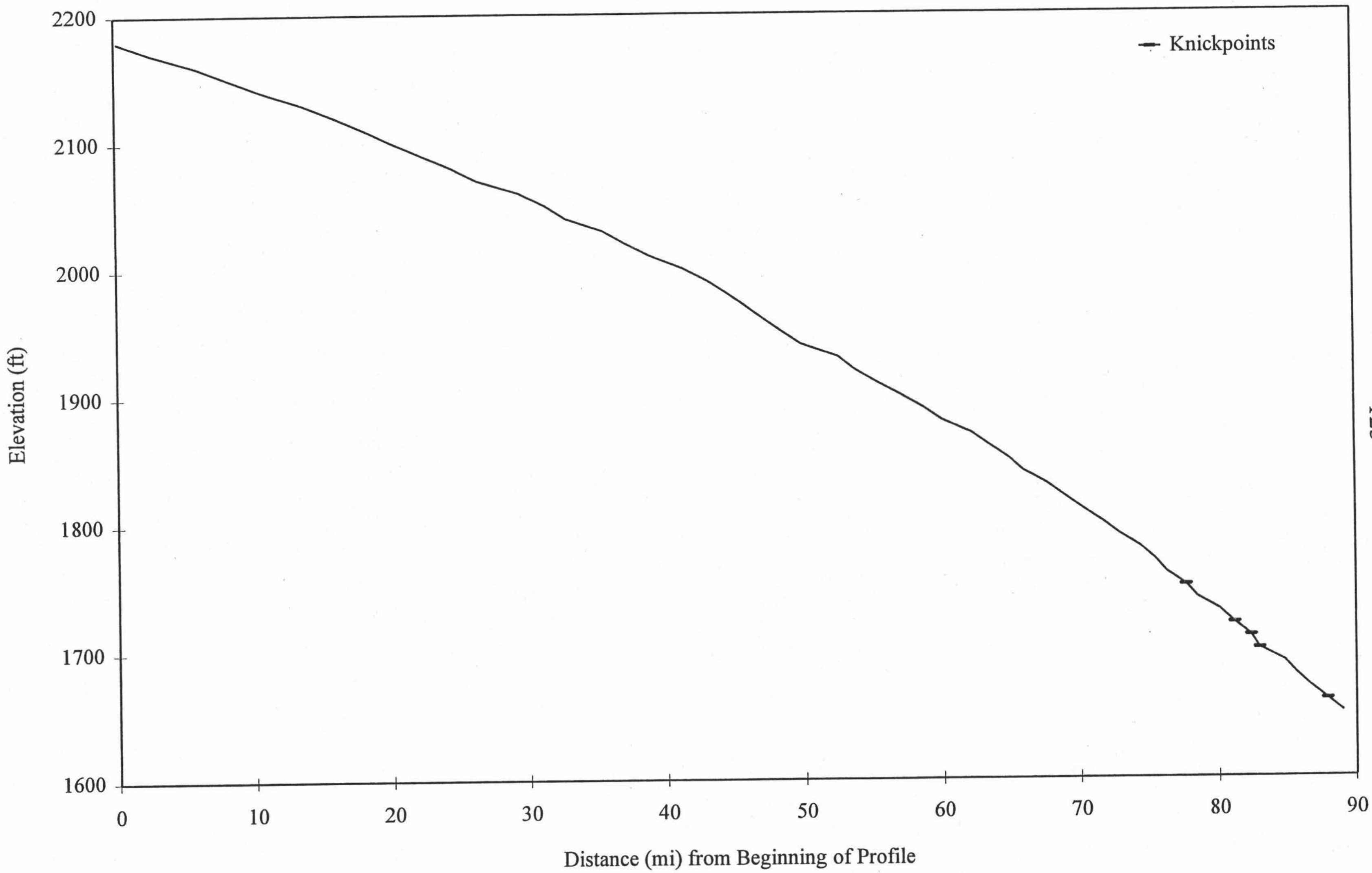


Figure 49. Ponca Creek profile. (See Figure 45 for knickpoint locations.)

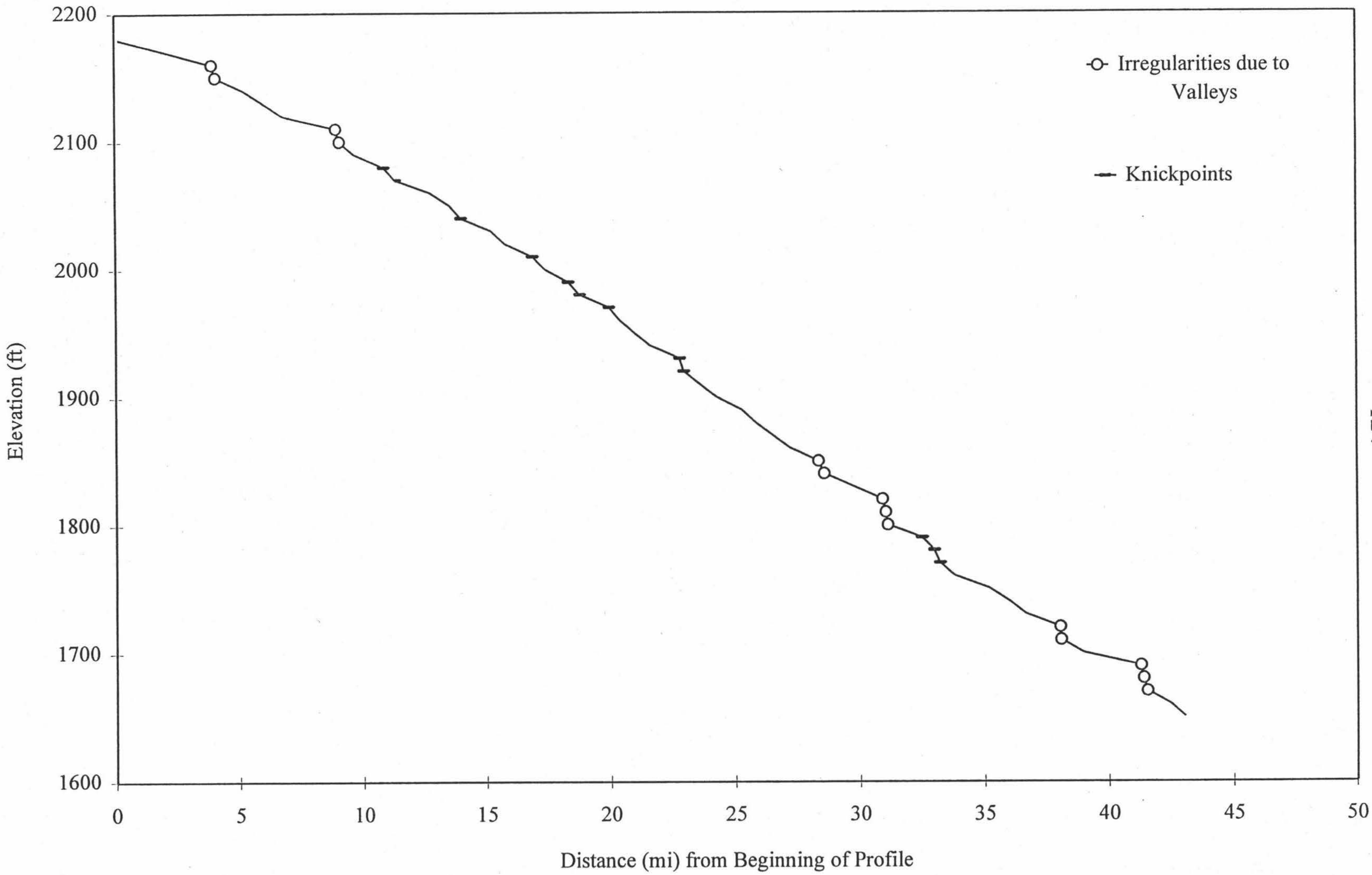


Figure 50. Ponca Creek land surface profile A. (See Figure 46 for valley irregularity and knickpoint locations.)

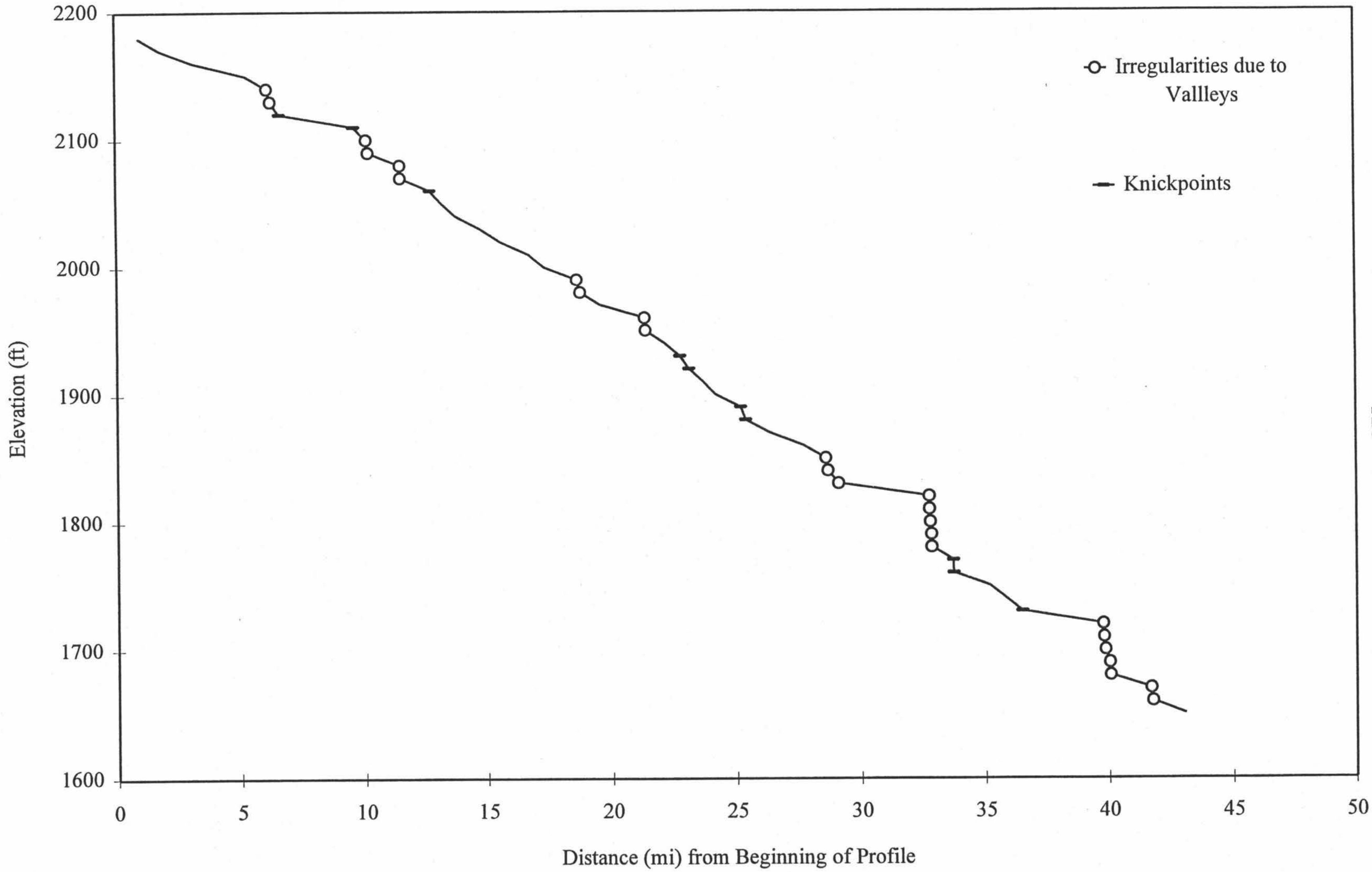


Figure 51. Ponca Creek land surface profile B. (See Figure 47 for valley irregularity and knickpoint locations).

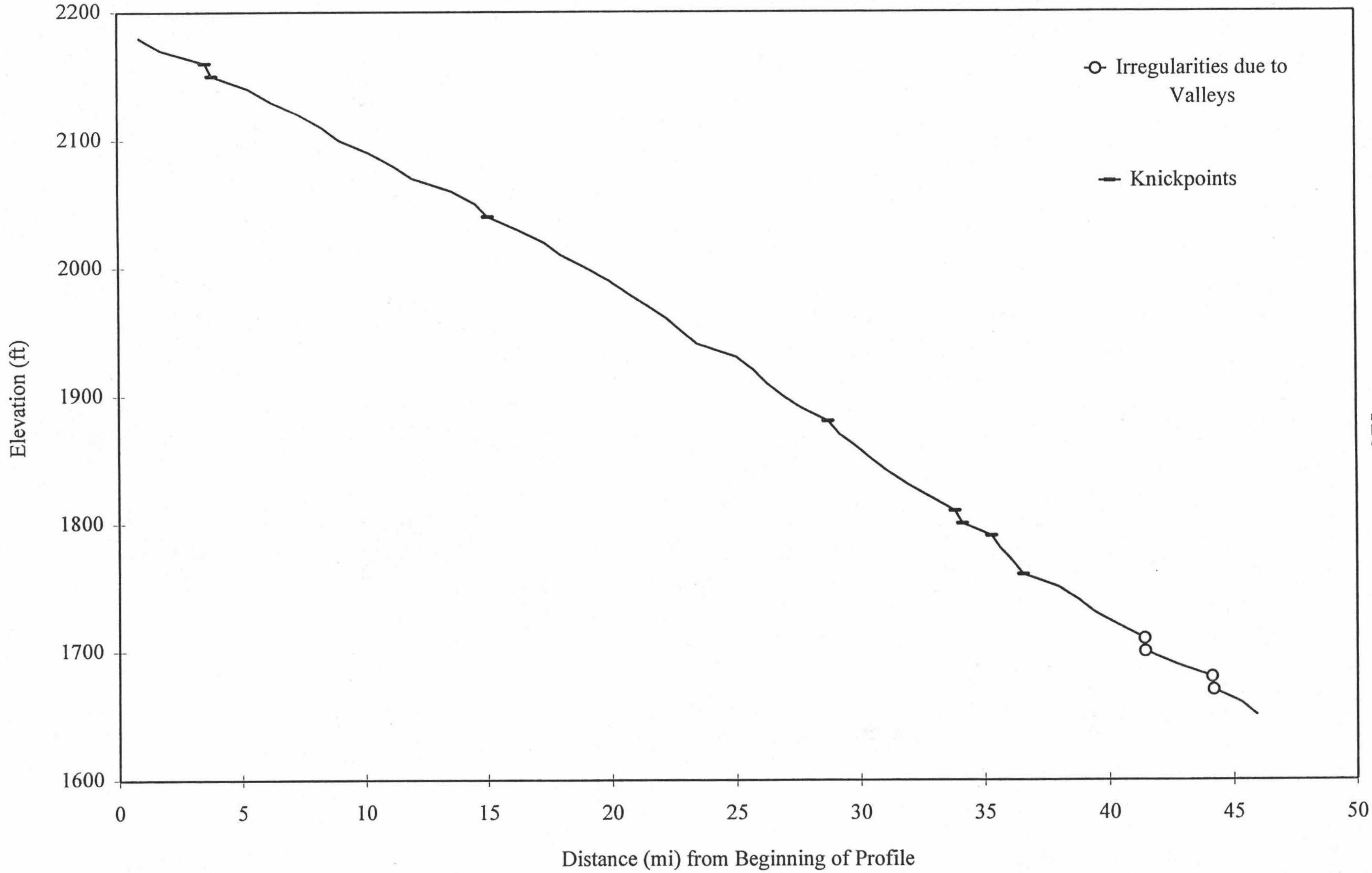


Figure 52. Ponca Creek land surface profile C. (See Figure 48 for valley irregularity and knickpoint locations.)

No knickpoints along profiles in this area correspond to changes in lithology (Figures 45-48; Appendix D). However, knickpoint number five along the Ponca Creek profile corresponds to a tributary juncture (Appendix D; Figure 45).

The equation of a trendline for the reach of land surface profile A above 1970 ft shows that the trendline at the end of the profile is 92.88 ft higher than the actual elevation (Table 1). The elevation of the trendline for the reach of Ponca Creek land surface profile C above 1880 ft is 76.96 ft higher than the actual elevation of the profile (Table 1).

Common knickpoints occur at elevations of 2040 and 1790 on land surface profiles A and C, and 1930, 1920, and 1770 ft on land surface profiles A and B (Table 2). Land surface profiles B and C also have common knickpoints at elevations of 1880 and 1760 ft.

When all profiles are plotted on the same axis, the Ponca Creek profile is much gentler than the land surface profiles (Figure 53). When only the land surface profiles are plotted on the same axis, profiles A and B are much steeper than profile C (Figure 54). Land surface profiles A and B are similar in slope and overlap significantly. This figure also shows much more noticeable irregularities in profile B than in profile A.

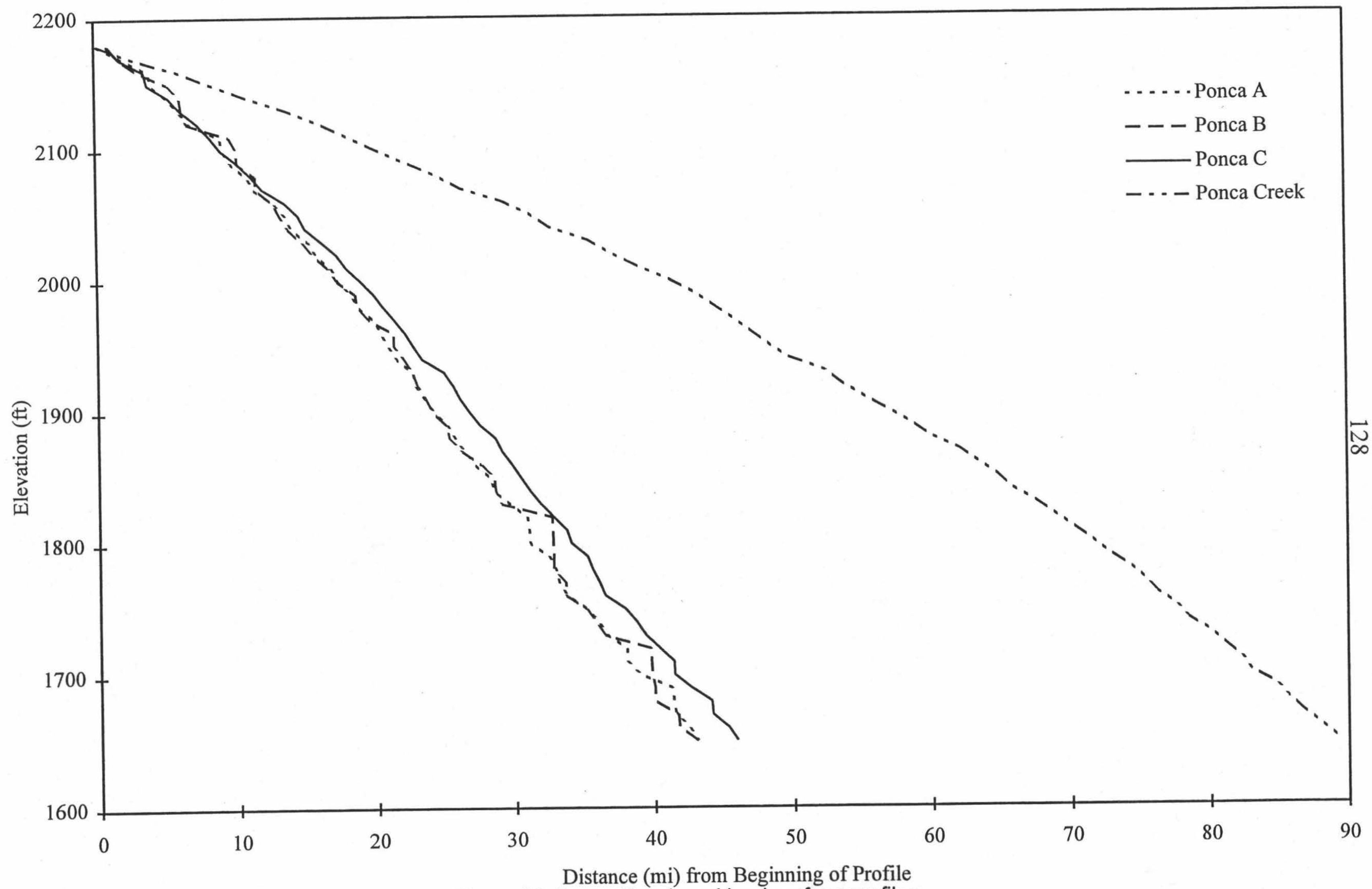


Figure 53. Ponca Creek and land surface profiles.

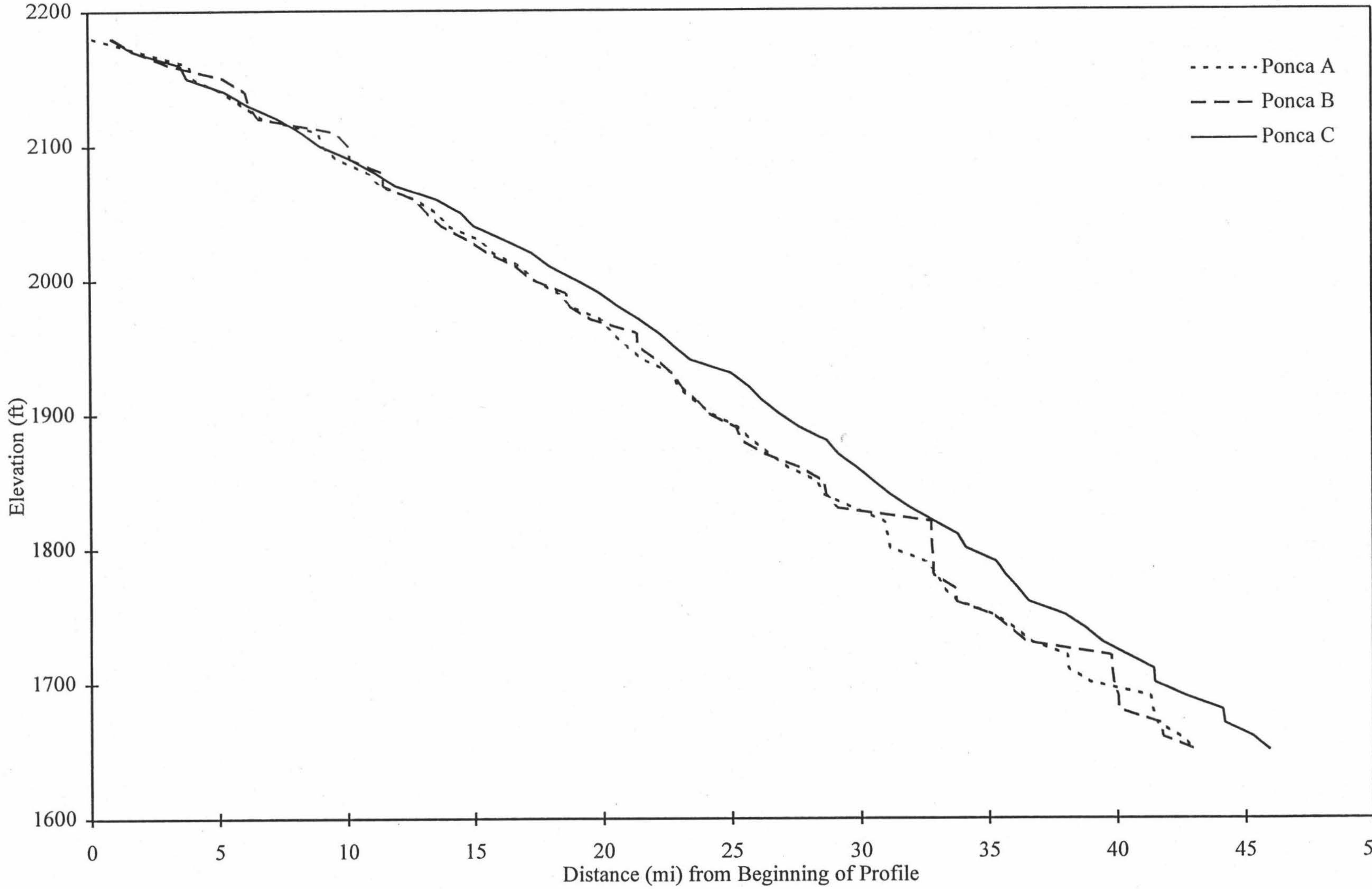


Figure 54. Ponca Creek land surface profiles.

Cannonball River GPS

In addition to the many profiles constructed from topographic maps, a profile has been constructed for an area adjacent to the Cannonball River using the data obtained from the GPS survey (Figure 55; Figure 56). This land surface profile is linear to convex in shape much like many of the other profiles in this study (Figure 57).

Knickpoints have been identified along this profile at elevations of 2302 (data site number two) and 2292 ft (data site number three; Appendix D). A knickpoint at data site number three corresponds to a lithology change from the Bullion Creek Formation to Upper Tertiary and Quaternary sediment (Figure 56).

An examination of knickpoints common to those identified from topographic maps is difficult because the elevation values along this profile do not correspond exactly to elevation values along any of the other Cannonball River area profiles. However, knickpoint number two or three on land surface profile B (Figure 21.) may be related to the knickpoint at elevation 2302 (data site number two; Figure 56), while the knickpoint at elevation 2292 (data site number three; Figure 56) may be related to knickpoint number three or four on land surface profile B (Figure 21).

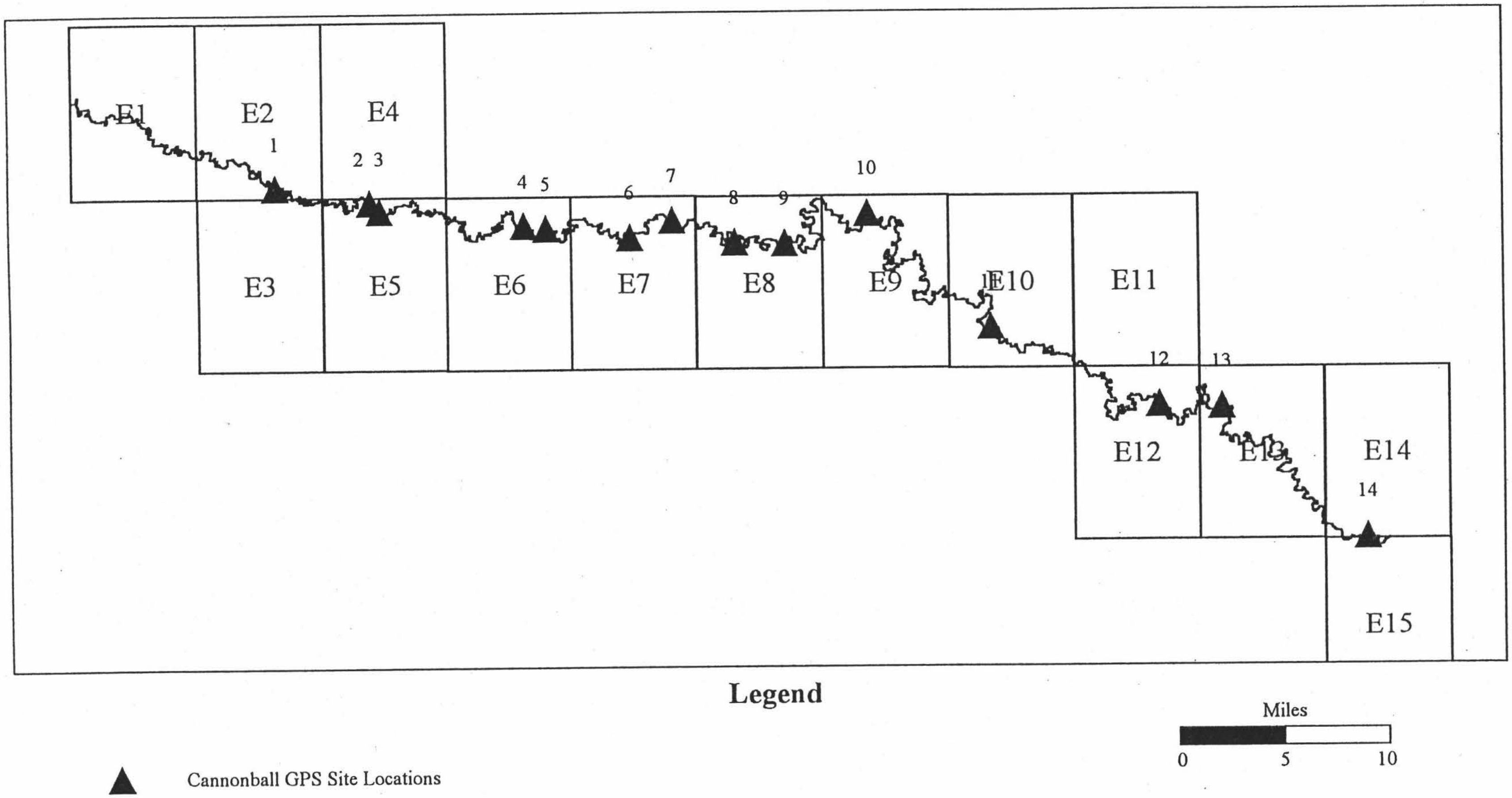


Figure 55. Location of Cannonball River GPS sites. (7.5 minute quadrangles are labeled, see Appendix B.)

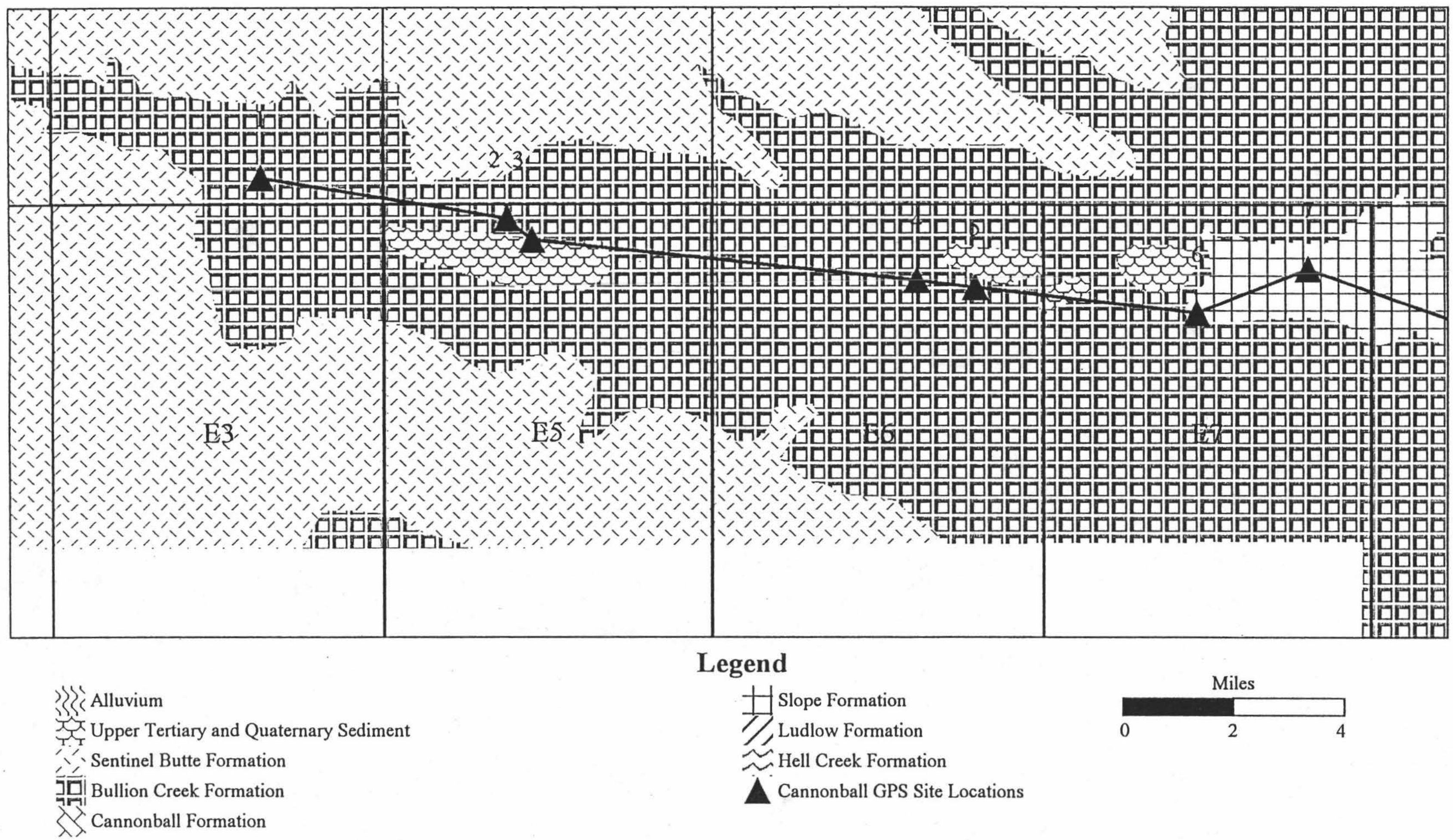


Figure 56. Map showing relationship of geology to data sites along the Cannonball River GPS profile.(From Clayton and others, 1980a) (See Figure 55 for quadrangle locations.)

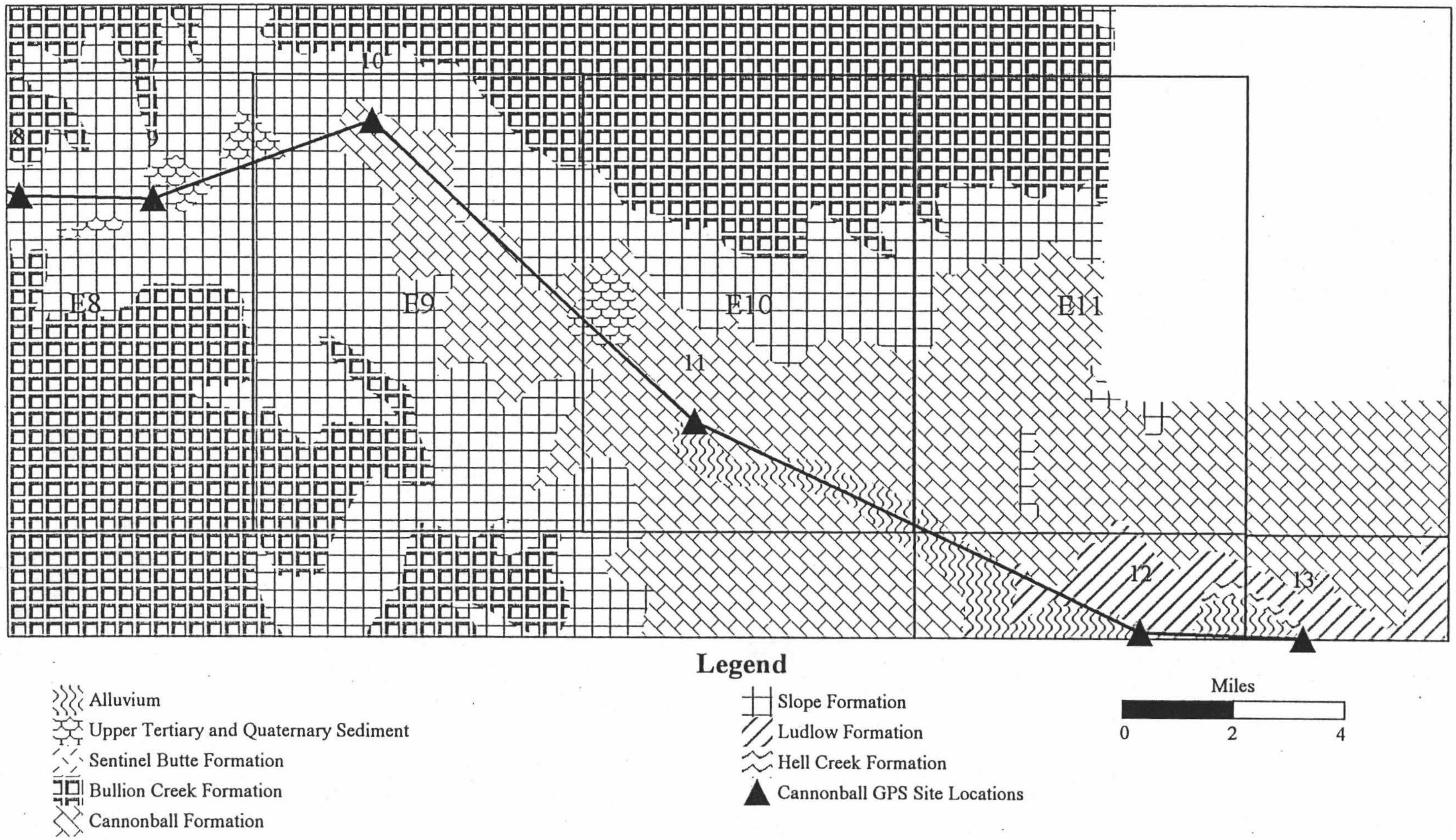


Figure 56. continued.

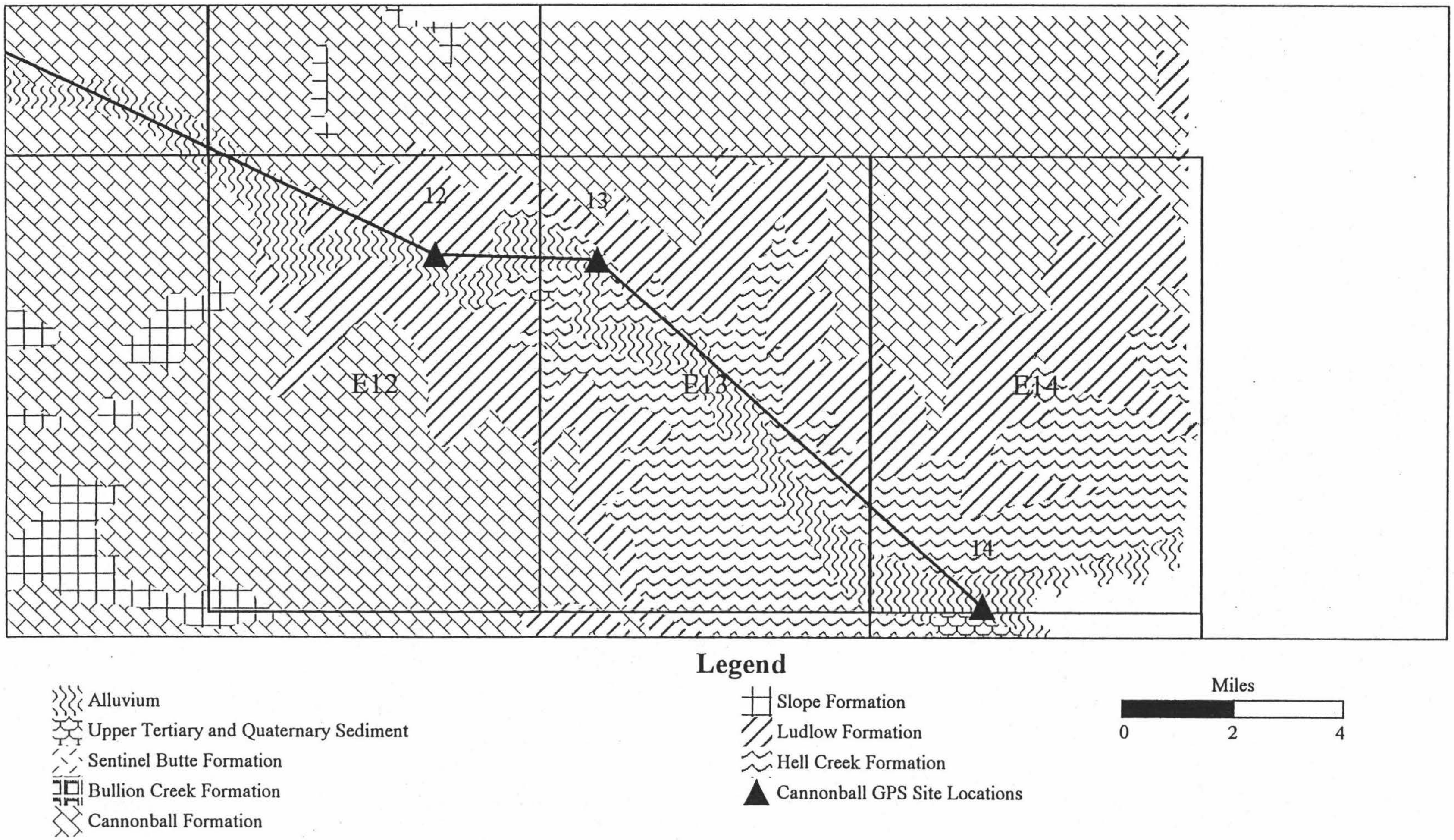


Figure 56. continued.

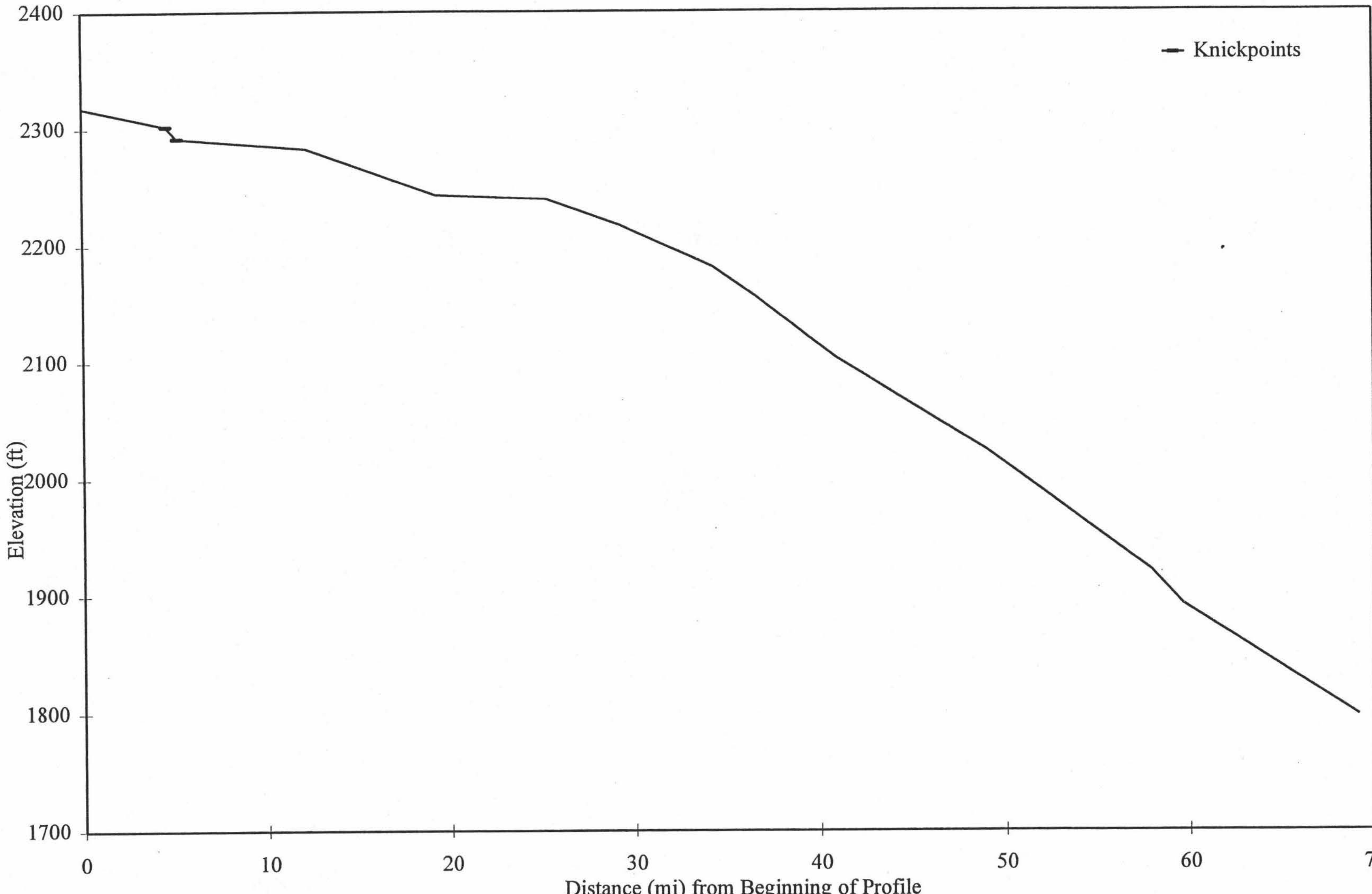


Figure 57. Cannonball River land surface profile from GPS data. (Knickpoints are stations one and two from Figure 55.)

DISCUSSION

Assumptions

Several assumptions of this study need to be addressed before interpretations of the data can be made. As discussed earlier, stream profiles were constructed by plotting distance between successive contour lines. Land surface profiles were also constructed by plotting distances between successive contour lines, but along and in close proximity to the river valley. Length of land surface profiles differs from that of the stream profiles, while the difference in elevation remains constant. Because all profiles trend downslope, generally following the river valley, they can be considered parallel to one another. Minor variations in shape between stream and land surface profiles will occur due to different erosional and depositional processes, but overall trends in the profiles should be the same, despite differences in length.

Some of the processes responsible for the development of knickpoints on stream profiles will also result in knickpoints on land surface profiles. Thus, irregularities resulting from these factors, such as tectonics and lithologic changes, should show up on both types of profiles. Oftentimes knickpoints resulting from similar processes will occur at or near the same elevation. For example, if a river crosses a fault, this may be reflected in the river profile. If this fault has displaced the land surface in the area surrounding the river it should also be expressed on the land surface profiles at an elevation close to that at which it was expressed on the stream profile.

Given the similarity between stream and land surface profiles in terms of shape and processes responsible for knickpoint development it should be possible to make meaningful comparisons between the two. However, erosional and depositional processes differ slightly between the two types of profiles, resulting in some difference in profile shape.

General Observations

A couple of general observations can be made from constructed profiles. Firstly, not many knickpoints can be correlated with lithologic changes. This is not very surprising considering most of the lithology along the streams in South Dakota and Nebraska is shale or fine grained material of the Pierre Formation, and does not vary significantly between members.

Secondly, the parameters used in this study have resulted in land surface profiles with similar lengths and thus similar overall slopes, especially in the cases of land surface profiles A and B. (For example see Figure 54.) Examination of profiles shows, however, that slopes are not constant over entire profile length, due to factors such as profiles crossing valleys. As a result, profiles with similar overall lengths, such as land surface profiles A and B, cross one another at several elevations (Figure 54).

Differences Among Profiles

As a result of stream meandering, stream profiles have a greater distance for the given elevation change than do land surface profiles. With the exception of the Keya Paha River area, the length of stream profiles in this study are approximately twice that of land surface profiles (For example see Figure 35). The relationship between lengths of the two types of profiles has not been studied in enough detail to determine if there is a significant reason for it or if the relationship is just a coincidence.

Stream and land surface profiles also differ in terms of the number of irregularities (For example see Figures 44-46). In general, land surface profiles have many more irregularities than stream profiles. The different erosional processes occurring on land as opposed to along the streams influences the number of irregularities. Erosion in streams is dominated, of course, by water, whereas erosion along the land surface is influenced by water only periodically, during and subsequent to rainfall or snowmelt. If water is the primary agent of irregularity removal then it makes sense that there are more knickpoints on land surface profiles, as it takes longer for them to be removed.

Similarities Among Profiles

Frequently in this study it was found that knickpoints occur at the same elevation in more than one profile for a given area. Given the similarity in elevation, the factors responsible for their origin can be similar (see Assumptions). However, not all processes responsible for knickpoint development occur both in streams and on the land surface. Thus, in areas with knickpoints at common elevations in multiple profiles, one should be able to limit the choice of factors responsible for their origin. Only those processes responsible for knickpoint development on both types of profiles should be considered.

Profiles constructed for this study show similarity in terms of overall shape, which is linear. Several reasons are possible for this shape. First of all, only a section of each stream and stream valley has been examined, which could produce the profile shape observed. Secondly, a stream profile may display a linear shape if there is a decrease in discharge in the downstream direction, due to infiltration or evaporation of water (Richards, 1982, p. 227). Lastly, a profile may also become linear if particle size increases downstream (Leopold, and others 1964, p. 254).

It seems that a significant enough portion of the streams and their valleys were examined in this study to expect concavity in the profiles, and thus this is probably not the reason for the observed profile shape. An increase in particle size downstream does not seem a likely reason for the observed profile shapes, as lithology is dominantly fine grained material of the Pierre Formation. In general, no significant increases in discharge due to tributaries are apparent along streams in the area as most are intermittent.

However, the Little White River may significantly influence discharge along the White River, as it is not intermittent. Hydrologic data were not examined to determine the influence of the Little White River on discharge of the White River. In general, decreased discharge seems probable for the stream profile shape observed here because the region is semi-arid.

Limitations/Problems

Some of the irregularity has been taken out of land surface profiles by plotting only successively lower contour lines, but some tributary valleys have such a steep slope where they are crossed by the profile line that two successive contours are crossed in a short distance. Thus, even given the method of profile construction , not all irregularities that are not knickpoints can be removed. This makes comparison of stream and land surface profiles more difficult.

Also, in eliminating these irregularities it seems likely some knickpoints may have also been eliminated. Knickpoints that may have been eliminated from one profile should show up on other land surface profiles or even along the stream profiles.

Another problem with this study is that the parameters used to identify knickpoints do not include all the visual breaks in slope along stream profiles. For example, a break in slope at an elevation of 2370 ft. on the Cannonball River profile appears to be significant enough to be called a knickpoint (Figure 25). However, the break in slope at this irregularity is not great enough for it to be called a knickpoint, based on the parameters used in knickpoint identification.

Another limitation of this study is the number and spacing of data points. Data points in this study have been collected only at 10 or 20 foot intervals, with the exception of those data points collected using the GPS system. Collecting more data points would result in a more significant database for profile construction.

CONCLUSIONS

The objectives of this study have been the construction of stream and land surface profiles for several streams in North Dakota, South Dakota and Nebraska, and subsequent identification of irregularities and their possible causes. A significant database was collected as part of this study from which profile irregularities could be identified. Some of the irregularities in the profiles can be related to lithologic changes, for example knickpoint number on six on White River land surface profile B (Figure 9), and tributary junctures, for example along the Keya Paha River (Appendix D). However, there are many irregularities for which no origin has been determined. None of the irregularities has been determined to be the result of tectonic activity, although this cannot be ruled out without field checking. Field checking of the identified irregularities should help determine if irregularities, for which no cause has been determined, are associated with tectonic activity, or other factors.

The use of multiple profiles has allowed comparison of identified irregularities within each stream area. Many of these are at similar elevations; this is probably due to similar processes responsible for their formation. However, irregularities occurring only on stream profiles or only on land surface profiles may result from factors that affect only the slope of the stream or land surface area.

It is important to consider some of the limitations of this study. Because of the method of construction of the land surface profiles, not every irregularity is a knickpoint. In an attempt to compensate for this, those irregularities resulting from land surface profile lines crossing stream valleys are ignored. However, by eliminating some of these irregularities it is quite possible that irregularities resulting from factors such as lithologic changes have also been eliminated. This confirms the need for field checking of the data.

Based on the findings in this study, the next step might be to obtain more data through the use of precision GPS equipment. Such work began as part of this study, but more data need to be obtained. Following this, identified knickpoints should be field investigated to test the hypothesis that knickpoints develop at similar elevations on land surface and stream profiles for similar reasons. It would also help in determining the cause of knickpoints that remain unexplained, including those that may be associated with tectonic activity.

APPENDICES

Appendix A. Calculation of distance between GPS site locations.

Site Location #	Latitude	Longitude	Latitude (Rad)	Longitude (Rad)	E	F	G	H	J	K	Dist(km)	Dist(mi)
1	46.38	102.42	0.810	1.788	0.761	0.724	0.690	1.000	1.000	0.001	7.3	4.5
2	46.37	102.33	0.809	1.786	0.761	0.724	0.690					
2	46.37	102.33	0.809	1.786	0.761	0.724	0.690	1.000	1.000	0.000	1.0	0.6
3	46.37	102.32	0.809	1.786	0.762	0.724	0.690					
3	46.37	102.32	0.809	1.786	0.762	0.724	0.690	1.000	1.000	0.002	11.2	7.0
4	46.35	102.17	0.809	1.783	0.762	0.724	0.690					
4	46.35	102.17	0.809	1.783	0.762	0.724	0.690	1.000	1.000	0.002	11.3	7.1
5	46.36	102.03	0.809	1.781	0.762	0.724	0.690					
5	46.36	102.03	0.809	1.781	0.762	0.724	0.690	1.000	1.000	0.002	9.6	6.0
6	46.35	102.15	0.809	1.783	0.762	0.724	0.690					
6	46.35	102.15	0.809	1.783	0.762	0.724	0.690	1.000	1.000	0.001	6.5	4.0
7	46.35	102.07	0.809	1.781	0.762	0.724	0.690					
7	46.35	102.07	0.809	1.781	0.762	0.724	0.690	1.000	1.000	0.001	8.0	5.0
8	46.34	101.96	0.809	1.780	0.762	0.723	0.690					
8	46.34	101.96	0.809	1.780	0.762	0.723	0.690	1.000	1.000	0.001	3.8	2.4
9	46.34	101.91	0.809	1.779	0.762	0.723	0.690					
9	46.34	101.91	0.809	1.779	0.762	0.723	0.690	1.000	1.000	0.001	6.7	4.2
10	46.36	101.83	0.809	1.777	0.762	0.724	0.690					
10	46.36	101.83	0.809	1.777	0.762	0.724	0.690	1.000	1.000	0.002	13.0	8.1
11	46.28	101.71	0.808	1.775	0.763	0.723	0.691					

E =Pi/2-Latitude (Rad)
F= Cos (E)
G= Sin (E)
H= Cos(Longitude p1-longitudep2)

J= (F*F2)+(G1*G2*H1)
K= 1.570796-ATAN(J1/SQRT(1-J*J))
Dist(km)= (K*6356.75)
Dist (mi)= Dist (km)/1.603(km/mi)

Site Location #	Latitude	Longitude	Latitude (Rad)	Longitude (Rad)	E	F	G	H	J	K	Dist(km)	Dist(mi)
11	46.28	101.71	0.808	1.775	0.763	0.723	0.691	1.000	1.000	0.002	14.4	9.0
12	46.22	101.54	0.807	1.772	0.764	0.722	0.692					
12	46.22	101.54	0.807	1.772	0.764	0.722	0.692	1.000	1.000	0.001	4.7	2.9
13	46.22	101.48	0.807	1.771	0.764	0.722	0.692					
13	46.22	101.48	0.807	1.771	0.764	0.722	0.692	1.000	1.000	0.002	15.3	9.6
14	46.13	101.33	0.805	1.769	0.766	0.721	0.693					

Appendix B. List of 7.5 minute quadrangles and their labels used in this study.

River	Quadrangle Label	Quadrangle	State
Bad River	A1	Philip	SD
	A2	Philip SE	SD
	A3	Powell	SD
	A4	Nowlin	SD
	A5	Midland	SD
	A6	Midland SE	SD
	A7	Capa	SD
	A8	Capa NW	SD
	A9	Capa SE	SD
	A10	Van Metre	SD
	A11	Wendte	SD
	A12	Oahe SW	SD
	A13	Wendte NE	SD
	A14	Teton	SD
	A15	Pierre SW	SD
White River	B1	Pass Creek NW	SD
	B2	Belvidere SW	SD
	B3	Belvidere	SD
	B4	Stamford SW	SD
	B5	Stamford SE	SD
	B6	Okaton SW	SD
	B7	Okaton SE	SD
	B8	Murdo 3 NE	SD
	B9	Murdo SW	SD
	B10	Westover	SD
	B11	Murdo SE	SD
	B12	White River NE	SD
	B13	Badnation NW	SD
	B14	Badnation	SD
	B15	Presho 4 NW	SD
	B16	Presho 4 NE	SD
	B17	Ideal NW	SD
	B18	Ideal NE	SD
	B19	Hamill NW	SD
	B20	Reliance SW	SD
	B21	Hamill NE	SD
	B22	Reliance SE	SD
	B23	Oacoma	SD
	B24	Iona NW	SD
Keya Paha River	C1	Hidden Timber	SD
	C2	Hidden Timber NE	SD
	C3	Keya Paha NW	SD
	C4	Clearfield	SD
	C5	Keya Paha	SD
	C6	Keya Paha SE	SD
	C7	Millbora	SD
	C8	Wewela	SD
	C9	Dallas SW	SD
	C10	Springview NW	SD/NE
	C11	Paxton	SD
	C12	Burton	SD/NE
	C13	Mills	SD/NE

River	Quadrangle Label	Quadrangle	State
Keya Paha River	C14	Jamison	SD/NE
	C15	Naper NW	SD/NE
	C16	Naper	SD/NE
	C17	Butte NW	SD/NE
Ponca Creek	D1	Dallas	SD
	D2	Gregory	SD
	D3	Burke	SD
	D4	Gregory SE	SD
	D5	Herrick	SD
	D6	St. Charles	SD
	C16	Naper	SD/NE
	C17	Butte NW	SD/NE
Cannonball River	E1	Regent	ND
	E2	Mott NW	ND
	E3	Mott SW	ND
	E4	Mott North	ND
	E5	Mott South	ND
	E6	Burt	ND
	E7	Bently	ND
	E8	New Leipzig	ND
	E9	Sheep Creek Dam	ND
	E10	Leith	ND
	E11	Carson SE	ND
	E12	Paradise Flats	ND
	E13	Bell Coulee West	ND
	E14	Bell Coulee East	ND
	E15	Lookout Butte SE	ND

Appendix C. Distance and slope values used in defining knickpoints for profiles in the study area.

Profile	Elevation (ft)	Distance (mi)	2-Point Slope (ft/mi)A	Slope Difference B	Knickpoint ? C
Cannonball River	2450-2440	2.79	-3.59	0.82	no
	2440-2430	3.62	-2.77	0.24	no
	2430-2420	3.33	-3.00	0.81	no
	2420-2410	4.57	-2.19	1.40	no
	2410-2400	2.79	-3.59	1.10	no
	2400-2390	4.02	-2.49	0.71	no
	2390-2380	3.13	-3.20	2.46	no
	2380-2370	1.77	-5.66	4.62	no
	2370-2360	9.58	-1.04	2.31	no
	2360-2350	2.98	-3.35	1.00	no
	2350-2340	4.25	-2.36	1.64	no
	2340-2330	2.50	-4.00	1.65	no
	2330-2320	4.26	-2.35	0.40	no
	2320-2310	3.64	-2.75	0.54	no
	2310-2300	4.53	-2.21	1.48	no
	2300-2290	2.71	-3.68	0.84	no
	2290-2280	3.52	-2.84	1.92	no
	2280-2270	2.10	-4.77	0.64	no
	2270-2260	2.42	-4.12	1.73	no
	2260-2250	4.17	-2.40	0.59	no
	2250-2240	3.35	-2.98	0.22	no
	2240-2230	3.13	-3.20	0.42	no
	2230-2220	2.76	-3.62	1.02	no
	2220-2210	3.85	-2.60	0.16	no
	2210-2200	3.62	-2.76	0.50	no
	2200-2190	3.06	-3.27	1.09	no
	2190-2180	4.59	-2.18	1.79	no
	2180-2160	5.04	-3.97	0.35	no
	2160-2140	5.53	-3.62	1.12	no
	2140-2120	8.01	-2.50	1.31	no
	2120-2100	5.26	-3.80	0.13	no
	2100-2080	5.09	-3.93	0.92	no
	2080-2060	4.12	-4.85	0.60	no
	2060-2040	4.70	-4.25	0.12	no
	2040-2000	9.15	-4.37	1.66	no
	2000-1980	7.38	-2.71	0.20	no
	1980-1960	6.86	-2.91	0.37	no
	1960-1940	6.10	-3.28	0.12	no
	1940-1920	5.88	-3.40	1.12	no
	1920-1900	4.43	-4.52	7.75	yes
	1900-1880	1.63	-12.27		
Cannonball A	2450-2440	1.41	-7.07	2.11	no
	2440-2430	2.02	-4.95	1.35	no
	2430-2420	1.58	-6.31	1.46	no
	2420-2410	2.06	-4.85	1.32	no
	2410-2400	1.62	-6.17	2.54	no
	2400-2390	1.15	-8.72	1.67	no
	2390-2380	0.96	-10.39	6.02	no
	2380-2360	4.58	-4.37	2.04	no

A 2-Point Slope = (Elevation / Distance)

B Slope Differential =(2-Point Slope in the Next Row Down)- (2-Point Slope of Given Row).

C Knickpoints Resulting from Profiles Crossing Valleys are not Removed.

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Cannonball A	2360-2350	1.56	-6.41	1.22	no
	2350-2340	1.93	-5.19	9.92	no
	2340-2330	0.66	-15.10	8.62	no
	2330-2320	1.54	-6.48	0.64	no
	2320-2310	1.40	-7.12	1.07	no
	2310-2300	1.22	-8.19	3.51	no
	2300-2290	0.85	-11.70	7.21	no
	2290-2280	2.23	-4.49	843.34	yes
	2280-2270	0.01	-847.84	838.54	yes
	2270-2260	1.08	-9.30	4.66	no
	2260-2250	2.16	-4.64	0.38	no
	2250-2240	1.99	-5.02	12.71	yes
	2240-2230	0.56	-17.73	8.55	no
	2230-2220	1.09	-9.17	2.71	no
	2220-2210	1.55	-6.46	1.60	no
	2210-2200	2.05	-4.87	15.21	yes
	2200-2190	0.50	-20.08	16.74	yes
	2190-2180	2.99	-3.34	15.11	yes
	2180-2160	1.08	-18.45	9.67	no
	2160-2140	2.28	-8.78	10.03	yes
	2140-2120	1.06	-18.81	10.92	yes
	2120-2100	2.54	-7.89	3.65	no
	2100-2080	1.73	-11.53	5.47	no
	2080-2060	3.30	-6.06	24.29	yes
	2060-2040	0.66	-30.35	21.06	yes
	2040-2020	2.15	-9.29	2.88	no
	2020-2000	3.12	-6.41	0.54	no
	2000-1980	3.41	-5.87	2.69	no
	1980-1960	2.34	-8.56	1.76	no
	1960-1940	2.94	-6.80	6.93	no
	1940-1920	1.46	-13.73	2.17	no
	1920-1900	1.73	-11.56	18.72	yes
	1900-1880	0.66	-30.27	25.28	yes
	1880-1860	4.01	-4.99		
Cannonball B	2450-2440	1.43	-7.00	2.38	no
	2440-2430	2.16	-4.62	2.43	no
	2430-2420	1.42	-7.05	2.20	no
	2420-2410	2.07	-4.84	0.68	no
	2410-2400	1.81	-5.52	10.34	yes
	2400-2390	0.63	-15.86	7.29	no
	2390-2380	1.17	-8.57	4.12	no
	2380-2360	4.49	-4.46	1.49	no
	2360-2350	3.37	-2.97	792.97	yes
	2350-2340	0.01	-795.94	782.53	yes
	2340-2330	0.75	-13.41	7.77	no
	2330-2320	1.77	-5.64	8.27	no
	2320-2310	0.72	-13.91	10.17	yes
	2310-2300	2.68	-3.74	653.04	yes
	2300-2290	0.02	-656.77	653.76	yes
	2290-2280	3.32	-3.02	43.35	yes
	2280-2270	0.22	-46.36	589.87	yes
	2270-2260	0.02	-636.24	627.82	yes

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Cannonball B	2260-2250	1.19	-8.41	6.67	no
	2250-2240	5.73	-1.75	249.94	yes
	2240-2230	0.04	-251.68	242.46	yes
	2230-2220	1.08	-9.22	1741.50	yes
	2220-2210	0.01	-1750.72	977.20	yes
	2210-2200	0.01	-773.52	585.41	yes
	2200-2190	0.01	-1358.93	1352.74	yes
	2190-2180	1.61	-6.20	0.87	no
	2180-2160	2.83	-7.07	3511.52	yes
	2160-2140	0.01	-3518.59	3509.03	yes
	2140-2120	2.09	-9.56	5.16	no
	2120-2100	1.36	-14.72	5.74	no
	2100-2080	2.23	-8.99	2.37	no
	2080-2060	3.02	-6.62	24.21	yes
	2060-2040	0.65	-30.82	28.01	yes
	2040-2020	7.13	-2.81	1015.31	yes
	2020-2000	0.02	-1018.12	740.81	yes
	2000-1980	0.07	-277.31	247.18	yes
	1980-1960	0.66	-30.12	22.34	yes
	1960-1940	2.57	-7.78	0.35	no
	1940-1920	2.69	-7.43	14.14	yes
	1920-1900	0.93	-21.57	6.48	no
	1900-1880	1.33	-15.09	10.16	yes
	1880-1860	4.06	-4.93		
Cannonball C	2450-2440	1.16	-8.61	4.02	no
	2440-2430	2.18	-4.59	0.99	no
	2430-2420	1.79	-5.58	1.25	no
	2420-2410	2.31	-4.33	1.56	no
	2410-2400	1.70	-5.90	0.26	no
	2400-2390	1.62	-6.16	3.51	no
	2390-2380	1.03	-9.67	5.78	no
	2380-2360	5.15	-3.89	0.93	no
	2360-2350	2.08	-4.81	1.14	no
	2350-2340	1.68	-5.95	6.37	no
	2340-2330	0.81	-12.32	7.23	no
	2330-2320	1.96	-5.09	2.95	no
	2320-2310	1.24	-8.04	3.81	no
	2310-2300	2.36	-4.23	4.53	no
	2300-2290	1.14	-8.77	3.69	no
	2290-2280	1.97	-5.08	13.06	yes
	2280-2270	0.55	-18.13	9.29	no
	2270-2260	1.13	-8.84	4.67	no
	2260-2250	2.40	-4.17	0.05	no
	2250-2240	2.37	-4.21	13.50	yes
	2240-2230	0.56	-17.72	8.55	no
	2230-2220	1.09	-9.17	2.54	no
	2220-2210	1.51	-6.63	1.49	no
	2210-2200	1.95	-5.13	5.11	no
	2200-2190	0.98	-10.24	5.48	no
	2190-2180	2.10	-4.76	1.39	no
	2180-2160	3.25	-6.16	3.10	no

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Cannonball C	2160-2140	2.16	-9.26	2.75	no
	2140-2120	3.08	-6.50	3.04	no
	2120-2100	2.10	-9.54	0.70	no
	2100-2080	2.26	-8.84	0.61	no
	2080-2060	2.43	-8.24	0.22	no
	2060-2040	2.37	-8.46	0.62	no
	2040-2020	2.55	-7.83	1.24	no
	2020-2000	3.03	-6.60	0.55	no
	2000-1980	3.31	-6.05	1.07	no
	1980-1960	4.02	-4.98	6.49	no
	1960-1940	1.74	-11.47	4.76	no
	1940-1920	2.98	-6.71	7.08	no
	1920-1900	1.45	-13.79	16.13	yes
	1900-1880	0.67	-29.92	25.79	yes
	1880-1860	4.83	-4.14		
Bad River	2140-2130	1.31	7.64	17.84	yes
	2130-2120	0.98	-10.20	4.81	no
	2120-2110	1.86	-5.39	1.69	no
	2110-2100	1.41	-7.08	1.10	no
	2100-2090	1.67	-5.98	1.71	no
	2090-2080	2.34	-4.28	2.44	no
	2080-2070	1.49	-6.72	3.44	no
	2070-2060	0.98	-10.16	2.88	no
	2060-2050	1.37	-7.28	3.67	no
	2050-2040	0.91	-10.95	3.12	no
	2040-2030	1.28	-7.82	2.97	no
	2030-2020	2.06	-4.85	1.61	no
	2020-2010	1.55	-6.46	0.55	no
	2010-2000	1.69	-5.90	1.10	no
	2000-1990	2.08	-4.80	0.65	no
	1990-1980	2.41	-4.16	2.41	no
	1980-1970	1.52	-6.57	0.94	no
	1970-1960	1.78	-5.63	1.64	no
	1960-1950	2.51	-3.99	1.48	no
	1950-1940	1.83	-5.47	0.96	no
	1940-1930	1.55	-6.43	3.52	no
	1930-1920	3.43	-2.91	0.32	no
	1920-1910	3.09	-3.24	3.20	no
	1910-1900	1.55	-6.44	1.63	no
	1900-1890	2.08	-4.81	2.60	no
	1890-1880	1.35	-7.41	4.14	no
	1880-1870	3.06	-3.27	1.67	no
	1870-1860	2.03	-4.93	0.58	no
	1860-1850	1.81	-5.51	2.44	no
	1850-1840	1.26	-7.95	5.16	yes
	1840-1830	3.57	-2.80	3.65	no
	1830-1820	1.55	-6.45	0.09	no
	1820-1810	1.53	-6.54	2.89	no
	1810-1800	2.73	-3.66	0.06	no
	1800-1790	2.69	-3.72	4.07	no
	1790-1780	1.28	-7.79	4.20	no
	1780-1770	2.78	-3.59	1.93	no

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Bad River	1770-1760	1.81	-5.52	0.42	no
	1760-1750	1.68	-5.95	0.10	no
	1750-1740	1.71	-5.85	2.48	no
	1740-1730	2.96	-3.37	3.56	no
	1730-1720	1.44	-6.93	2.80	no
	1720-1710	2.42	-4.12	0.37	no
	1710-1700	2.22	-4.50	0.31	no
	1700-1690	2.08	-4.81	8.40	yes
	1690-1680	0.76	-13.21	9.35	yes
	1680-1670	2.59	-3.86	0.03	no
	1670-1660	2.61	-3.83	0.86	no
	1660-1650	2.13	-4.70	0.69	no
	1650-1640	2.49	-4.01	0.55	no
	1640-1630	2.89	-3.46	0.84	no
	1630-1620	2.32	-4.30	0.99	no
	1620-1610	1.89	-5.29	1.51	no
	1610-1600	2.65	-3.78	1.73	no
	1600-1590	1.81	-5.51	1.43	no
	1590-1580	2.45	-4.08	3.19	no
	1580-1570	1.38	-7.27	3.92	no
	1570-1560	2.98	-3.35	0.14	no
	1560-1550	3.11	-3.22	1.11	no
	1550-1540	2.31	-4.33	1.69	no
	1540-1530	1.66	-6.02	1.66	no
	1530-1520	2.29	-4.36	1.42	no
	1520-1510	3.40	-2.94	1.76	no
	1510-1500	2.13	-4.70	1.06	no
	1500-1490	2.75	-3.64	0.65	no
	1490-1480	3.35	-2.99	0.65	no
	1480-1470	2.75	-3.63	0.91	no
	1470-1460	2.20	-4.54	0.53	no
	1460-1450	2.49	-4.01	0.41	no
	1450-1440	2.77	-3.60	1.32	no
	1440-1430	2.03	-4.93	0.40	no
	1430-1420	1.88	-5.33		
Bad River A	2140-2130	0.92	10.92	17.32	yes
	2130-2120	0.35	28.24	15.41	yes
	2120-2110	0.78	12.83	0.40	no
	2110-2100	0.81	12.42	0.61	no
	2100-2090	0.85	11.81	0.92	no
	2090-2080	0.79	12.73	1.14	no
	2080-2070	0.86	11.59	2.17	no
	2070-2060	0.73	13.76	6.06	no
	2060-2050	1.30	7.70	173.56	yes
	2050-2040	0.06	181.26	163.72	yes
	2040-2030	0.57	17.54	8.89	no
	2030-2020	1.16	8.65	1.34	no
	2020-2010	1.00	10.00	2.24	no
	2010-2000	0.82	12.24	0.58	no
	2000-1990	0.86	11.66	1.63	no
	1990-1980	0.75	13.28	26.96	yes

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Bad River A	1980-1970	0.25	40.24	31.33	yes
	1970-1960	1.12	8.91	1.12	no
	1960-1950	1.28	7.80	0.06	no
	1950-1940	1.29	7.73	14.77	yes
	1940-1930	0.44	22.51	10.18	yes
	1930-1920	0.81	12.33	4.48	no
	1920-1910	1.27	7.84	0.35	no
	1910-1900	1.33	7.50	4.56	no
	1900-1890	0.83	12.06	27.07	yes
	1890-1880	0.26	39.13	33.53	yes
	1880-1870	1.79	5.60	0.17	no
	1870-1860	1.84	5.42	12.59	yes
	1860-1850	0.56	18.01	13.09	yes
	1850-1840	2.03	4.92	16.96	yes
	1840-1830	0.46	21.88	3.58	no
	1830-1820	0.39	25.46	14.35	yes
	1820-1810	0.90	11.12	8.32	no
	1810-1800	0.51	19.44	13.58	yes
	1800-1790	1.71	5.86	287.79	yes
	1790-1780	0.03	293.64	284.30	yes
	1780-1770	1.07	9.34	44.11	yes
	1770-1760	0.19	53.46	49.10	yes
	1760-1750	2.30	4.36	581.47	yes
	1750-1740	0.02	585.83	578.81	yes
	1740-1730	1.42	7.02	3.29	no
	1730-1720	0.97	10.31	10.64	yes
	1720-1710	0.48	20.95	13.32	yes
	1710-1700	1.31	7.63	2.07	no
	1700-1690	1.03	9.70	917.69	yes
	1690-1680	0.01	927.39	920.70	yes
	1680-1670	1.49	6.69	0.18	no
	1670-1660	1.53	6.52	12.77	yes
	1660-1650	0.52	19.29	12.54	yes
	1650-1640	1.48	6.74	3.05	no
	1640-1630	1.02	9.79	5.38	no
	1630-1620	2.27	4.41	640.54	yes
	1620-1610	0.02	644.95	636.71	yes
	1610-1600	1.21	8.24	6.79	no
	1600-1590	0.67	15.03	11.39	yes
	1590-1580	2.75	3.64	1607.80	yes
	1580-1570	0.01	1611.44	379.80	yes
	1570-1560	0.01	1231.65	1223.51	yes
	1560-1550	1.23	8.14	3.01	no
	1550-1540	1.95	5.13	22.55	yes
	1540-1530	0.36	27.67	22.75	yes
	1530-1520	2.03	4.92	5.70	no
	1520-1510	0.94	10.63	6.15	no
	1510-1500	2.23	4.48	430.21	yes
	1500-1490	0.02	434.68	425.53	yes
	1490-1480	1.09	9.15	0.50	no
	1480-1470	1.04	9.66	3.72	no
	1470-1460	1.69	5.93	0.49	no
	1460-1450	1.56	6.43	1.84	no

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Bad River A	1450-1440	2.18	4.59	729.63	yes
	1440-1430	0.01	734.22		
Bad River B	2140-2130	0.97	10.26	0.00	no
	2130-2120	0.40	-25.29	17.54	yes
	2120-2110	1.29	-7.74	17.33	yes
	2110-2100	0.40	-25.08	7.22	no
	2100-2090	0.56	-17.85	6.25	no
	2090-2080	0.86	-11.60	0.27	no
	2080-2070	0.88	-11.34	1.40	no
	2070-2060	0.79	-12.74	3.77	no
	2060-2050	1.12	-8.97	4.22	no
	2050-2040	0.76	-13.19	380.03	yes
	2040-2030	0.03	-393.22	384.02	yes
	2030-2020	1.09	-9.20	5.48	no
	2020-2010	0.68	-14.68	5.92	no
	2010-2000	1.14	-8.75	2.51	no
	2000-1990	0.89	-11.26	1.89	no
	1990-1980	0.76	-13.16	12.03	yes
	1980-1970	0.40	-25.19	12.49	yes
	1970-1960	0.79	-12.70	6.20	no
	1960-1950	1.54	-6.50	2.60	no
	1950-1940	1.10	-9.10	13.15	yes
	1940-1930	0.45	-22.25	13.98	yes
	1930-1920	1.21	-8.27	2.03	no
	1920-1910	0.97	-10.30	2.27	no
	1910-1900	1.25	-8.03	8.50	no
	1900-1890	0.61	-16.53	10.28	yes
	1890-1880	1.60	-6.25	7.50	no
	1880-1870	0.73	-13.75	8.10	no
	1870-1860	1.77	-5.65	12.01	yes
	1860-1850	0.57	-17.66	7.03	no
	1850-1840	0.40	-24.69	19.62	yes
	1840-1830	1.97	-5.07	12.66	yes
	1830-1820	0.56	-17.73	5.95	no
	1820-1810	0.85	-11.79	6.49	no
	1810-1800	0.55	-18.28	8.04	no
	1800-1790	0.98	-10.24	3.56	no
	1790-1780	0.72	-13.80	5.15	no
	1780-1770	1.16	-8.65	46.69	yes
	1770-1760	0.18	-55.34	47.60	yes
	1760-1750	1.29	-7.74	0.42	no
	1750-1740	1.37	-7.32	2.25	no
	1740-1730	1.05	-9.57	6.14	no
	1730-1720	0.64	-15.70	4.37	no
	1720-1710	0.88	-11.34	3.87	no
	1710-1700	1.34	-7.46	3.75	no
	1700-1690	2.69	-3.72	35.37	yes
	1690-1680	0.26	-39.09	398.94	yes
	1680-1670	0.02	-438.03	426.42	yes
	1670-1660	0.86	-11.61	6.99	no
	1660-1650	2.17	-4.62	895.79	yes
	1650-1640	0.01	-900.41	890.94	yes

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Bad River B	1640-1630	1.06	-9.47	6.19	no
	1630-1620	3.05	-3.28	375.04	yes
	1620-1610	0.03	-378.32	126.07	yes
	1610-1600	0.02	-504.39	498.05	yes
	1600-1590	1.58	-6.34	38.97	yes
	1590-1580	0.22	-45.32	30.49	yes
	1580-1570	0.67	-14.82	5.87	no
	1570-1560	1.12	-8.95	0.90	no
	1560-1550	1.24	-8.06	2.49	no
	1550-1540	1.80	-5.56	2.94	no
	1540-1530	3.82	-2.62	35.94	yes
	1530-1520	0.26	-38.56	31.59	yes
	1520-1510	1.44	-6.97	683.38	yes
	1510-1500	0.01	-690.35	449.82	yes
	1500-1490	0.01	-1140.17	1125.66	yes
	1490-1480	0.69	-14.51	12.10	yes
	1480-1470	4.16	-2.40	1.67	no
	1470-1460	2.46	-4.07	342.63	yes
	1460-1450	0.03	-346.70	68.42	yes
	1450-1440	0.04	-278.29	333.67	yes
	1440-1430	0.02	-611.95	1236.66	yes
	1430-1420	0.01	-1848.61		
Bad River C	2140-2130	0.91	11.02	41.90	yes
	2130-2120	0.32	-30.88	21.31	yes
	2120-2110	1.05	-9.57	6.54	no
	2110-2100	0.62	-16.11	4.01	no
	2100-2090	0.83	-12.10	1.68	no
	2090-2080	0.96	-10.42	2.97	no
	2080-2070	0.75	-13.39	4.26	no
	2070-2060	1.10	-9.13	11.43	yes
	2060-2050	0.49	-20.56	10.24	yes
	2050-2040	0.97	-10.32	11.86	yes
	2040-2030	0.45	-22.18	13.66	yes
	2030-2020	1.17	-8.52	12.68	yes
	2020-2010	0.47	-21.20	12.82	yes
	2010-2000	1.19	-8.38	0.32	no
	2000-1990	1.15	-8.71	4.65	no
	1990-1980	0.75	-13.36	34.51	yes
	1980-1970	0.21	-47.87	38.04	yes
	1970-1960	1.02	-9.83	3.21	no
	1960-1950	1.51	-6.62	2.49	no
	1950-1940	1.10	-9.11	12.91	yes
	1940-1930	0.45	-22.02	13.73	yes
	1930-1920	1.21	-8.29	1.95	no
	1920-1910	0.98	-10.24	2.22	no
	1910-1900	1.25	-8.02	8.95	no
	1900-1890	0.59	-16.97	0.21	no
	1890-1880	0.60	-16.76	10.75	yes
	1880-1870	1.66	-6.01	2.46	no
	1870-1860	1.18	-8.47	0.38	no
	1860-1850	1.24	-8.09	3.70	no
	1850-1840	0.85	-11.79	6.23	no

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Bad River C	1840-1830	1.80	-5.55	27.93	yes
	1830-1820	0.30	-33.48	14.70	yes
	1820-1810	0.53	-18.78	13.85	yes
	1810-1800	2.03	-4.93	26.54	yes
	1800-1790	0.32	-31.47	20.49	yes
	1790-1780	0.91	-10.97	2.99	no
	1780-1770	0.72	-13.97	3.53	no
	1770-1760	0.57	-17.50	9.57	no
	1760-1750	1.26	-7.93	0.43	no
	1750-1740	1.20	-8.36	0.17	no
	1740-1730	1.17	-8.53	2.06	no
	1730-1720	0.95	-10.58	10.08	yes
	1720-1710	0.48	-20.67	13.44	yes
	1710-1700	1.38	-7.23	2.60	no
	1700-1690	1.02	-9.83	1498.74	yes
	1690-1680	0.01	-1508.57	1501.87	yes
	1680-1670	1.49	-6.70	0.88	no
	1670-1660	1.72	-5.82	0.54	no
	1660-1650	1.57	-6.37	6.73	no
	1650-1640	0.76	-13.09	0.50	no
	1640-1630	0.74	-13.59	9.53	no
	1630-1620	2.46	-4.06	1051.94	yes
	1620-1610	0.01	-1056.00	1046.51	yes
	1610-1600	1.05	-9.49	23.78	yes
	1600-1590	0.30	-33.27	27.02	yes
	1590-1580	1.60	-6.25	8.73	no
	1580-1570	0.67	-14.98	2.13	no
	1570-1560	0.58	-17.11	11.65	yes
	1560-1550	1.83	-5.45	2.39	no
	1550-1540	1.28	-7.84	2.94	no
	1540-1530	2.04	-4.90	86.61	yes
	1530-1520	0.11	-91.51	86.12	yes
	1520-1510	1.85	-5.39	0.51	no
	1510-1500	2.05	-4.88	11.18	yes
	1500-1490	0.62	-16.06	4.73	no
	1490-1480	0.88	-11.33	2.06	no
	1480-1470	1.08	-9.27	3.24	no
	1470-1460	1.66	-6.03	0.28	no
	1460-1450	1.74	-5.75	1.04	no
	1450-1440	1.47	-6.78	14.41	yes
	1440-1430	0.47	-21.20	6.87	no
	1430-1420	0.70	-14.33		
White River	2130-2120	0.76	13.10	44.57	yes
	2120-2100	0.64	-31.47	28.16	yes
	2100-2090	3.02	-3.31	0.52	no
	2090-2080	2.61	-3.83	0.32	no
	2080-2070	2.85	-3.51	0.73	no
	2070-2060	2.36	-4.24	1.03	no
	2060-2050	3.11	-3.21	0.18	no
	2050-2040	2.94	-3.40	0.17	no
	2040-2030	2.81	-3.56	1.03	no

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
White River	2030-2020	3.95	-2.53	2.97	no
	2020-2010	1.82	-5.51	2.30	no
	2010-2000	3.12	-3.21	0.61	no
	2000-1990	2.62	-3.81	2.43	no
	1990-1980	1.60	-6.24	2.69	no
	1980-1970	2.82	-3.55	0.87	no
	1970-1960	2.26	-4.42	2.01	no
	1960-1950	4.14	-2.41	1.50	no
	1950-1940	2.56	-3.91	0.43	no
	1940-1930	2.88	-3.48	0.08	no
	1930-1920	2.94	-3.40	1.76	no
	1920-1910	1.94	-5.16	1.89	no
	1910-1900	3.06	-3.27	0.58	no
	1900-1890	2.60	-3.84	1.64	no
	1890-1880	4.53	-2.21	5.30	yes
	1880-1870	1.33	-7.51	5.28	yes
	1870-1860	4.48	-2.23	0.23	no
	1860-1850	4.98	-2.01	1.78	no
	1850-1840	2.64	-3.78	0.63	no
	1840-1830	2.27	-4.41	0.33	no
	1830-1820	2.45	-4.08	2.22	no
	1820-1810	5.37	-1.86	0.45	no
	1810-1800	4.32	-2.32	0.27	no
	1800-1790	3.88	-2.58	1.00	no
	1790-1780	2.79	-3.58	1.03	no
	1780-1770	3.92	-2.55	1.86	no
	1770-1760	2.26	-4.42	0.74	no
	1760-1750	2.72	-3.68	1.53	no
	1750-1740	1.92	-5.21	1.44	no
	1740-1730	2.65	-3.77	0.79	no
	1730-1720	3.35	-2.99	0.37	no
	1720-1710	2.98	-3.36	1.05	no
	1710-1700	2.27	-4.40	0.57	no
	1700-1690	2.01	-4.97	2.32	no
	1690-1680	3.77	-2.65	1.29	no
	1680-1670	2.54	-3.94	0.10	no
	1670-1660	2.47	-4.05	0.75	no
	1660-1650	3.03	-3.30	0.57	no
	1650-1640	2.59	-3.86	1.66	no
	1640-1630	1.81	-5.52	3.35	no
	1630-1620	4.60	-2.18	2.31	no
	1620-1610	2.23	-4.49	1.57	no
	1610-1600	3.43	-2.92	1.78	no
	1600-1590	2.13	-4.70	0.20	no
	1590-1580	2.22	-4.50	0.66	no
	1580-1570	1.94	-5.16	2.59	no
	1570-1560	3.90	-2.57	0.54	no
	1560-1550	3.22	-3.11	0.13	no
	1550-1540	3.09	-3.23	0.26	no
	1540-1530	3.36	-2.98	0.27	no
	1530-1520	3.08	-3.25	0.73	no
	1520-1510	3.97	-2.52	0.84	no
	1510-1500	2.98	-3.36	3.42	no
	1500-1490	1.48	-6.78	3.06	no

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
White River	1490-1480	2.69	-3.72	0.73	no
	1480-1470	2.25	-4.44	1.19	no
	1470-1460	1.78	-5.63	1.11	no
	1460-1450	2.21	-4.52	1.12	no
	1450-1440	2.95	-3.39	0.53	no
	1440-1430	2.55	-3.92	0.47	no
	1430-1420	2.90	-3.44	0.20	no
	1420-1410	3.08	-3.24	0.66	no
	1410-1400	3.87	-2.58	2.90	no
	1400-1390	1.83	-5.48	1.61	no
	1390-1380	2.58	-3.87	1.05	no
	1380-1370	3.55	-2.82	0.28	no
	1370-1360	3.22	-3.10	3.16	no
	1360-1350	1.60	-6.27	2.04	no
	1350-1340	2.37	-4.22	1.17	no
	1340-1330	3.28	-3.05	3.35	no
White River A	2120-2110	0.83	-11.98	5.52	no
	2110-2100	0.57	-17.51	8.72	no
	2100-2090	1.14	-8.78	1.85	no
	2090-2080	1.44	-6.93	0.66	no
	2080-2070	1.60	-6.27	2.34	no
	2070-2060	1.16	-8.61	2.95	no
	2060-2050	1.77	-5.66	5.29	no
	2050-2040	0.91	-10.95	4.14	no
	2040-2030	1.47	-6.81	2.47	no
	2030-2020	2.30	-4.34	354.97	yes
	2020-2010	0.03	-359.31	352.28	yes
	2010-2000	1.42	-7.03	1.82	no
	2000-1990	1.92	-5.20	9.24	no
	1990-1980	0.69	-14.45	7.76	no
	1980-1970	1.49	-6.69	6.20	no
	1970-1960	0.78	-12.89	8.06	no
	1960-1950	2.07	-4.83	5.09	no
	1950-1940	1.01	-9.92	4.33	no
	1940-1930	1.79	-5.60	1.75	no
	1930-1920	1.36	-7.35	0.09	no
	1920-1910	1.34	-7.44	1.19	no
	1910-1900	1.16	-8.64	1.29	no
	1900-1890	1.01	-9.93	1.60	no
	1890-1860	3.60	-8.33	2.85	no
	1860-1850	1.83	-5.48	3.25	no
	1850-1840	1.15	-8.72	4.33	no
	1840-1830	2.28	-4.39	14.60	yes
	1830-1820	0.53	-18.99	12.24	yes
	1820-1810	1.48	-6.75	3.52	no
	1810-1800	0.97	-10.27	6.10	no
	1800-1790	2.40	-4.16	23.13	yes
	1790-1780	0.37	-27.29	23.37	yes
	1780-1770	2.55	-3.92	11.73	yes
	1770-1760	0.64	-15.65	7.32	no
	1760-1750	1.20	-8.34	4.15	no

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
White River A	1750-1740	2.39	-4.19	1.22	no
	1740-1730	1.85	-5.41	0.74	no
	1730-1720	1.63	-6.15	2.29	no
	1720-1710	2.59	-3.85	8.20	no
	1710-1700	0.83	-12.05	1.29	no
	1700-1690	0.93	-10.76	4.94	no
	1690-1680	1.72	-5.82	0.57	no
	1680-1670	1.56	-6.39	3.19	no
	1670-1660	3.13	-3.20	6.26	no
	1660-1650	1.06	-9.46	3.55	no
	1650-1640	1.69	-5.91	4.92	no
	1640-1630	0.92	-10.83	7.04	no
	1630-1620	2.64	-3.79	1.61	no
	1620-1610	1.85	-5.39	2.15	no
	1610-1600	3.09	-3.24	13.98	yes
	1600-1590	0.58	-17.23	13.32	yes
	1590-1580	2.56	-3.91	8.71	no
	1580-1570	0.79	-12.62	9.00	no
	1570-1560	2.76	-3.62	5.66	no
	1560-1550	1.08	-9.28	4.62	no
	1550-1540	2.15	-4.66	0.52	no
	1540-1530	2.42	-4.14	4.06	no
	1530-1520	1.22	-8.20	0.94	no
	1520-1510	1.09	-9.14	4.32	no
	1510-1500	2.07	-4.82	0.10	no
	1500-1490	2.12	-4.73	5.70	no
	1490-1480	0.96	-10.43	4.67	no
	1480-1470	1.73	-5.76	0.87	no
	1470-1460	2.04	-4.90	594.79	yes
	1460-1450	0.02	-599.69	591.32	yes
	1450-1440	1.19	-8.37	0.86	no
	1440-1430	1.08	-9.24	4.50	no
	1430-1420	0.73	-13.73	4.53	no
	1420-1410	1.09	-9.20	5.34	no
	1410-1400	2.59	-3.87	157.27	yes
	1400-1390	0.06	-161.14	156.41	yes
	1390-1380	2.12	-4.73	283.85	yes
	1380-1370	0.03	-288.58	274.76	yes
	1370-1360	0.72	-13.82	7.74	no
	1360-1350	1.65	-6.08	523.03	yes
	1350-1340	0.02	-529.10	526.32	yes
	1340-1330	3.59	-2.79	77.88	yes
	1330-1320	0.12	-80.67		
White River B	2110-2100	1.10	-9.11	1.00	no
	2100-2090	1.23	-8.11	0.89	no
	2090-2080	1.38	-7.23	1.36	no
	2080-2070	1.70	-5.87	1.88	no
	2070-2060	0.00	-10043.14	3729995.82	yes
	2060-2050	0.00	-3740038.96	3650004.17	yes
	2050-2040	0.00	-90034.79	7282979.70	yes
	2040-2030	0.00	-7373014.48	1428501.11	yes

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
White River B	2030-2020	0.00	-5944513.37	5944499.00	yes
	2020-2010	0.70	-14.37	10.22	yes
	2010-2000	2.41	-4.15	7.15	no
	2000-1990	0.88	-11.30	4.17	no
	1990-1980	0.65	-15.47	9.42	no
	1980-1970	1.65	-6.05	0.44	no
	1970-1960	1.54	-6.49	0.97	no
	1960-1950	1.34	-7.47	3.88	no
	1950-1940	0.88	-11.35	5.85	no
	1940-1930	1.82	-5.50	1.05	no
	1930-1920	1.53	-6.55	1.41	no
	1920-1910	1.26	-7.96	0.91	no
	1910-1900	1.13	-8.87	0.12	no
	1900-1890	1.14	-8.74	4.80	no
	1890-1880	2.53	-3.95	111.20	yes
	1880-1870	0.09	-115.15	108.89	yes
	1870-1860	1.60	-6.26	0.30	no
	1860-1850	1.68	-5.95	10.58	yes
	1850-1840	0.60	-16.54	12.15	yes
	1840-1830	2.28	-4.39	0.84	no
	1830-1820	1.91	-5.23	480.02	yes
	1820-1810	0.02	-485.25	473.88	yes
	1810-1800	0.88	-11.37	8.79	no
	1800-1790	3.87	-2.59	557.99	yes
	1790-1780	0.02	-560.58	119.94	yes
	1780-1770	0.02	-440.64	433.88	yes
	1770-1760	1.48	-6.76	4.82	no
	1760-1750	5.14	-1.94	286.01	yes
	1750-1740	0.03	-287.95	225.56	yes
	1740-1730	0.16	-62.39	46.89	yes
	1730-1720	0.64	-15.51	9.94	no
	1720-1710	1.80	-5.57	6.29	no
	1710-1700	0.84	-11.86	1.51	no
	1700-1690	0.97	-10.35	3.87	no
	1690-1680	1.54	-6.48	1.43	no
	1680-1670	1.98	-5.05	1.76	no
	1670-1660	3.04	-3.29	7.99	no
	1660-1650	0.89	-11.28	5.44	no
	1650-1640	1.71	-5.84	5.78	no
	1640-1630	0.86	-11.62	7.77	no
	1630-1620	2.60	-3.85	0.75	no
	1620-1610	2.18	-4.60	2.17	no
	1610-1600	1.48	-6.77	3.45	no
	1600-1590	3.02	-3.32	7.15	no
	1590-1580	0.96	-10.46	217.89	yes
	1580-1570	0.04	-228.35	223.02	yes
	1570-1560	1.88	-5.33	0.96	no
	1560-1550	1.59	-6.29	4.07	no
	1550-1540	4.50	-2.22	15.70	yes
	1540-1530	0.56	-17.92	8.14	no
	1530-1520	1.02	-9.77	0.78	no
	1520-1510	1.11	-9.00	7.02	no
	1510-1500	5.05	-1.98	535.26	yes

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
White River B	1500-1490	0.02	-537.24	456.09	yes
	1490-1480	0.12	-81.15	50.71	yes
	1480-1470	0.33	-30.44	26.65	yes
	1470-1460	2.64	-3.79	651.35	yes
	1460-1450	0.02	-655.14	646.81	yes
	1450-1440	1.20	-8.33	0.96	no
	1440-1430	1.08	-9.29	4.55	no
	1430-1420	0.72	-13.84	4.65	no
	1420-1410	1.09	-9.20	5.34	no
	1410-1400	2.60	-3.85	157.52	yes
	1400-1390	0.06	-161.37	156.65	yes
	1390-1380	2.12	-4.72	340.31	yes
	1380-1370	0.03	-345.03	331.23	yes
	1370-1360	0.72	-13.80	7.72	no
	1360-1350	1.65	-6.08	561.62	yes
	1350-1340	0.02	-567.69	564.97	yes
	1340-1330	3.67	-2.73	644.56	yes
White River C	2100-2090	1.49	-6.73	0.34	no
	2090-2080	1.41	-7.07	0.51	no
	2080-2070	1.32	-7.59	1.09	no
	2070-2060	1.54	-6.50	1.04	no
	2060-2050	1.83	-5.46	6.90	no
	2050-2040	0.81	-12.36	8.00	no
	2040-2030	2.30	-4.35	8.13	no
	2030-2020	0.80	-12.48	3.24	no
	2020-2010	1.08	-9.25	3.83	no
	2010-2000	1.85	-5.42	0.52	no
	2000-1990	1.69	-5.93	7.94	no
	1990-1980	0.72	-13.87	8.71	no
	1980-1970	1.94	-5.16	6.82	no
	1970-1960	0.84	-11.98	6.97	no
	1960-1950	2.00	-5.00	8.42	no
	1950-1940	0.74	-13.42	7.55	no
	1940-1930	1.70	-5.87	2.64	no
	1930-1920	3.10	-3.23	4.65	no
	1920-1910	1.27	-7.88	4.94	no
	1910-1900	0.78	-12.82	6.37	no
	1900-1890	1.55	-6.45	0.64	no
	1890-1880	1.41	-7.09	9.40	no
	1880-1870	0.61	-16.49	9.99	no
	1870-1860	1.54	-6.50	2.96	no
	1860-1850	2.83	-3.54	11.16	yes
	1850-1840	0.68	-14.70	8.42	no
	1840-1830	1.59	-6.27	0.88	no
	1830-1820	1.40	-7.15	1.24	no
	1820-1810	1.19	-8.39	4.14	no
	1810-1800	2.36	-4.25	3.41	no
	1800-1790	1.31	-7.66	0.93	no
	1790-1780	1.49	-6.73	1.80	no
	1780-1770	2.03	-4.93	0.04	no

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
White River C	1770-1760	2.01	-4.97	8.36	no
	1760-1750	0.75	-13.33	9.14	no
	1750-1740	2.39	-4.19	1.24	no
	1740-1730	1.84	-5.43	0.69	no
	1730-1720	1.63	-6.12	2.18	no
	1720-1710	2.54	-3.94	6.43	no
	1710-1700	0.96	-10.37	0.85	no
	1700-1690	0.89	-11.22	7.91	no
	1690-1680	3.01	-3.32	8.67	no
	1680-1670	0.83	-11.99	8.00	no
	1670-1660	2.51	-3.98	1.88	no
	1660-1650	1.71	-5.86	1.00	no
	1650-1640	1.46	-6.86	6.78	no
	1640-1630	0.73	-13.63	9.96	no
	1630-1620	2.72	-3.68	0.32	no
	1620-1610	2.50	-4.00	2.90	no
	1610-1600	1.45	-6.90	2.96	no
	1600-1590	1.01	-9.86	2.67	no
	1590-1580	1.39	-7.19	2.10	no
	1580-1570	1.96	-5.09	1.15	no
	1570-1560	2.54	-3.94	3.00	no
	1560-1550	1.44	-6.94	2.36	no
	1550-1540	2.18	-4.58	0.17	no
	1540-1530	2.11	-4.75	0.73	no
	1530-1520	2.49	-4.01	4.40	no
	1520-1510	1.19	-8.42	4.57	no
	1510-1500	2.60	-3.84	9.30	no
	1500-1490	0.76	-13.14	7.72	no
	1490-1480	1.84	-5.42	2.44	no
	1480-1470	1.27	-7.86	4.39	no
	1470-1460	2.88	-3.48	0.37	no
	1460-1450	2.60	-3.84	1.13	no
	1450-1440	2.01	-4.98	0.44	no
	1440-1430	1.84	-5.42	9.02	no
	1430-1410	1.39	-14.44	8.77	no
	1410-1400	1.76	-5.67	0.28	no
	1400-1390	1.68	-5.96	1.33	no
	1390-1380	2.16	-4.62	2.19	no
	1380-1370	4.11	-2.43	2.41	no
	1370-1360	2.06	-4.85	7.46	no
	1360-1350	0.81	-12.30	4.38	no
	1350-1340	1.26	-7.93	5.68	no
	1340-1330	4.45	-2.25	1.87	no
Keya Paha River	2370-2360	2.13	-4.69	6.87	yes
	2360-2350	0.86	-11.56	5.66	yes
	2350-2340	1.69	-5.90	1.30	no
	2340-2330	1.39	-7.20	2.02	no
	2330-2320	1.08	-9.22	2.10	no
	2320-2310	0.88	-11.32	5.87	yes
	2310-2300	1.83	-5.45	1.59	no
	2300-2290	2.59	-3.86	12.14	yes

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Keya Paha River	2290-2280	0.63	-16.00	5.93	yes
	2280-2270	0.99	-10.07	5.04	yes
	2270-2260	1.99	-5.03	0.71	no
	2260-2250	1.74	-5.74	1.77	no
	2250-2240	1.33	-7.51	1.98	no
	2240-2230	1.81	-5.53	10.57	yes
	2230-2220	0.62	-16.10	12.52	yes
	2220-2210	2.79	-3.58	2.81	no
	2210-2200	1.57	-6.39	1.36	no
	2200-2190	1.29	-7.75	3.32	no
	2190-2180	2.26	-4.43	1.06	no
	2180-2170	1.82	-5.49	1.66	no
	2170-2160	2.61	-3.83	1.28	no
	2160-2150	1.96	-5.11	0.52	no
	2150-2140	2.18	-4.59	0.18	no
	2140-2130	2.10	-4.77	0.70	no
	2130-2120	2.46	-4.07	2.92	no
	2120-2110	1.43	-6.99	3.58	no
	2110-2100	2.94	-3.40	3.14	no
	2100-2090	1.53	-6.55	0.63	no
	2090-2080	1.69	-5.92	2.57	no
	2080-2070	1.18	-8.49	3.99	no
	2070-2060	2.22	-4.50	0.74	no
	2060-2050	2.66	-3.76	9.04	yes
	2050-2040	0.78	-12.79	9.34	yes
	2040-2030	2.89	-3.46	2.74	no
	2030-2020	1.61	-6.19	0.38	no
	2020-2010	1.52	-6.57	0.90	no
	2010-2000	1.76	-5.67	1.75	no
	2000-1990	2.55	-3.92	1.26	no
	1990-1980	1.93	-5.18	0.74	no
	1980-1970	1.69	-5.91	1.60	no
	1970-1960	1.33	-7.51	1.63	no
	1960-1950	1.70	-5.88	0.75	no
	1950-1940	1.95	-5.14	0.29	no
	1940-1930	2.06	-4.84	1.55	no
	1930-1920	1.57	-6.39	0.15	no
	1920-1910	1.53	-6.54	2.07	no
	1910-1900	2.24	-4.47	4.10	no
	1900-1890	1.17	-8.57	2.90	no
	1890-1880	1.76	-5.68	1.32	no
	1880-1870	1.43	-7.00	0.54	no
	1870-1860	1.55	-6.46	1.24	no
	1860-1850	1.92	-5.22	0.21	no
	1850-1840	1.84	-5.43	3.66	no
	1840-1830	1.10	-9.09	1.76	no
	1830-1820	1.36	-7.33	0.41	no
	1820-1810	1.29	-7.74	0.35	no
	1810-1800	1.35	-7.39	0.00	no
	1800-1790	1.35	-7.39	0.02	no
	1790-1780	1.36	-7.36	0.61	no
	1780-1770	1.25	-7.97	2.95	no
	1770-1760	1.99	-5.02	4.07	no
	1760-1750	1.10	-9.09	4.78	no

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Keya Paha River	1750-1740	2.32	-4.31	3.63	no
	1740-1730	1.26	-7.94	1.01	no
	1730-1720	1.44	-6.93	0.47	no
	1720-1710	1.55	-6.46	0.39	no
	1710-1700	1.65	-6.07	0.08	no
	1700-1690	1.67	-5.99	0.19	no
	1690-1680	1.62	-6.19	0.81	no
	1680-1670	1.43	-7.00	0.37	no
	1670-1660	1.51	-6.63	0.55	no
	1660-1650	1.64	-6.08	0.07	no
	1650-1640	1.66	-6.01		
Keya Paha A	2370-2360	0.66	-15.21	12.07	yes
	2360-2350	3.19	-3.14	1.56	no
	2350-2340	2.13	-4.69	7.32	no
	2340-2330	0.83	-12.02	211.66	yes
	2330-2320	0.04	-223.67	286.77	yes
	2320-2310	0.02	-510.44	390.47	yes
	2310-2300	0.08	-119.97	111.49	yes
	2300-2290	1.18	-8.48	350.88	yes
	2290-2280	0.03	-359.36	352.00	yes
	2280-2270	1.36	-7.36	32.43	yes
	2270-2260	0.25	-39.79	35.96	yes
	2260-2250	2.61	-3.83	33.06	yes
	2250-2240	0.27	-36.88	25.98	yes
	2240-2230	0.92	-10.90	226.30	yes
	2230-2220	0.04	-237.20	231.85	yes
	2220-2210	1.87	-5.35	0.15	no
	2210-2200	1.93	-5.19	4.00	no
	2200-2190	1.09	-9.20	0.45	no
	2190-2180	1.14	-8.75	1.87	no
	2180-2170	1.45	-6.87	2.98	no
	2170-2160	2.57	-3.89	17.56	yes
	2160-2150	0.47	-21.45	8.25	no
	2150-2140	0.76	-13.21	5.10	no
	2140-2130	1.23	-8.10	1.25	no
	2130-2120	1.07	-9.35	1.44	no
	2120-2110	1.26	-7.91	2.89	no
	2110-2100	1.99	-5.02	97.27	yes
	2100-2090	0.10	-102.29	94.12	yes
	2090-2080	1.22	-8.17	2.35	no
	2080-2070	1.72	-5.82	27.73	yes
	2070-2060	0.30	-33.55	45.43	yes
	2060-2050	0.13	-78.98	71.74	yes
	2050-2040	1.38	-7.25	11.39	yes
	2040-2030	0.54	-18.63	9.67	no
	2030-2020	1.12	-8.97	6.86	no
	2020-2010	0.63	-15.83	8.41	no
	2010-2000	1.35	-7.42	0.36	no
	2000-1990	1.29	-7.78	0.07	no
	1990-1980	1.30	-7.71	8.64	no
	1980-1970	0.61	-16.34	5.41	no
	1970-1960	0.91	-10.93	17.26	yes

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Keya Paha A	1960-1950	0.35	-28.19	23.20	yes
	1950-1940	2.00	-4.99	6.03	no
	1940-1930	0.91	-11.02	11.03	yes
	1930-1920	0.45	-22.05	14.41	yes
	1920-1910	1.31	-7.64	2.85	no
	1910-1900	2.09	-4.79	1.74	no
	1900-1890	1.53	-6.53	297.88	yes
	1890-1880	0.03	-304.41	296.78	yes
	1880-1870	1.31	-7.63	19.66	yes
	1870-1860	0.37	-27.29	17.04	yes
	1860-1850	0.98	-10.25	3.68	no
	1850-1840	1.52	-6.58	4.86	no
	1840-1830	0.87	-11.43	1.08	no
	1830-1820	0.97	-10.35	9.79	no
	1820-1810	0.50	-20.14	8.70	no
	1810-1800	0.87	-11.44	4.61	no
	1900-1790	1.46	-6.83	29.45	yes
	1790-1780	0.28	-36.28	28.42	yes
	1780-1770	1.27	-7.85	1.37	no
	1770-1760	1.54	-6.49	28.35	yes
	1760-1750	0.29	-34.83	28.53	yes
	1750-1740	1.59	-6.31	10.09	yes
	1740-1730	0.61	-16.40	11.55	yes
	1730-1720	2.06	-4.85	57.86	yes
	1720-1710	0.16	-62.71	51.25	yes
	1710-1700	0.87	-11.47	7.58	no
	1700-1690	2.58	-3.88	33.24	yes
	1690-1680	0.27	-37.12	17.98	yes
	1680-1670	0.52	-19.14	10.89	yes
	1670-1660	1.21	-8.25	3.67	no
	1660-1650	0.84	-11.91	3.57	no
	1650-1640	1.20			
Keya Paha B	2370-2360	4.76	-2.10	3.94	no
	2360-2350	1.65	-6.05	33.12	yes
	2350-2340	0.26	-39.17	25.83	yes
	2340-2330	0.15	-65.00	41.14	yes
	2330-2320	0.42	-23.86	868.74	yes
	2320-2310	0.01	-892.60	63.29	yes
	2310-2300	0.01	-829.32	821.02	yes
	2300-2290	1.20	-8.30	302.57	yes
	2290-2280	0.03	-310.87	306.13	yes
	2280-2270	2.11	-4.74	20.19	yes
	2270-2260	0.40	-24.93	19.45	yes
	2260-2250	1.83	-5.48	25.70	yes
	2250-2240	0.32	-31.18	8.79	no
	2240-2230	0.25	-39.97	25.33	yes
	2230-2220	0.68	-14.64	8.79	no
	2220-2210	1.71	-5.85	0.79	no
	2210-2200	1.98	-5.06	2.88	no
	2200-2190	1.26	-7.94	13.03	yes
	2190-2180	0.48	-20.98	11.27	yes

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Keya Paha B	2180-2170	1.03	-9.70	2.53	no
	2170-2160	1.39	-7.17	4.49	no
	2160-2150	3.73	-2.68	380.89	yes
	2150-2140	0.03	-383.56	375.75	yes
	2140-2130	1.28	-7.81	42.25	yes
	2130-2120	0.20	-50.06	34.64	yes
	2120-2110	0.65	-15.42	5.76	no
	2110-2100	1.04	-9.66	3.81	no
	2100-2090	0.74	-13.47	9.67	no
	2090-2080	2.63	-3.80	5.89	no
	2080-2070	1.03	-9.68	2.26	no
	2070-2060	1.35	-7.42	816.95	yes
	2060-2050	0.01	-824.37	751.61	yes
	2050-2040	0.14	-72.76	65.06	yes
	2040-2030	1.30	-7.70	2.83	no
	2030-2020	0.95	-10.54	995.22	yes
	2020-2010	0.01	-1005.75	992.47	yes
	2010-2000	0.75	-13.29	6.99	no
	2000-1990	1.59	-6.30	0.96	no
	1990-1980	1.38	-7.25	6.77	no
	1980-1970	0.71	-14.02	6.83	no
	1970-1960	0.48	-20.85	17.27	yes
	1960-1950	2.79	-3.58	508.67	yes
	1950-1940	0.02	-512.25	505.54	yes
	1940-1930	1.49	-6.71	1.63	no
	1930-1920	1.20	-8.34	560.62	yes
	1920-1910	0.02	-568.96	563.83	yes
	1910-1900	1.95	-5.13	1.35	no
	1900-1890	1.54	-6.48	494.13	yes
	1890-1880	0.02	-500.61	493.01	yes
	1880-1870	1.32	-7.60	12.51	yes
	1870-1860	0.50	-20.12	6.94	no
	1860-1850	0.76	-13.18	4.19	no
	1850-1840	1.11	-8.98	1.58	no
	1840-1830	1.35	-7.41	4.10	no
	1830-1820	0.87	-11.50	2.80	no
	1820-1810	0.70	-14.31	2.13	no
	1810-1800	0.82	-12.17	4.24	no
	1800-1790	0.61	-16.41	8.97	no
	1790-1780	1.34	-7.44	10.11	yes
	1780-1770	0.57	-17.55	13.70	yes
	1770-1760	2.59	-3.85	157.39	yes
	1760-1750	0.06	-161.25	156.73	yes
	1750-1740	2.22	-4.51	211.76	yes
	1740-1730	0.05	-216.27	137.63	yes
	1730-1720	0.13	-78.65	67.69	yes
	1720-1710	0.91	-10.96	9.46	no
	1710-1700	6.65	-1.50	424.10	yes
	1700-1690	0.02	-425.60	65.59	yes
	1690-1680	0.03	-360.01	160.11	yes
	1680-1670	0.05	-199.90	41.47	yes
	1670-1660	0.06	-158.43	2.96	no
	1660-1650	0.06	-161.39	143.75	yes

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Keya Paha B	1650-1640	0.57	-17.64		
Keya Paha C	2370-2360	0.75	-13.25	2.68	no
	2360-2350	0.95	-10.57	5.42	no
	2350-2340	0.63	-15.99	8.70	no
	2340-2330	1.37	-7.30	2.15	no
	2330-2320	1.06	-9.45	1.44	no
	2320-2310	1.25	-8.01	7.86	no
	2310-2300	0.63	-15.87	10.76	yes
	2300-2290	1.96	-5.11	13.92	yes
	2290-2280	0.53	-19.03	8.15	no
	2280-2270	0.92	-10.89	4.84	no
	2270-2260	0.64	-15.72	8.88	no
	2260-2250	1.46	-6.84	9.76	no
	2250-2240	0.60	-16.60	9.83	no
	2240-2230	1.48	-6.77	219.84	yes
	2230-2220	0.04	-226.61	221.98	yes
	2220-2210	2.16	-4.63	5.43	no
	2210-2200	0.99	-10.06	1.51	no
	2200-2190	1.17	-8.55	2.52	no
	2190-2180	1.66	-6.04	4.89	no
	2180-2170	0.92	-10.93	4.11	no
	2170-2160	1.47	-6.82	1.92	no
	2160-2150	1.15	-8.73	0.23	no
	2150-2140	1.18	-8.50	1.73	no
	2140-2130	1.48	-6.77	2.70	no
	2130-2120	1.06	-9.47	1.12	no
	2120-2110	1.20	-8.34	0.17	no
	2110-2100	1.17	-8.52	0.61	no
	2100-2090	1.10	-9.13	21.39	yes
	2090-2080	0.33	-30.52	14.19	yes
	2080-2070	0.61	-16.33	5.60	no
	2070-2060	0.93	-10.74	4.70	no
	2060-2050	1.66	-6.04	111.50	yes
	2050-2040	0.09	-117.54	113.13	yes
	2040-2030	2.27	-4.41	12.41	yes
	2030-2020	0.59	-16.81	11.99	yes
	2020-2010	2.07	-4.83	102.46	yes
	2010-2000	0.09	-107.28	97.95	yes
	2000-1990	1.07	-9.33	1.48	no
	1990-1980	1.27	-7.85	6.11	no
	1980-1970	0.72	-13.96	2.33	no
	1970-1960	0.86	-11.63	1.35	no
	1960-1950	0.77	-12.99	6.90	no
	1950-1940	1.64	-6.09	5.19	no
	1940-1930	0.89	-11.28	2.78	no
	1930-1920	1.18	-8.50	8.14	no
	1920-1910	0.60	-16.64	11.85	yes
	1910-1900	2.09	-4.79	14.17	yes
	1900-1890	0.53	-18.96	10.90	yes
	1890-1880	1.24	-8.06	0.26	no
	1880-1870	1.20	-8.32	10.11	yes

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Keya Paha C	1870-1860	0.54	-18.44	4.57	no
	1860-1850	0.72	-13.87	4.70	no
	1850-1840	1.09	-9.17	1.00	no
	1840-1830	0.98	-10.17	0.39	no
	1830-1820	0.95	-10.56	0.27	no
	1820-1810	0.97	-10.29	1.13	no
	1810-1800	0.88	-11.41	0.59	no
	1800-1790	0.92	-10.83	2.35	no
	1790-1780	1.18	-8.47	9.01	no
	1780-1770	0.57	-17.48	10.20	yes
	1770-1760	1.37	-7.29	1.54	no
	1760-1750	1.13	-8.83	1.96	no
	1750-1740	1.45	-6.87	10.95	yes
	1740-1730	0.56	-17.82	11.67	yes
	1730-1720	1.63	-6.15	1.21	no
	1720-1710	1.36	-7.36	5.83	no
	1710-1700	0.76	-13.19	4.11	no
	1700-1690	1.10	-9.08	0.57	no
	1690-1680	1.17	-8.51	2.45	no
	1680-1670	0.91	-10.96	0.37	no
	1670-1660	0.88	-11.33	3.52	no
	1660-1650	1.28	-7.81	0.39	no
	1650-1640	1.35			
	2180-2170	2.51	-3.15	1.02	no
	2170-2160	3.18	-4.16	0.11	no
	2160-2150	2.40	-4.06	0.56	no
	2150-2140	2.46	-3.50	0.65	no
	2140-2130	2.86	-4.15	0.56	no
	2130-2120	2.41	-4.71	0.37	no
	2120-2110	2.12	-5.08	0.58	no
	2110-2100	1.97	-4.50	0.01	no
	2100-2090	2.22	-4.50	0.92	no
	2090-2080	2.22	-5.42	2.09	no
	2080-2070	1.85	-3.33	1.92	no
	2070-2060	3.00	-5.25	1.76	no
	2060-2050	1.91	-7.00	3.38	no
	2050-2040	1.43	-3.63	2.47	no
	2040-2030	2.76	-6.10	0.86	no
	2030-2020	1.64	-5.25	0.85	no
	2020-2010	1.91	-4.39	1.26	no
	2010-2000	2.28	-5.65	1.37	no
	2000-1990	1.77	-7.02	0.38	no
	1990-1980	1.42	-7.40	0.53	no
	1980-1970	1.35	-7.93	0.28	no
	1970-1960	1.26	-7.65	0.49	no
	1960-1950	1.31	-7.16	3.38	no
	1950-1940	1.40	-3.79	4.50	no
	1940-1930	2.64	-8.28	1.90	no
	1930-1920	1.21	-6.38	0.81	no
	1920-1910	1.57	-5.57	0.53	no
	1910-1900	1.79	-6.10	1.34	no
	1900-1890	1.64	-7.44	2.72	no
	1890-1880	1.34	-4.72	2.73	no

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Ponca Creek	1880-1870	2.12	-7.45	0.20	no
	1870-1860	1.34	-7.25	2.81	no
	1860-1850	1.38	-10.06	4.25	no
	1850-1840	0.99	-5.81	1.64	no
	1840-1830	1.72	-7.45	0.12	no
	1830-1810	2.69	-7.33	0.95	no
	1810-1800	1.36	-8.28	1.63	no
	1800-1790	1.21	-6.65	2.58	no
	1790-1780	1.50	-9.23	2.96	no
	1780-1770	1.08	-12.19	4.99	no
	1770-1760	0.82	-7.20	4.64	no
	1760-1750	1.39	-11.84	5.76	yes
	1750-1740	0.84	-6.08	3.24	no
	1740-1730	1.64	-9.33	0.79	no
	1730-1720	1.07	-8.54	7.95	yes
	1710-1700	0.61	-5.34	6.69	yes
	1700-1690	1.87	-12.03	2.47	no
	1690-1680	0.83	-9.56	1.24	no
	1680-1670	1.05	-8.32	0.20	no
	1670-1660	1.20	-8.52	27.04	yes
	1660-1650	1.17	18.52		
Ponca Creek A	2180-2170	1.89	-5.30	0.07	no
	2170-2160	1.86	-5.37	61.68	yes
	2160-2150	0.15	-67.06	58.31	yes
	2150-2140	1.14	-8.75	3.92	no
	2140-2130	0.79	-12.67	0.21	no
	2130-2120	0.80	-12.46	7.77	no
	2120-2110	2.13	-4.69	59.89	yes
	2110-2100	0.15	-64.58	47.66	yes
	2100-2090	0.59	-16.91	8.45	no
	2090-2080	1.18	-8.46	12.93	yes
	2080-2070	0.47	-21.40	14.24	yes
	2070-2060	1.40	-7.16	4.86	no
	2060-2050	0.83	-12.02	9.75	no
	2050-2040	0.46	-21.77	13.48	yes
	2040-2030	1.21	-8.29	9.77	no
	2030-2020	0.55	-18.06	8.92	no
	2020-2010	1.09	-9.14	11.16	yes
	2010-2000	0.49	-20.30	9.81	no
	2000-1990	0.95	-10.50	11.18	yes
	1990-1980	0.46	-21.68	13.22	yes
	1980-1970	1.18	-8.46	15.00	yes
	1970-1960	0.43	-23.46	6.28	no
	1960-1950	0.58	-17.18	1.59	no
	1950-1940	0.64	-15.59	6.97	no
	1940-1930	1.16	-8.63	50.02	yes
	1930-1920	0.17	-58.65	43.24	yes
	1920-1910	0.65	-15.41	1.03	no
	1910-1900	0.70	-14.38	4.30	no
	1900-1890	0.99	-10.08	7.83	no
	1890-1880	0.56	-17.91	3.44	no

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Ponca Creek A	1880-1870	0.69	-14.47	0.33	no
	1870-1860	0.71	-14.13	5.15	no
	1860-1850	1.11	-8.99	36.55	yes
	1850-1840	0.22	-45.54	37.07	yes
	1840-1820	2.36	-8.47	72.37	yes
	1820-1810	0.12	-80.84	31.08	yes
	1810-1800	0.09	-111.92	104.61	yes
	1800-1790	1.37	-7.30	13.32	yes
	1790-1780	0.48	-20.62	22.30	yes
	1780-1770	0.23	-42.92	25.93	yes
	1770-1760	0.59	-16.98	9.86	no
	1760-1750	1.40	-7.13	5.14	no
	1750-1740	0.81	-12.27	2.94	no
	1740-1730	0.66	-15.22	7.99	no
	1730-1720	1.38	-7.23	383.66	yes
	1720-1710	0.03	-390.89	379.60	yes
	1710-1700	0.89	-11.28	6.96	no
	1700-1690	2.31	-4.32	95.67	yes
	1690-1680	0.10	-99.99	34.33	yes
	1680-1670	0.15	-65.67	54.92	yes
	1670-1660	0.93	-10.75	5.98	no
	1660-1650	0.60	-16.73		
Ponca Creek B	2180-2170	0.85	-11.79	4.31	no
	2170-2160	1.34	-7.48	2.71	no
	2160-2150	2.10	-4.77	6.98	no
	2150-2140	0.85	-11.75	57.81	yes
	2140-2130	0.14	-69.56	42.08	yes
	2130-2120	0.36	-27.48	24.12	yes
	2120-2110	2.97	-3.36	16.20	yes
	2110-2100	0.51	-19.56	116.86	yes
	2100-2090	0.07	-136.42	128.65	yes
	2090-2080	1.29	-7.77	1010.43	yes
	2080-2070	0.01	-1018.20	1009.96	yes
	2070-2060	1.21	-8.24	12.36	yes
	2060-2050	0.49	-20.60	3.73	no
	2050-2040	0.59	-16.88	7.06	no
	2040-2030	1.02	-9.82	2.90	no
	2030-2020	0.79	-12.72	3.62	no
	2020-2010	1.10	-9.09	6.86	no
	2010-2000	0.63	-15.96	8.43	no
	2000-1990	1.33	-7.52	68.81	yes
	1990-1980	0.13	-76.34	64.25	yes
	1980-1970	0.83	-12.09	6.50	no
	1970-1960	1.79	-5.59	355.56	yes
	1960-1950	0.03	-361.15	347.71	yes
	1950-1940	0.74	-13.44	3.22	no
	1940-1930	0.60	-16.66	11.14	yes
	1930-1920	0.36	-27.80	10.70	yes
	1920-1910	0.59	-17.09	2.73	no
	1910-1900	0.50	-19.82	9.99	no
	1900-1890	1.02	-9.84	39.12	yes

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Ponca Creek B	1890-1880	0.20	-48.96	38.24	yes
	1880-1870	0.93	-10.72	3.37	no
	1870-1860	1.36	-7.35	3.61	no
	1860-1850	0.91	-10.96	104.58	yes
	1850-1840	0.09	-115.55	91.86	yes
	1840-1830	0.42	-23.69	20.94	yes
	1830-1820	3.64	-2.75	740.50	yes
	1820-1810	0.01	-743.24	426.87	yes
	1810-1800	0.03	-316.38	28.90	yes
	1800-1790	0.03	-287.47	805.24	yes
	1790-1780	0.01	-1092.72	1081.05	yes
	1780-1770	0.86	-11.66	375.72	yes
	1770-1760	0.03	-387.38	380.54	yes
	1760-1750	1.46	-6.84	8.46	no
	1750-1730	1.31	-15.30	12.26	yes
	1730-1720	3.29	-3.04	379.92	yes
	1720-1710	0.03	-382.97	220.15	yes
	1710-1700	0.06	-162.81	104.75	yes
	1700-1690	0.17	-58.06	278.42	yes
	1690-1680	0.03	-336.48	330.37	yes
	1680-1670	1.64	-6.11	133.07	yes
	1670-1660	0.07	-139.18	131.46	yes
	1660-1650	1.30	-7.71		
Ponca Creek C	2180-2170	0.88	-11.31	5.73	no
	2170-2160	1.79	-5.58	31.65	yes
	2160-2150	0.27	-37.23	30.47	yes
	2150-2140	1.48	-6.76	4.51	no
	2140-2130	0.89	-11.26	2.69	no
	2130-2120	1.17	-8.57	2.37	no
	2120-2110	0.91	-10.94	3.31	no
	2110-2100	0.70	-14.25	5.98	no
	2100-2090	1.21	-8.27	2.21	no
	2090-2080	0.95	-10.48	2.04	no
	2080-2070	0.80	-12.52	6.25	no
	2070-2060	1.59	-6.28	3.92	no
	2060-2050	0.98	-10.20	9.50	no
	2050-2040	0.51	-19.70	11.01	yes
	2040-2030	1.15	-8.69	0.40	no
	2030-2020	1.10	-9.09	5.26	no
	2020-2010	0.70	-14.35	4.35	no
	2010-2000	1.00	-9.99	0.76	no
	2000-1990	0.93	-10.76	3.18	no
	1990-1980	0.72	-13.94	1.83	no
	1980-1970	0.83	-12.10	1.03	no
	1970-1960	0.76	-13.14	3.68	no
	1960-1950	0.59	-16.82	1.08	no
	1950-1940	0.64	-15.73	9.36	no
	1940-1930	1.57	-6.37	7.99	no
	1930-1920	0.70	-14.37	5.20	no
	1920-1910	0.51	-19.57	4.72	no
	1910-1900	0.67	-14.85	1.95	no

Profile	Elevation (ft)	Distance (mi)	2-Point Slope	Slope Differential	Knickpoint ?
Ponca Creek C	1900-1890	0.78	-12.90	3.38	no
	1890-1880	1.05	-9.51	12.37	yes
	1880-1870	0.46	-21.88	7.46	no
	1870-1860	0.69	-14.42	1.53	no
	1860-1850	0.63	-15.95	0.71	no
	1850-1840	0.66	-15.25	2.59	no
	1840-1830	0.79	-12.66	1.93	no
	1830-1810	1.86	-10.73	21.23	yes
	1810-1800	0.31	-31.96	23.36	yes
	1800-1790	1.16	-8.59	18.03	yes
	1790-1780	0.38	-26.62	5.57	no
	1780-1770	0.47	-21.06	2.90	no
	1770-1760	0.42	-23.95	16.93	yes
	1760-1750	1.42	-7.03	5.25	no
	1750-1740	0.81	-12.28	2.82	no
	1740-1730	0.66	-15.10	4.83	no
	1730-1720	0.97	-10.27	0.45	no
	1720-1710	1.02	-9.83	383.83	yes
	1710-1700	0.03	-393.66	385.32	yes
	1700-1690	1.20	-8.34	1.53	no
	1690-1680	1.47	-6.82	144.73	yes
	1680-1670	0.07	-151.55	142.68	yes
	1670-1660	1.13	-8.87	6.67	no
	1660-1650	0.64	-15.53		
Cannonball GPS	2318-2302	4.52	-3.48	-13.11	Yes
	2302-2292	0.62	-16.60	15.31	Yes
	2292-2283	6.98	-1.29	-4.36	No
	2283-2243	7.06	-5.65	5.04	No
	2243-2240	6.01	-0.60	-5.03	No
	2240-2217	4.04	-5.63	-1.57	No
	2217-2181	4.99	-7.21	-3.78	No
	2181-2155	2.39	-10.99	-1.27	No
	2155-2103	4.21	-12.26	2.53	No
	2103-2024	8.12	-9.72	-1.80	No
	2024-1921	8.97	-11.52	-5.45	No
	1921-1892	1.69	-16.97	7.05	No
	1892-1797	9.55	-9.92		

Appendix D. Defined knickpoints from the river and land surface profiles, and relationship to lithologic changes and tributaries.

Profile	Knickpoint #	Median Elevation	Lithology Change?	Tributaries Near?
Cannonball River	1	1900	No	No
Cannonball A	1	2240	No	-
	2	2200	Yes	-
	3	2190	Yes	-
	4	2180	No	-
	5	2140	No	-
	6	2120	No	-
	7	2060	No	-
	8	2040	No	-
	9	1900	Yes	-
	10	1880	Yes	-
Cannonball B	1	2400	No	-
	2	2310	No	-
	3	2300	No	-
	4	2290	No	-
	5	2280	No	-
	6	2260	No	-
	7	2240	No	-
	8	1920	No	-
	9	1880	No	-
Cannonball C	1	2280	No	-
	2	2240	No	-
	3	1900	No	-
	4	1880	No	-
Bad River	1	2130	No	No
	2	1840	No	No
	3	1690	No	No
	4	1680	No	No
Bad River A	1	2120	No	-
	2	1980	No	-
	3	1970	No	-
	4	1940	No	-
	5	1930	No	-
	6	1890	No	-
	7	1880	No	-
	8	1860	No	-
	9	1850	No	-
	10	1840	No	-
	11	1820	No	-
	12	1800	No	-
	13	1770	No	-
	14	1760	No	-
	15	1720	No	-
	16	1710	No	-

Profile	Knickpoint #	Elevation	Lithology Change	Tributaries Near
Bad River A	17	1660	Yes	-
	18	1650	Yes	-
	19	1590	No	-
	20	1540	No	-
	21	1530	No	-
	22	1440	No	-
Bad River B	1	2120	No	-
	2	2110	No	-
	3	1980	No	-
	4	1970	No	-
	5	1940	No	-
	6	1930	No	-
	7	1890	No	-
	8	1860	No	-
	9	1770	No	-
	10	1760	No	-
	11	1480	No	-
Bad River C	1	2120	No	-
	2	2060	No	-
	3	2050	No	-
	4	2040	No	-
	5	2030	No	-
	6	2020	No	-
	7	2010	No	-
	8	1980	No	-
	9	1970	No	-
	10	1940	No	-
	11	1930	No	-
	12	1880	No	-
	13	1830	No	-
	14	1820	No	-
	15	1810	No	-
	16	1800	No	-
	17	1790	No	-
	18	1720	No	-
	19	1710	No	-
	20	1600	No	-
	21	1590	No	-
Bad River C.	22	1560	No	-
	23	1530	No	-
	24	1520	No	-
	25	1500	No	-
	26	1440	No	-
White River	1	2100	No	No
	2	1880	No	No
	3	1870	No	No

Profile	Knickpoint #	Elevation	Lithology Change	Tributaries Near
White River A	1	2020	No	-
	2	2010	No	-
	3	1790	No	-
	4	1780	No	-
	5	1770	No	-
	6	1600	No	-
	7	1590	No	-
	8	1330	Yes	-
White River B	1	2010	No	-
	2	1850	No	-
	3	1840	No	-
	4	1540	No	-
	5	1330	Yes	-
White River C	1	1850	No	-
Keya Paha River	1	2360	No	Yes
	2	2350	No	Yes
	3	2310	No	Yes
	4	2290	No	No
	5	2280	No	Yes
	6	2270	No	No
	7	2230	No	No
	8	2220	No	No
	9	2050	No	Yes
	10	2040	No	Yes
Keya Paha A	1	2360	No	-
	2	2270	No	-
	3	2260	No	-
	4	2250	No	-
	5	2240	No	-
	6	2160	No	-
	7	2070	No	-
	8	2060	No	-
	9	2050	No	-
	10	2040	No	-
	11	1960	No	-
	12	1950	No	-
	13	1930	No	-
	14	1920	No	-
	15	1870	No	-
	16	1860	No	-
	17	1790	No	-
	18	1780	No	-
	19	1760	No	-
	20	1750	No	-
	21	1740	No	-
	22	1730	No	-

Profile	Knickpoint #	Elevation	Lithology Change	Tributaries Near
Keya Paha A	23	1720	No	-
	24	1710	No	-
	25	1690	No	-
	26	1680	No	-
	27	1670	No	-
Keya Paha B	1	2270	No	-
	2	2260	No	-
	3	2250	No	-
	4	2230	No	-
	5	2190	No	-
	6	2180	No	-
	7	2130	No	-
	8	2120	No	-
	9	1960	No	-
	10	1870	No	-
	11	1780	No	-
	12	1770	No	-
Keya Paha C	1	2300	No	-
	2	2290	No	-
	3	2090	No	-
	4	2080	No	-
	5	2030	No	-
	6	2020	No	-
	7	1910	No	-
	8	1900	No	-
	9	1870	No	-
	10	1770	No	-
	11	1740	No	-
	12	1730	No	-
Ponca Creek	1	1750	No	No
	2	1720	No	Yes
	3	1710	No	No
	4	1700	No	No
	5	1660	No	Yes
Ponca Creek A	1	2080	No	-
	2	2070	No	-
	3	2040	No	-
	4	2010	No	-
	5	1990	No	-
	6	1980	No	-
	7	1970	No	-
	8	1930	No	-
	9	1920	No	-
	10	1790	No	-
	11	1780	No	-

Profile	Knickpoint #	Elevation	Lithology Change	Tributaries Near
Ponca Creek A	12	1770	No	-
Ponca Creek B	1	2120	No	-
	2	2110	No	-
	3	2060	No	-
	4	1930	No	-
	5	1920	No	-
	6	1890	No	-
	7	1880	No	-
	8	1770	No	-
	9	1760	Yes	-
	10	1730	No	-
Ponca Creek C	1	2160	No	-
	2	2150	No	-
	3	2040	No	-
	4	1880	No	-
	5	1810	No	-
	6	1800	No	-
	7	1790	No	-
	8	1760	No	-
Cannonball GPS	1	2302	No	-
	2	2292	No	-

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