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**QUATERNARY GEOMORPHOLOGY OF THE MEADVILLE  
SLOPE FAILURE; NIOBRARA RIVER VALLEY,  
NEBRASKA.**

**(GEOMORPHOLOGICAL MAPPING)**

**BY**

**MAHTAB A. LODHI**

**A thesis submitted to the  
Department of Geography-Geology  
and the Faculty of the Graduate College  
University of Nebraska**

**In Partial Fulfilment of the  
Requirements for the Degree  
Master of Arts  
University of Nebraska at Omaha**

**August 1990**

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QUATERNARY GEOMORPHOLOGY OF THE MEADVILLE SLOPE FAILURE;  
NIOBRARA RIVER VALLEY, NEBRASKA

ABSTRACT

BY

MAHTAB AHMED LODHI

The study area is located 2 km south of Meadville town on the right bank of the Niobrara River. Lying on the cut-bank side in the meander curve of the Niobrara River, the area is subjected to intensive slope failure of numerous forms, further accelerated by the continuous and very rapid lateral undercutting of the steep cliffs by the Niobrara River, and the unstable geologic formations exposed in the area. The impermeable Pierre Shale of the Cretaceous period and overlying Rosebud and Valentine formations of the Tertiary period are highly susceptible to mass wasting. The instability of the Pierre Shale and the impermeability of the Rosebud formations are the major causes of slope failure and associated geomorphic features in this area. The study is focused on the types of mass wasting caused by the above mentioned lithologic units and the preparation of geomorphic maps showing sites and types of mass wasting and other associated features. The study site, which covers approximately an area of 0.8 by 2.0 km, was mapped on a large scale topographic map. The geomorphological map was compiled and prepared from the data obtained as the result of several field trips, field photography, and the interpretation of aerial photographs in black and white and color infrared.

## ACKNOWLEDGMENTS

My sincere gratitude is extended to all those individuals who produced material and helped in the completion of this project. I wish to thank Mr. Jim Kirkpatrick and many other residents of Brown and Keya Paha counties for their cooperation and assistance received during these three years of field trips. I am most grateful to my thesis supervisor, Dr. Shrodér, whose constant help and supervision from the very first day have been a great source of inspiration. I extend my gratitude to my other advisors, Drs. Langran and Sharpe, for their valuable time and expertise. Many thanks go to Tom Schafer, fellow graduate student, who read the first draft critically and constructively. Finally, I thank Mary, secretary-department of Geography and Geology, for her assistance and help on several occasions.

## CHAPTER ONE

### 1 INTRODUCTION

#### 1.1. STUDY AREA

The study area 2 km south of Meadville town on the right bank of the Niobrara River (42° 45' 10" N latitude 99° 50' 40" W longitude or Meadville Quadrangle, NE sec. 11, 12, 13, 14, T32N, RW21, 22), is an area of approximately 10 km<sup>2</sup>, covering both Brown and parts of Keya Paha counties on either side of the Niobrara River (Fig. 1). Only a portion of this area is the focus of this study. The entire slope failure area is approximately 0.8 by 2.0 km comprising also the area affected by the older movements of undeterminable age, located west of the Plum Creek (Fig. 2). The present study site is the location of the most recent movements and covers an approximate area of 0.8 by 0.5 km. Here the deeply entrenched Niobrara River bisects the study area and forms the boundary between Brown and Keya Paha counties.

According to Lugan (1934, 1935) the Niobrara River drainage system was in existence in early Pleistocene time. The Niobrara River and many of its southern and northern tributaries are deeply entrenched in Pleistocene deposits. The initial entrenchment of the Niobrara River started in the middle Pleistocene. The causes of this entrenchment were multiple: (1) regional uplift, (2) increased development of the Missouri River system during the late Pleistocene, and (3) change in overall rainfall to the west (Skinner and Hibbard 1972). The present drainage is highly complicated by stream piracy. The deeply entrenched Niobrara River and

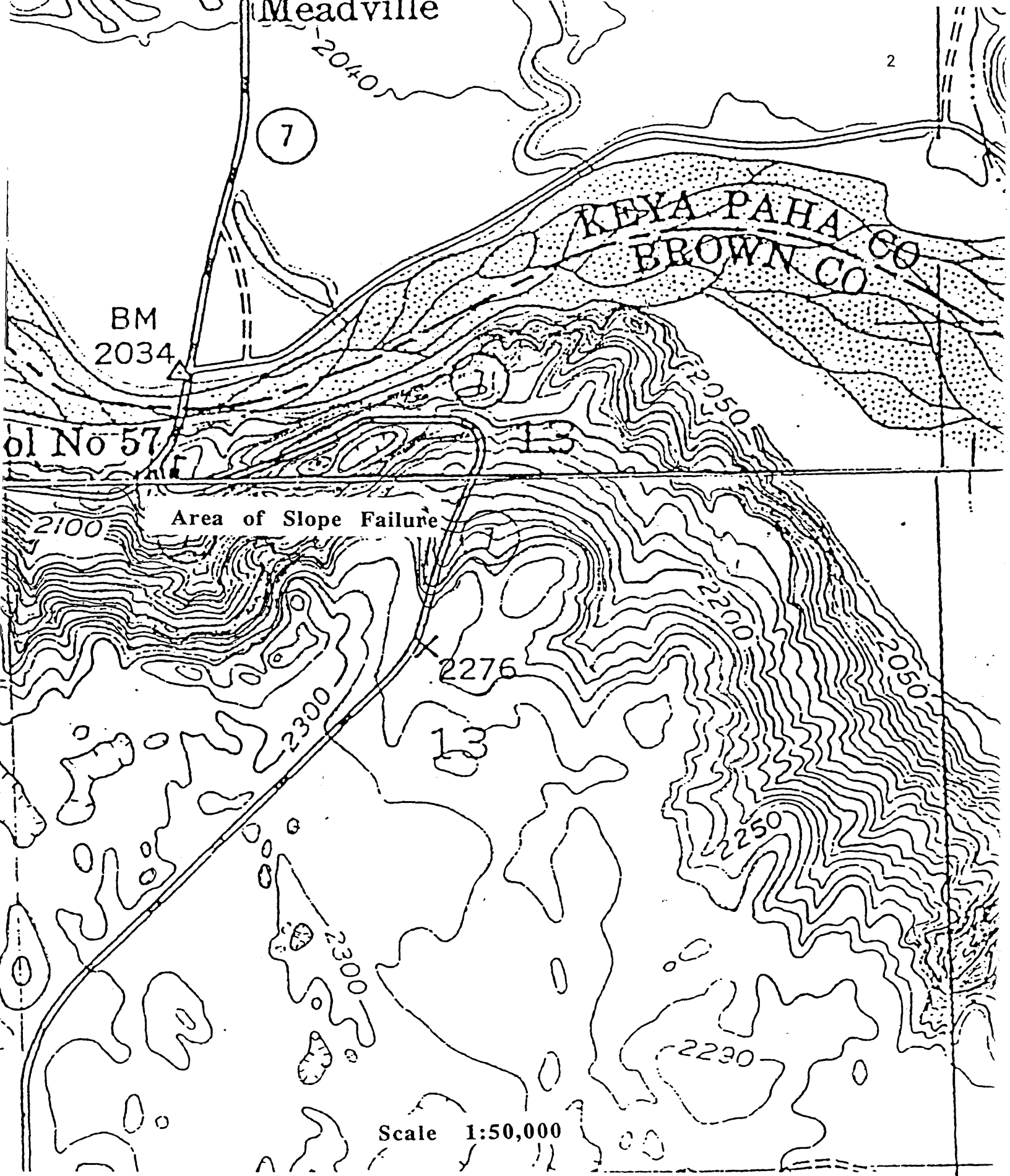


Fig. 1. Map showing the area effected by slope failure, both older and recent movements (Meadville and Dutch Creek Quadrangle, NE. USGS)

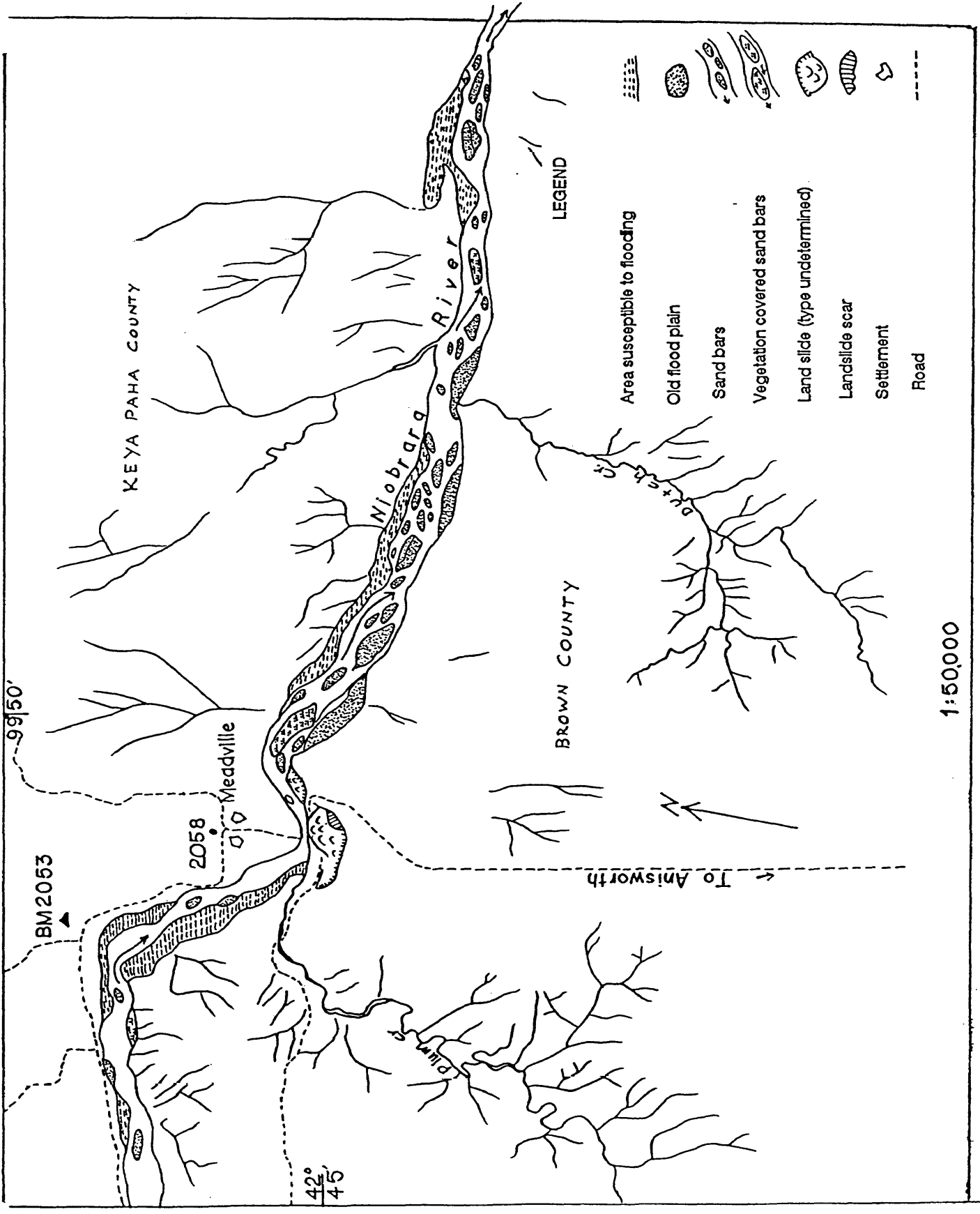


Fig. 2. Location map of the research area showing the regional geomorphology of the Niobrara River.

its head-ward eroding tributaries have captured and diverted the shallow, previously southeast trending drainage northward where they are now deeply entrenched. On the northeast of Meadville town, Springview Table separates the Niobrara River and Keya Paha Rivers. The majority of large landforms are the product of Pleistocene times. It is believed that the area that is now northern Brown and Southern Keya Paha counties, until late Pleistocene times, was a broad flat plain with gently degrading, shallow valleys, showing none of the present day features (Skinner and Hibbard, 1972).

The study area, former site of the proposed Meadville Dam and reservoir, lying on the cut-bank side in the meander curve of the Niobrara River, is subjected to intensive slope failure of numerous forms, as the result of the very unstable lithologies of the geologic formations exposed in the area, further accelerated by continuous and suspected rapid lateral undercutting of the banks and slopes by the river (Fig. 3). The Pierre Shale of the Cretaceous period and the Tertiary Rosebud and Valentine formations of the Ogallala Group are the chief formations exposed in this area. The Pierre Shale as a whole is very easily eroded because of the large proportion of clay and the small proportion of quartz, poor consolidation, and the presence of layers of bentonite. In dry and unweathered form the Pierre Shale is compact and firm. According to Flint (1955), when the Pierre Shale is wet with rain or melting snow the weathered mantle absorbs water quickly and swells. The shale becomes a plastic mass. In consequence the surface shale flows downslope, even on very gentle surfaces. As the flowed material dries, it cracks and spalls into



Fig. 3. Exposed cliff on the right bank of the Niobrara River. Lower gray exposure in middle is unoxidized Pierre Shale; middle reddish tan exposure is oxidized Pierre Shale; uppermost light tan exposure is sand and gravel of Valentine and Rosebud formations. The entire frontal cliff at the river edge here is moving into the river toward the viewer as a landslide glide block. Recent undercutting and erosion of this cliff occurs in lower right.

small flaky particles suitable for removal by slope wash, streams, and wind. The Pierre Shale becomes susceptible to both fluvial and eolian erosion almost as rapidly as it is weathered. On nearly flat surfaces its destruction is retarded by the root network of the grasses. But on many slopes erosion is so rapid that it overcomes the development of soil and thus inhibits the formation of a cover of soil and vegetation. The Pierre Shale is not the only formation susceptible to slope failure in this area. The Rosebud Formation of the Ogallala Group, which consists mostly of siltstones alternated with layers of bentonitic clays, are also zones of incompetent deposits (Skinner and Hibbard, 1972). Hearty (1978) observed that the failure of the Rosebud Formation was partially or entirely responsible for many major and minor slope failures in the Meadville and Norden Dam sites.

## 1.2 PURPOSE OF RESEARCH

The Meadville slope failure is one of the largest in Nebraska and has affected a highway bridge, the roads, power lines, houses, and buried telephone lines. Besides these damages the failure also considerably affected and displaced the natural vegetation (Friskopp, 1990). Many trees have been uprooted and damaged by this failure. The area is unique in natural vegetation, for here we have deciduous and coniferous species together, and the boundary between them is very sharp. The Meadville landslide caused notable displacement of these species which can be observed on color IR photographs of this area (Fig. 4). The Meadville landslide is a continuous activity, and the processes causing instability are always in action. This continuous phenomena of landsliding has been



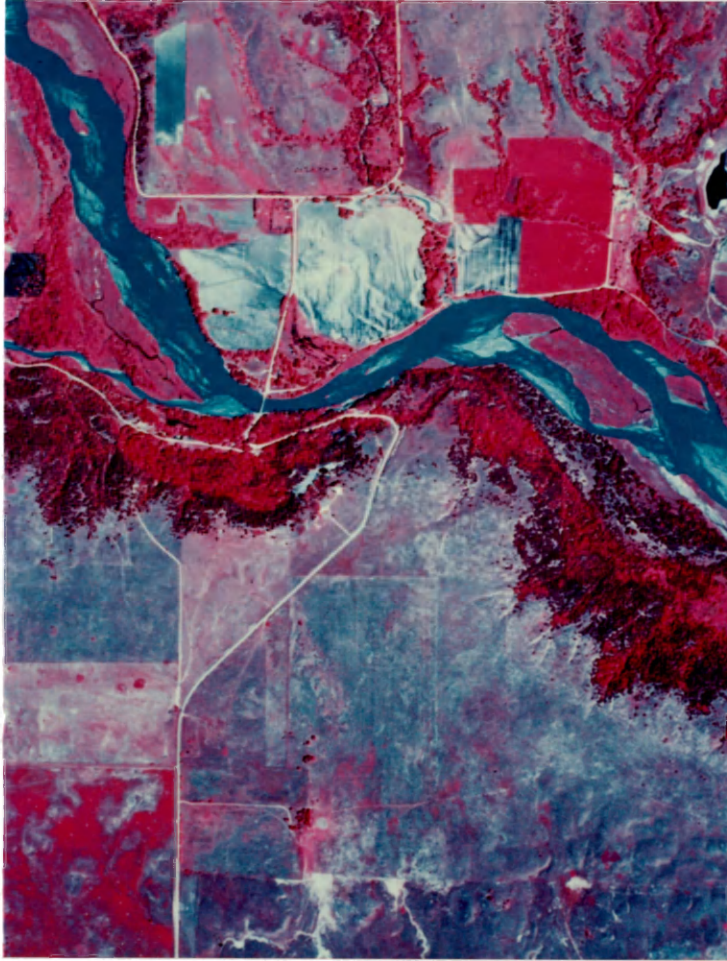


Fig. 4 . Color IR photograph of study area, showing the coniferous and deciduous vegetation. Dark color indicates coniferous trees, while the red color indicates deciduous vegetation. Noon ridge in the landslide appears as a white scar below the orange gray scar of the main scarp. Also note the displacement of vegetation as the result of landslides, so that there are coniferous at the rivers edge directly right (east) of the bridge.

constantly monitored since the initiation of this research work in the fall of 1987. The prime interest of this research was the preparation of detailed geomorphological mapping of the study area. The intention was that this geomorphological map would include information on material and the processes involved in the development of geomorphic features. A large scale (1:1,578) topographic map of the study area, based on plane table surveying and supplemented by aerial photograph interpretations served as a base map for the geomorphological mapping. On the geomorphological map, individual landforms were depicted by particular symbols reflecting their shape and areal extent and also the material and processes involved. For this purpose, keeping in consideration the specific demands of study area, a legend for the preparation of the geomorphological map has been prepared (Appendix A). The output of this work is anticipated to be useful for geomorphologists and engineers, as well as for soil scientists and land managers. In addition to this, the prepared map will serve as a first example of geomorphological mapping effort on such a large scale in Nebraska.

### 1.3 RESEARCH METHODOLOGY

The first trip to the study area for very preliminary field observations was conducted in late fall of 1987. The areas along the Niobrara River upstream from Meadville in western Keya Paha County and Brown County were visited. As a result of this trip, it was concluded that the present study should be concentrated on the area along the right bank of the Niobrara River south of Meadville town. This selection was primarily due to the fact that the Meadville slope failure is one of the

largest landslide areas in Nebraska. The physiographic uniqueness of the Meadville landslide area seemed to necessitate, from the very beginning that multi-disciplinary research such as dendrochronology, distribution of deciduous and coniferous vegetation, and structural and geotechnical research should also be conducted, since the main objective of this research was to prepare a large scale geomorphological map. Therefore, a research methodology suitable for this type of task was adopted. A detailed discussion of techniques involved in the preparation of a geomorphological map is cited in final chapter of this report. After the confirmation of the study area the historical search for old and new air photographs and USGS topo sheets was conducted at the Conservation and Survey Division of the University of Nebraska–Lincoln. The search yielded a list of available black and white aerial photographs for the years 1939, 1954, 1968 and color IR photograph for 1984. These aerial photographs and maps were initially used for preliminary mapping of the Meadville area. The plane table surveying was carried out to prepare a topographic map on a scale of 1:1578. This map served as a base map for a geomorphological map on the same scale. The task of preparing the geomorphological map was mostly performed in the field and partly supplemented by air photograph interpretation in the laboratory using standard air photograph interpretation equipment such as stereo zoom transfer scope. Information from these photos was also incorporated onto the geomorphological map simply by visual observation. A detailed survey of the literature available on the techniques of geomorphological mapping, legends, and the selection of different types of symbols to express landforms on maps was also

conducted. Photographs were taken quite often during every field trip to record the changes through time on the mass movement activities.

## CHAPTER TWO

### RELEVANT LITERATURE REVIEW

The literature review chapter is presented for the general understanding of the reader about the subject matter of geomorphological mapping and slope failure. It is hoped that the chapter will provide sufficient explanation of the geomorphological processes involved in mass movement and also the role and effects of lithology on the stability of slopes. The description of geomorphological maps, their importance and need for different tasks has been fully explained in this chapter. As stated earlier the main objective of conducting this research is the depiction of landslide-affected areas and associated landforms of the study area on an interpretable geomorphological map. Therefore, in this context, an effort has been made to review all available literature not only on local geology and stratigraphy but also on slope failure and geomorphological mapping. However, the previous work on geology and stratigraphy has been cited earlier in the preceding pages. Here in this section of the literature review, the emphasis is on mass wasting or land-sliding and the techniques and history of geomorphological mapping. It should be mentioned here that the techniques of geomorphological mapping for landslide-affected areas have been very successful and been continuously used for such purposes. A large amount of published material is available on landslides, their causes and their triggering mechanisms, but here an attempt has been made to review only selected parts of this literature for the sake of brevity, although almost all available literature on geomorphological mapping

written in the English language has been covered. The literature on landsliding and mass wasting has been reviewed to highlight the following three major aspects of this topic:

- a. Terminology
- b. Classification
- c. Causes

## 2.1. TERMINOLOGY AND CLASSIFICATION OF THE SLOPE FAILURE

The occurrence of slope failure does not take place in isolation; they are a product of their environment. The internal working of the slope which causes slope failure can be linked to past and present environmental factors. In this review, besides landsliding and mass wasting, terms like “slope failure”, “stability”, and “instability” are also used as very broad and general terms, and will be differentiated later from other forms of mass wasting. For the sake of the present research work, the emphasis is on landsliding or slope failure which is a result of the slope instability, a general term which refers to the predisposition of a slope to mass movement (Crozier, 1986). The terms “slope movement” (Varnes, 1978) and “mass movement” (Hutchinson, 1968) are used interchangeably. “Landslide” is the most common and widely used collective term for most slope movements of the mass movement types. It embraces those down slope movements of soil or rock masses as a result of shear failure at the boundaries of the moving mass. According to Crozier (1973) and Varnes (1978), however, the term “landsliding”, on many occasions, has been considered unsuitable, since the displacement may occur by flow rather

than by sliding. Varnes (1978) has advocated the terms “slope movement” or “slope failure” for mass movement restricted to slopes. He did not use the term “mass movement” in his classification because he included subsidence and ground sinkage as well. Sharpe (1938) defines a landslide as the perceptible downward sliding or falling of a relatively dry mass of earth, rock or mixture of both. Much earlier in 1896, Walther Penck described mass movement and mass wasting by using the term mass transport. According to him the term mass movement describes movement under the influence of gravity without any transporting medium, whereas mass transport allows material to be carried in a moving medium such as water, air or ice. Coates (1977) highlighted the broad concept of the word landslide by quoting the following points of agreement among several experts on this subject:

- (1) Landslides represent one category of phenomena included under the general heading of mass movement.
- (2) Gravity is the principal force involved.
- (3) The movement of material must be rapid, because creep is too slow to be included as landsliding.
- (4) Movement of the material is down and out with a free face, and subsidence is not included.
- (5) The displaced material may include parts of the regolith and or bedrock.
- (6) Movement may include falling, sliding and flowing.

Several classifications of mass wasting and mass movement exist in the literature (Ladd, 1935; Sharpe, 1938; Ward, 1945; Rapp, 1960;

Hutchinson, 1968; Savage, 1968; Zaruba and Mencl, 1969; Shroder, 1971; Blong, 1973; Crozier, 1973; Coates, 1977; Varnes, 1978;). All these classification schemes are primarily based on the following chief discriminating factors (Hansen, 1984):

- (1) Type of material moved including coherence and size of material.
- (2) Type of movement.
- (3) Bedrock geology (underlying geology).
- (4) Age of movement
- (5) Velocity of movement (relative).
- (6) Causes of movement and triggering mechanisms of movement.
- (7) Morphology of deposited material.
- (8) Morphology of failure surface.
- (9) Climatic type.
- (10) Geographic location.

However, it has been a general agreement that the best classification should be based on the type of movement, and the type and size of material (Shroder, 1971; Varnes, 1978). Both of these factors are widely used in existing classifications. The type and size of material are interdependent in many classification schemes, mainly based on bedrock, detritus and soil material. In such cases, the subdivision of these groups such as flow (Varnes, 1978) reflects the type of material and its grain size, i.e., wet sand or silt–flow, quick clay–flow, earth–flow, dry sand–flow and loess flow. The coherence of material as a factor is also used by Zaruba and Mencl (1969), and Coates (1977). Coates, in his classification, used liquefaction–



flow, loess–flow and sand–flow. In Sharpe’s (1938) classification, which has been considered the best early classification scheme (Shroder, 1971), materials have lesser importance, and only two types of movement were distinguished: flow and slip. Falls were incorporated as a very rapid subdivision of slip, and the emphasis is on the rate of movement of the mass rather than of the material. Varnes (1978) listed all three types of material for each type of movement.

On the basis of type of movement, it is easy to separate landslides into slides, flows and falls (Coates, 1977), and also into further, more complex divisions such as falls, topples, slides, lateral spreads, flows and complex movements. Hutchinson (1968) used creep and landslides as two categories and then further subdivided into various types of slides, flows, falls and slips. The earlier landslide classifications by Ladd (1935), Sharpe (1938) and Ward (1945) are given in tables 1, 2, and 3; whereas, the later and more accepted classification of Shroder (1971), Coates (1977), and Varnes (1978) are given in tables 4, 5, and 6 for comparison and understanding of the concepts of classification. In as much as Varnes (1978) is the most accepted classification of slope failure in use today, this classification is used throughout the remainder of this paper.

Table. 1: The landslide classification of Ladd (1935) (abbreviated).

- (1) Flows:
  - (a) Mud flows consisting of clay size materials
- (2) Slope readjustment in the following materials:
  - (a) Insitu soil accumulation
  - (b) Talus accumulations
  - (c) Sand accumulations
  - (d) Artificial fills made of earth materials
- (3) Undermined strata with horizontal movement:
  - (a) Collapse with slide characteristics due to squeezing of underlying wet clay and sand beds
  - (b) Collapse with slide characteristics due to breaking down of underlying weak, poorly consolidated strata
- (4) Structural slides. Movement on:
  - (a) Bedding planes
  - (b) Joint planes
  - (c) Fault planes

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Table. 2: Ward (1945) classification of mass movement (abbreviated)

<i>Type of Failure</i>	<i>Type of Movement</i>
Surface erosion, creep	Soil erosion, involving rapid transport of surface material by wind or rain Soil creep
Fragmental slides:	
(1) Dry	Rolling down of surface layers of, scree, sand, and gravel slopes
(2) Partially saturated	Shale scree develop cohesion and become detritus slides
(3) Saturated	Saturated fine loose sands may pack closer and behave as a heavy liquid
(4) Seepage instability	Collapse of overlying strata undermined by washing out of sand
Detritus Slides	Shallow mass slides in predominantly cohesive material.

MOVEMENT		EARTH OR ROCK					
KIND	RATE	CHIEFLY ICE	EARTH OR ROCK PLUS ICE	EARTH OR ROCK DRY OR WITH MINOR AMOUNTS OF ICE OR WATER	EARTH OR ROCK PLUS WATER	CHIEFLY WATER	
WITH FREE SIDE	FLOW	TRANSPORTATION	ROCK GLACIER CREEP	ROCK - CREEP			
			TALUS CREEP	TALUS CREEP			
			SOLIFLUCTION	SOIL CREEP	SOLIFLUCTION		
					EARTHFLOW		
					MUDFLOW SEMIARID, ALPINE, VOLCANIC		
	SLIP (LANDSLIDE)	GLACIAL	TRANSPORTATION	DEBRIS - AVALANCHE	DEBRIS - AVALANCHE	DEBRIS - AVALANCHE	
					SLUMP		
					DEBRIS - SLIDE		
					DEBRIS - FALL		
					ROCKSLIDE		
NO FREE SIDE	SLIP OR FLOW	GLACIAL		ROCKFALL			
				SUBSIDENCE			
						FLUVIAL TRANSPORTATION	

Table. 3. Sharpe's classification of landslide and related phenomena (1938).

Table 4: Classification of mass movement (Shroder, 1971) (abbreviated).

<i>Type of Movement</i>	<i>Type of Material</i>
Falls (very rapid)	Rock-fall, Debris-fall, Earth-fall
Slides (slow to rapid)	Block-slide, Rock-slide, Debris-slide, lateral spreading
Flows	(dry) Rock-fragment (avalanche), Sand-run, Loess-run (wet) Debris-flow, Sand or Silt-flow, Mud-flow
Unknown (slip types)	Rock-slip, Debris-slip, Earth-slip

TYPE OF MOVEMENT			TYPE OF MATERIAL		
			BEDROCK	ENGINEERING SOILS	
				PREDOM. COARSE	PREDOMINANTLY FINE
FALLS			ROCK FALL	DEBRIS FALL	EARTH FALL
TOPPLES			ROCK TOPPLE	DEBRIS TOPPLE	EARTH TOPPLE
SLIDES	ROTATIONAL	FEW UNITS	ROCK SLUMP	DEBRIS SLUMP	EARTH SLUMP
	TRANSLATIONAL		ROCK BLOCK SLIDE	DEBRIS BLOCK SLIDE	EARTH BLOCK SLIDE
			MANY UNITS	ROCK SLIDE	DEBRIS SLIDE
LATERAL SPREADS			ROCK SPREAD	DEBRIS SPREAD	EARTH SPREAD
FLOWS			ROCK FLOW (DEEP CREEP)	DEBRIS FLOW (SOIL CREEP)	EARTH FLOW
COMPLEX			COMBINATION OF TWO OR MORE PRINCIPAL TYPES OF MOVEMENT		

Table. 5. Varne's classification of landslide (1978).

TYPE OF MATERIAL	TYPE OF MOVEMENT (INCREASING SPEED)				
	SLIDE			FLOW	FALL
	ROTATIONAL	PLANAR			
BEDROCK	ROCK SLUMP	ROCK SLIDE	BLOCK SLIDE	ROCK AVALANCHE	ROCK FALL
REGOLITH	EARTH SLUMP	DEBRIS SLIDE	DEBRIS AVALANCHE	DEBRIS FLOW	SOIL FALL
SEDI-MENTS	SEDIMENT SLUMP	SLAB SLIDE	EARTH FLOW	LIQUEFACTION FLOW LOESS FLOW SAND FLOW	SEDIMENT FALL

INCREASING ROCK COHERENCE ↑

INCREASING SEDIMENT SIZE →

Table. 6. Coate's landslide classification (1977).

## 2.2 CAUSES OF SLOPE FAILURE

Compared to cohesive rock, the less cohesive beds and unconsolidated regolith material are always more susceptible to landsliding. The presence of joints, faults, or bedding planes determine the ability of solid bedrock to resist landsliding, while on the other hand shearing and internal deformation cause instability in unconsolidated materials. The unstable conditions may occur anywhere, provided the type of material is favorable. However, surfaces of steeper slopes are more susceptible to such conditions. For example, in the research area, slower types of movements are mostly restricted to comparatively gentler slopes, and instability is mainly due to lithology, whereas the faster and much quicker types of movements are very frequent on the steep slopes and cliff surfaces along the Niobrara River.

In a landslide, the sliding mass of material is clearly distinguished from an underlying stationary bedrock. Generally the displacement occurs along a well-defined sliding or shearing surface, but in the case of flow, the identification of the shearing surface may not be distinct because of the gradual decrease of velocity downward. In the case of homogeneous masses of fine-grained soils in slopes, the sliding surface is roughly cylindrical or spherical in shape, and the sliding mass of material may rotate during failure.

Generally slope instability results from a number of processes. The movements occur under the action of gravity. Hence the prime requirement is a difference of elevation (Ward, 1945). The greater the difference of elevation, the higher the effects of gravity and the more

susceptible the slope will be to instability. When the downslope component of the forces acting on the earth mass exceeds the strength or shearing resistance of the material, the instability occurs. This can be expressed by the following safety factor equation (Cooke and Doornkamp, 1974):

$$F_s = \frac{\text{Strength or shear resistance of material}}{\text{Magnitude of stress}}$$

The slope will be stable if “Fs” is equal to 1.0 or more. Slope failure will occur if it is less than 1.0. Shear strength is the property of matter that resists gravitational stresses. Vegetation cover indirectly serves as a resisting factor by retarding the force of water moving across and through the material. The shear strength of any material is the function of three characteristics of the material: (1) the overall fractional characteristics of the material, (2) the effective normal stress, and (3) cohesion (Ritter, 1978). Generally the slope failure results from a combination of both an increase in shearing forces and a decrease in the resistance to shear. Mass movement is the product of two factors: (i) increased shear stress, and (ii) reduced shear strength (Varnes, 1978). Slope steepness, under-cutting, increasing difference in elevation, and the removal of underlying slope increase the shear stress. The creeping of earth materials can be due to any factor that disturbs the soil, such as growth of plant roots, swaying of trees in the wind, expansion of water by freezing in joints and cracks, the expansion of soil due to wetting, contraction due to drying, and downslope movement which occurs during both expansion and contraction. Burrowing and excavation by animals and the decay of plant roots leave voids. Seepage hollows and hillslope depressions are very likely mass

movement sites (depressions and voids are frequently observed in the study area on the back of steep slopes). Weathering, swelling, fracture development, and the softening of material by increased water content cause the reduction in shear resistance of the material. Unconsolidated wet materials become susceptible to failure. In summary, where relief, slope inclination, type of material and physiographic conditions are favorable, mass movement can dominate the landscape.

### 2.3 DEVELOPMENT OF GEOMORPHOLOGICAL MAPS

Geomorphological maps belong to the group of thematic maps and are graphic representations of the Earth's relief features (Scholz, 1974). The aim of geomorphological mapping is to investigate the morphology, genesis and age of earth surface relief (Gellert, 1969). The relief of the Earth is complex and consists of elevations and depressions. It is an open geosystem composed of a number of subsystems. In order to obtain a complete picture of the relief and knowledge of the geomorphological development of a particular area, an examination of all the forms is necessary. To investigate all the forms occurring in a particular area and to plot them on a topographical base map is the task of geomorphological surveying. In a geomorphological survey, landforms, recorded during the fieldwork, are plotted on a topographic map using special symbols. The description and dimensions, as well as genetical and chronological classification, are also incorporated. Until the late 1940s, the description of a landform or group of landforms and the explanation of their origin and age were done almost exclusively through written reports (Fairbridge, 1968). The idea of constructing a mapping system capable of making



accurate comparisons possible did not come about until World War I. The first such map, published by Passarge in 1914, remained the only example of its type until after World War II when planners, agronomists, engineers and others demanded something more precise and useful than learned discussions in scientific reports.

Another type of geomorphological mapping technique is morphological mapping (Savigear, 1965). If the map content is restricted to slope steepness and the relationship of slope forms in plan, without any interpretations of the landforms as to materials, form and processes, the resulting map will be known as a *Morphological Map* (Brunsden and Prior, 1984). The basis of morphological mapping lies in the recognition of breaks and changes of slope as they occur on the ground. Breaks in slope are represented by continuous lines and changes of slope, by broken lines with a V-shaped symbol, pointing downhill, and lying on the side of the steeper slope. Slope steepness is shown by an arrow pointing downhill, lying normal to the slope and by giving the angle of the slope in degrees. Special symbols are used for very steep slopes. For example, a steep cliff, or free face, is indicated by a solid black symbol along a line marking its crest. Some of the symbols used by Savigear for morphological mapping are reproduced in the legend for the geomorphological map of Meadville. An alternative cartographic technique for the presentation of landscape has been developed in Italy (Brunsden and Prior, 1984). This utilizes a less detailed, but annotated, legend which is subdivided into: (1) geology of superficial deposits, (2) slope landforms and processes, (3) fluvial landforms and processes, and (4) anthropogenic landforms and processes.

The first three are further subdivided into active and non-active, with Quaternary noted for superficial deposits and fluvial landforms.

Geomorphological mapping, as it is known today, began in Poland, where it has been used since the early 1950s, usually in the practical context of economic planning. The idea for a geomorphological map of Poland on a scale of 1:50,000 arose in 1946 and has been carried out within the scientific plan of the Institute of Geography of the Polish Academy of Sciences. The work began in 1950. The geomorphological mapping is being carried out by scientific workers at almost all of the institutes of the Polish Academy of Sciences. A complete and detailed geomorphological survey was conducted for this purpose and was based on the plotting of all the landforms identified during the field investigations, on a topographical map by means of special symbols. The resulting geomorphological map was compiled on a scale of 1: 25,000 in field and 1: 50,000 in press. Geomorphological mapping in Poland was not restricted only to the registration and localization of landforms of defined origin; rather, the maps were to be utilized for solving problems of geomorphology (Klimaszewski, 1962), as well as to recognize the geomorphological development and further tendency of development. The chronological and genetical concepts introduced into the content of the geomorphological map of Poland permit the reader to be oriented in the localization and the mutual relations of forms of different origin and of different ages. The purpose of geomorphological maps is to provide accurate graphic representations of an area's landforms and to indicate the range of influences, both past and present. Such maps covering areas of differing

geological structure under differing climatic conditions make comparisons possible; they show the sequence of events and the rocks which control the development of the relief.

The development of geomorphological mapping in Poland is mainly the result of the efforts of Pecsí (1969). Who prepared a geomorphological map of the Carpathian region on a scale of 1:1,000,000. His other maps (Pecsí, 1971, 1975, 1977, 1978) were published in the Atlas of the Danubian Countries. Pecsí's Geomorphological Map of the Danubian Countries on a scale of 1:2,000,000 (Pecsí, 1978), has been considered an exemplary geomorphological map by Gilewska (1980). She regarded this map as the first of its kind, unifying and integrating various available geological and geomorphological data into an overall geomorphological synthesis of both the Danubian Countries and parts of the surrounding countries. The compilation of this map has been based on a combination of map study and the author's personal intense field examination in almost all of the countries mapped. The map is one of the fifty charts to appear in the Atlas of the Danubian Countries. It covers the territories of Czechoslovakia, Hungary, Romania, Bulgaria, Yugoslavia, Albania, and Austria. The map legend, although very complex, is clear to read. It is supplemented by a commentary in Russian, English, French and German. Information is arranged into three groups. In Division I are three major relief types: (A) The tectonic destructional relief, (B) the accumulative relief prevailing in subsidiary areas, and (C) the accumulative denudational relief. Division II includes the smaller endogenetic and exogenetic single landforms. Division III contains the ages of surface formation and

of landforms, along with the ages of different orogenies. The contents of the map are drawn against the background of the stream network. The map legend is given in German with complete English, French, and Russian translations. Colors and symbols are carefully selected. Colors range from gold ochre, orange, violet and red for the tectonic destructional relief types to yellow, green and blue for the aggradational and accumulative-destructional relief types prevailing in the basins and major valleys. The different tectonic destructional relief types of similar morphogenesis are shown by slight changes of the tone, in the same color. Colors range from dark for the highest relief classes to light for the lowest.

Geomorphological maps may be classified on the basis of scale and the contents of the map. Classification on the basis of scale is however very complex. On the basis of scale the maps fall into large, medium and small scale geomorphological maps which are further subdivided into:

Geomorphological Plans	1:10,000 and Larger
Basic Geomorphological Maps	1:10,000–1:25,000
Detailed Geomorphological Maps	1:25,000–1:100,000
Synoptic Geomorphological Maps	1:100,000–1:1000,000
Geomorphological Maps of Countries	1:1000,000–1:5,000,000
Geomorphological Maps of Continents	1:5000,000–1:30,000,000
Geomorphological Map of the World	1:30,000,000 and Smaller

As stated earlier, the basic purposes of geomorphological mapping is to depict the geomorphological characteristics of an area on a map. For this purpose special mapping symbols are used, the use of the symbols depending upon demands of problems and area. For carrying out

geomorphological mapping the symbols or signatures are usually compiled according to I.T.C system (Verstappen and Zuidam, 1968) and I.G.U legends (Demek, 1972). Due to increasing demands for comparable detailed geomorphological maps for scientific and practical purposes, the need for the unification of geomorphological symbols or one single comprehensive legend capable of being used for the compilation of international detailed geomorphological maps became a necessity. In spite of the considerable efforts towards the unification of geomorphological legends, no one legend is capable of fulfilling the purposes of the complete detailed geomorphological map. The Institute of Geography of the Polish Academy of Sciences and I.G.U commission on Applied Geomorphology arranged a conference in 1962 (Klimaszewski, 1962), on the general subject of unification of geomorphological symbols. Considering the further development of geomorphology, the necessity of comparable geomorphological maps was emphasized and some important principles were recommended for future compilation of geomorphological maps: (1) the detailed geomorphological map should be the result of geomorphological mapping based on field investigations (field data must be plotted on a detailed topographic map which may be supplemented by aerial photographs), (2) the detailed geomorphological map should produced on the scale of 1:10,000–1:1,000,000 (the geomorphological map of Meadville will be on 1:1,500, it was suggested that the field research should be conducted on large scale maps, e.g., 1:25,000, and the completed map should be published on a smaller scale, e.g., 1:50,000), (3) since the aim of the detailed geomorphological map is to represent the relief from

which its character, its history and its further development tendencies can be inferred, the detailed geomorphological map must include morphographic, morphometric, and morphogenetical as well as morphochronological data, (4) the geomorphological content occurring in the investigated area must be plotted on contour lines by means of multicolored signs true to scale, and both the signs and the colors should indicate the morphometric data, the origin and the age of every landform, (5) in case of structural and depositional landforms the structural (lithological) data should be indicated by means of signs somewhat differentiated, and (6) the arrangement of the detailed geomorphological map legend should be in chronological–genetical order.

The table of landforms which have been classified according to age and origin should be permanently completed.

The process of unification of geomorphological map legends was based on Scholz's (1974) catalogue of signs, and the landform list and signs used by Klimaszewski (1963). Besides the unification of symbols the use of colors was also considered, with basic colors indicating the genetic types of landforms. The color scheme for mapping the genesis of landforms was recommended to be of this pattern: *red* –endogenous structure controlled forms; *brown* –forms resulting from destruction by denudation; *green* –forms resulting from deposition by denudation; *violet* –forms resulting from erosion by glaciers etc; *rose* –forms resulting from deposition by glaciers; *yellow* –aeolian forms; *black* –organogenous and, man–made features.

In 1967 a second conference was arranged by the working group at Lomonossow University of Moscow (Gellert, 1969), for the unification of symbols of detailed geomorphological maps of the I.G.U subcommission "Geomorphological Mapping." The basic demand for a detailed geomorphological map, that it should be readable and instructive, was emphasized. It was decided that besides adequate signatures for individual forms, contours should be printed. Six groups of slope gradients were intended;  $0^{\circ}$ – $2^{\circ}$ –level slightly inclined,  $5^{\circ}$ –moderately inclined,  $15^{\circ}$  steeply inclined,  $35^{\circ}$ –steep,  $55^{\circ}$ –very steep  $>55^{\circ}$  cliff. The age of the origin of a form was to be indicated according to the international geologic nomenclature such as Q4 = Holocene, Q3, Q2, Q1 = Upper, Middle, Lower Pleistocene, N2, N1 = Pliocene, Miocene.

As the result of the efforts of I.G.U commission on detailed geomorphological mapping, seven important legends capable of producing detailed geomorphological maps at any scale have been introduced. A brief description of the principles and symbols used in these legends are given below:

- (1) The Russian Legend: The Russian legend for geomorphological mapping at scales from 1:25,000 to 1:50,000 was the most elaborate (Fairbridge, 1968). It included more than 500 items which are divided into two major group; families of forms and single forms. The families of forms are represented by a wide variety of shades. The pattern of the color indicates the age of these forms. For instance, grayish blue printed with dots every 5mm indicates a marine terrace of

Holocene age. The same color printed with a pattern of vertical and oblique lines indicates a marine terrace of upper Pleistocene, and so on. The legends provides 36 such patterns, which makes it possible to indicate the age of forms from the Mesozoic to the Holocene period; single forms such as volcanic cones, glacial striae, and eskers are shown by symbols whose colors indicate the origin. The symbols are overprinted on the colors that indicate the family of forms. Active and fossil forms are differentiated by the appearance of the symbol; a solid line for an active form and broken line for a fossil form. The symbols in grey indicate lithology. The Russian maps utilizing this legend are attractive indeed, but the complexity of the legend has made them difficult to read. Their greatest drawback is the absence of any slope (morphometric) data. The Russian maps concentrate on the genetical–chronologic aspects of the landform and neglect the descriptive aspect of the relief. As a result, these maps could be interesting for specialists in geomorphology but are of less value for practical purposes

- (2) Czechoslovakian Legend: A geomorphological map at scales of 1:25,000 and 1:50,000 was published by the Geographical Institute of the Czechoslovakia Academy of Sciences in 1963. The legend of this map is based on a genetic classification, landforms being grouped under four main headings: structural, erosion–denudation, accumulation, and anthropo-



genic. Colors indicate origin. Age is shown by a pattern overprinted on these colors. Individual forms are shown either by lined patterns or by symbols. Slope values are not given.

- (3) Polish Legend: The Polish geographers were among the first to realize the great potential of geomorphological mapping in the field of applied geography; since 1950, a geomorphological survey of Poland has been one of their major undertakings. Since 1952, regional planners have had very close coordination with the geomorphological section of the Division of Geography at the Polish Academy of Sciences. The Polish maps produced in Cracow at the scale of 1:50,000 are considered the most readable and comprehensive of any existing set of maps. In geomorphological maps at this scale, forms which have been examined in detail, of known origin and age, were plotted against contours by means of colored patches and signatures. Colors were chosen to indicate both the origin, agent and process and also the geological age of particular forms. By these it is easy to recognize destructive or constructive action of agents responsible for the formation of relief in a specific period. Signatures in red indicate different forms which have been created by the destructive action of flowing water and of denudational processes in recent time. Blue signatures represent forms whose origin is due to the constructive action of rivers and of denudational

processes in recent time. Orange colored signatures indicate forms due to the destructive action of rivers and of denudational processes in Pleistocene times. Green signatures show forms due to the constructive action of flowing waters and of the denudational processes in the Pleistocene. The geomorphological map of Poland not only indicates the age and the origin of strictly localized forms but also gives some indication of morphometric conditions. Particular forms are shown true to scale; thus their true dimensions may be calculated. The absolute or relative height may be found from the contours. The depth and height of small forms is indicated by the thickness of lines. Thus the geomorphological map of Poland gave sufficient information concerning the appearance, morphography, dimensions, morphometry, origin, morphogenesis and the age, morphochronology etc of the various features. In short, it contains all the data necessary for depicting the character and the development of the relief. The Polish legend makes it possible to distinguish three periods (Neogene, Pleistocene, and Holocene), three slope values (less than  $4^\circ$ , from  $4^\circ$ – $20^\circ$ , and more than  $20^\circ$ ) shown by shades of color, and at least three orders of magnitude for terrace scarps. Fossil slopes of the Tertiary are indicated in grey, steep ridges, summits and similar features are indicated in black. Erosion–denudation forms of the Pleistocene are shown in orange, and those of construction–sedimentation in green;

for the Holocene, the red indicates erosion, and blue is used for sedimentation. Maps constructed on this legend are clear and easy to read. The principal shortcoming of maps utilizing this legend is the absence of lithological information. The nature of unconsolidated deposits, whether recent or old, is not given.

- (4) French Legend: The French geomorphological mapping system is primarily based on the Tricart legend (Tricart and others.,1965). Tricart presented a legend consisting of 265 symbols and explanatory text with 5 sample maps: two at 1:50,000 and three at 1:25,000. In the French legend, lithology is shown by colors. Solid colors indicated fresh rock, and lined pattern weathered rock. Landforms are denoted by symbols that are overprinted on the lithological colors, grouped according to processes, and are drawn to give the visual impression of the form. The symbols used by Tricart are good, but the maps still lack legibility, particularly in areas that depict unweathered rock. Slope values are not given except for terrace edges. Tricart's legend emphasizes lithology, genesis and age.
- (5) Belgian Legend: Gullentops, of the University of Louvain, suggested a legend (Gullentops, 1964), which made it possible to give quantitative values for all landforms, including hydrographical forms. Slopes are indicated by hachures, the density of which corresponds to the value. The slope classes

are based on a geometric scale. For example, lines 6 mm apart indicate a slope of  $0.5^{\circ}$ – $1^{\circ}$ , lines 4mm apart a slope of  $1^{\circ}$ – $2^{\circ}$ . Breaks in slopes are indicated by a line with arrowheads whose frequency shows the number of degrees missing between the two slope segments. The similar techniques are used for ridges, gullies, banks and other structural forms. Landforms of sedimentary origin are denoted by dots of different size and symbols, such as crosses for clay and very fine dots for silts. Where slopes are associated with these sedimentary landform, the dots or symbols are aligned along the slopes. The color of a sign or of the symbol indicates its origin, e.g., carmine red denotes fluvial erosion and bright green indicates sedimentation. Active and older (fossil) landforms are distinguished by using color shades. The maps prepared on this legend are easy to interpret; however, the maps are difficult to draw and complicated to print.

- (6) Canadian legend: St-Onge (1964) constructed a geomorphological map at a scale of 1:30,000. This Canadian legend is similar to the Belgian legend, but it contains more symbols. Slopes are represented by lines whose thickness indicates slope values. The unconsolidated material is shown on subhorizontal surfaces but not on slopes. The color of the signs and symbols indicates origin of the landforms.
- (7) Hungarian legend: Pecsí (1963) prepared a geomorphological map legend, which was compiled by the geomorphological

Research Institute of the Hungarian Academy of Sciences. The legend contains 346 symbols covering five groups: (1) lithological properties of the rocks covering the surface or building up the assemblages of the surface, according to the processes of formation, (2) processes shaping the surface and subsurface features, (3) genetic surface features, (4) age of the surface and subsurface features, and (5) morphometric and hydrographic elements of the surface. Landforms and other features are shown by different shades of red, brown, green, violet, pink, yellow, blue and black. The legend itself looks attractive and clear, is of good quality and can be interpreted very easily.

- (8) German legend: In recent years the Bundesrepublik Deutschland (FRG) has undertaken detailed mapping at a scale of 1:25,000 of some of West Germany. Slope angles, axes of curved segments, steps and breaks of slope and various types of valley and geomorphic processes are included as black symbols. Water features are blue and various other colors are used to show the substrate and areas of different geomorphological processes. In recognition of the common difficulty of reading complex geomorphical maps Mäusbacher (1985) developed a series of “translation” or simplification keys for specific different landuses in regional planning.

Examples of geomorphological maps which result from the utilization of the above mentioned approaches were given by Gilewska (1967). The same area was mapped to illustrate the French, Hungarian, Soviet and Polish methods.

Applied geomorphological maps can be of great value in hazard assessment, particularly at the reconnaissance and site investigation stages of engineering projects. Geomorphological maps are also extremely useful to planners and economists. A genetical–chronological classification makes it possible to separate active from inactive forms, and also makes it possible to forecast the anthropo–effects for the modification of relief. Morphometric information makes such maps valuable to economic planners. There are many examples of the practical application of geomorphological mapping (Cooke and Doornkamp, 1974). Some major applications of geomorphological mapping are given in Table 7.

Table. 7: Application of Geomorphological mapping in planning and economic development.

I. Land use:

Territorial planning

Regional area planning

Conservation of the natural and cultural landscape

II. Agriculture:

Soil conservation

Reclamation of destroyed or new areas

Soil reclamation

### Drainage and irrigation

- III. Subsurface and surface civil engineering
  - Reconstruction and replanning of settlements
  - Designing of industrial buildings
  - Slope stability determination
  - Communications
  - Hydro-engineering:
    - reservoirs and dams
    - regulation of rivers
    - irrigation canals
- IV. Prospecting and exploitation of mineral resources
  - Geological survey
  - Landslide areas and regions of subsidence due to mining.

The geomorphological map shown in Fig. 5, is an example of a simple geomorphological map produced for planning purposes by Klimaszewski (1961). This includes information about the nature and location of features formed by denudation, fluvial action and eolian processes. The *Center de Geographie Appliquee* of the University of Strasbourg used geomorphological mapping for acquiring data for the design of a land reclamation scheme on the Senegal River (Tricart, 1959, 1961). The center also undertook the task of producing geomorphological maps which have been used as a basis for defining the desirable limits of urban development and for route planning. In Venezuela a geomorphological map was used to define areas of limited value for agriculture, because of the dangers of erosion, thin or stony soils, excessive local relief,

insufficient drainage, or flooding (Tricart, 1966). Geomorphological mapping has been an important tool in landscape evaluation in Europe for the past three decades. Considerable use of geomorphological mapping has been made by the International Institute of Aerial Survey and Earth Sciences (I.T.C), Netherlands, especially in land use planning in the Far East, for conservation purposes in Southern Italy and Northern Spain (Verstappen and Zuidam, 1968). Verstappen (1970) also use geomorphological maps for irrigation and hydrological studies on the Indus Plain.

The planning of towns, settlements and industrial complexes, urban, rural and industrial buildings and communication lines (roads and railways), require a knowledge of both the main relief features (slope) and the distribution of unsuitable forms such as scarps, steep slopes, gorges, canyons, sink holes, active alluvial fans, landslides, etc. (Fairbridge, 1968). An accurate description of relief and morphogenetic processes actively modifying valley walls and river basins is essential in the planning of dams and canals. Knowledge of the relief and form, both favorable and unfavorable to various types of economy, and knowledge of the distribution of the landforms, facilitates the process of better planning.

In the present study, the purpose of the geomorphological mapping is to show landslide-affected areas (both active and potential). Geomorphological maps have been used extensively for this type of work (Shroder, 1972; Cooke and Doornkamp, 1974; Brunnsden and others, 1975; Carrara and Merenda, 1974, 1976). The types of geomorphological maps at much larger scales can include information with respect to landslide type as well as other landforms and processes in the area. Shroder (1972) used arrow



symbols for fall, slide, flow, and creep types of gravity movement. The symbols are oriented in the dominant direction of the movement. These symbols are combined with types of material which constitute the main body of the mass wasting. Cooke and Doornkampe's landslide oriented geomorphological map (Fig. 6) is another good example of the utilization of geomorphological mapping symbols. Brunsden and others., (1975) used landslide-oriented geomorphological maps for depicting the slope stability hazards along a 65 km road in the Himalayan foothills of Eastern Nepal. The map shows the features of the river valleys, drainage and unstable ground with geological and morphological information. Carrara and Merenda (1974, 1976) have published a detailed slope instability and erosion map of the Lattarico (Italy) at a scale of 1:25,000. Landslide and erosion prone areas are exhibited on a geological base map where the depth of color tint is used to define three slope classes. Individual landslide scarps and debris limits are shown. Landslide classification is made according to the type of landslide: superficial or deep; active, dormant, or stabilized; recent or old. Another example of applied geomorphological mapping is from Czechoslovakia where slope deformations have destroyed many roads, wells, electric lines, and several villages (Mahr and Malgot, 1978). The third example of landslide-oriented geomorphological hazards maps comes from French ZERMOS program, which has produced maps at a scale of 1:25,000 for sample areas in many upland regions of France (Hansen, 1980). Each map is accompanied by a brief text which describes the local types of instability, geology, hydrology, climate, seismicity, and human activity including agriculture. The hazard

evaluation is determined by using ancient landslide locations, signs of instability, lithology, structure, morphology and hydrology. Such examples indicate clearly the suitability of geomorphological mapping techniques to represent the landscape cartographically.

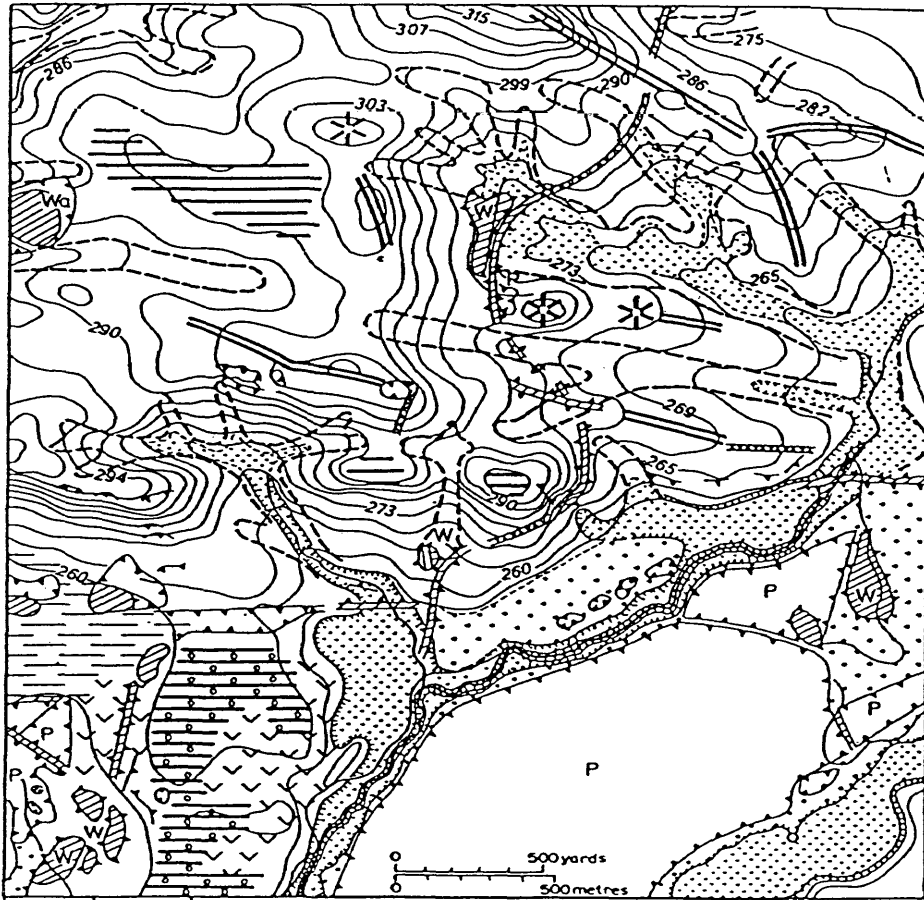


Fig. 5 : Geomorphological map of a part of the Upper Silesian industrial district (Klimaszewski, 1961)

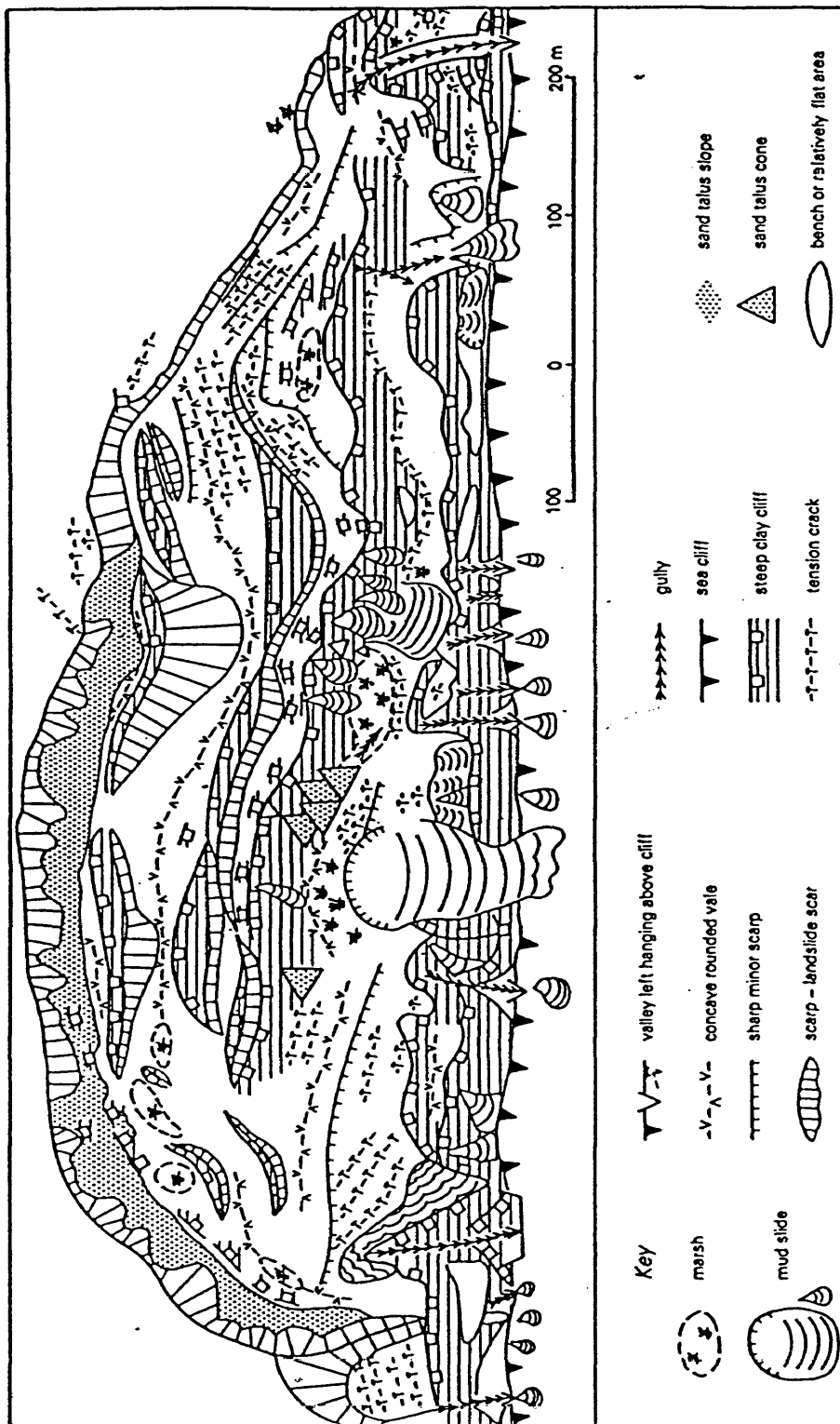


Fig. 6 : Geomorphological map of a Coastal landslide area (Cooke and Doornkamp 1974)

## CHAPTER THREE

### PHYSICAL ENVIRONMENT OF THE STUDY AREA

#### 3.1 REGIONAL GEOLOGY

Throughout much of the study area four formations, Pierre Shale of Cretaceous period and Valentine, Rosebud, and Chadron formations of the Tertiary period are found extensively. The Valentine Formation (Ogallala Group) which is Pliocene in age, underlies the Pliocene sediments. The sediments of the Valentine Formation dip gently along the river on a gradient roughly comparable to the slope of the river bed. Extending eastward from Valentine to some distance below Meadville town, the Valentine Formation lies in unconformable contact with the Rosebud Formation of Arikaree Group. The Chadron Formation of the White River Group outcrops at its type locality south of Springview in Keya Paha County. The formation lies between the Rosebud Formation and Pierre Shale near Meadville and also along U.S Highway 183 in Keya Paha County. The Rosebud Formation overlies the Pierre Shale in certain areas in Brown and Keya Paha counties (Skinner and Gooris, 1968). Near Meadville the river cuts into the Pierre Shale Formation.

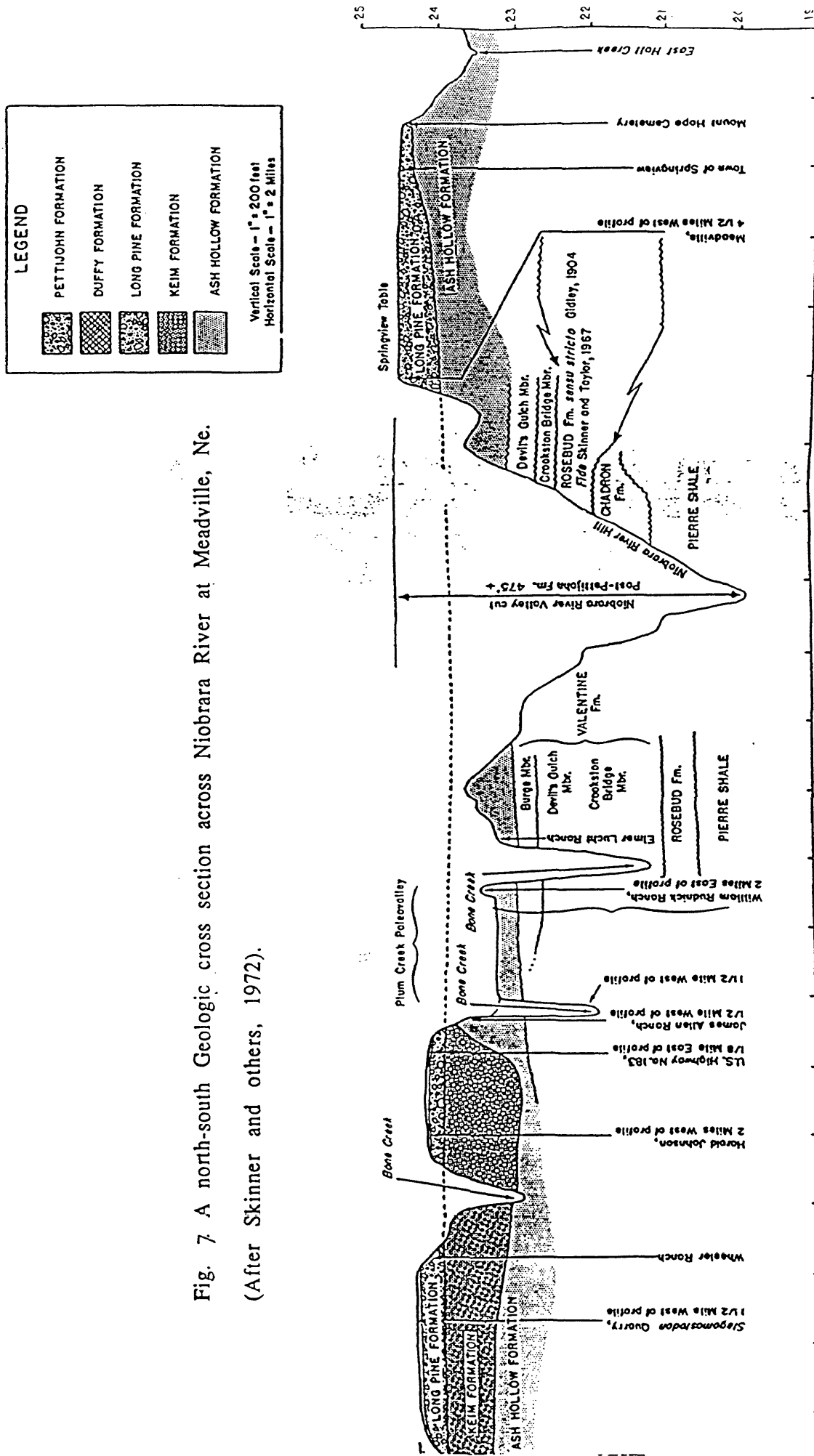
A maximum of 54 meters of Pierre Shale is exposed at the U.S. Highway 183 locality just 4 km downstream along the Niobrara River from the study area. Thin, limy concretionary zones show that the beds dip slightly, but outcrops are not extensive enough to determine the exact degree of dip and strike. This outcrop and others in study area show that the surface formed on the Pierre Shale in Pre-Tertiary time had over 30

meters of local relief, and was usually overlain by the early Miocene Rosebud Formation (Skinner and Gorris., 1968). Lithologically the formation is made up of yellowish, rust colored, dusty gray to black shale with thin layers of cemented, fine sands and some pyrites of iron. The shale is of marine origin and is high in clay content (Fig. 7).

At the Highway 183 locality just north of the Niobrara River, the Pierre Shale Formation is overlain by an outcrop that is lithologically referable to the Chadron Formation; on the Chadron, in direct superposition, is the Rosebud Formation. The Chadron Formation is yellowish buff clay with brown iron oxide stained zones interspersed with purplish red stains that suggest a condition similar to the paleosol at the top of the Pierre Shale. The major part of this outcrop is composed of greenish gray, black manganese-stained, semi-bentonitic clay that peels and cracks on the surface and has the characteristic clear quartz sand grains.

The fine grained, horizontally bedded, pinkish tan to gray silt stones of the Rosebud Formation are easily distinguished from the gray green, rough weathering mineral-stained clay of the Chadron Formation. Two adjacent outcrops along Highway 183, on the hill just north of the Niobrara River, show more than 22 meters exposure of Rosebud Formation. The lower outcrop is composed of fine, tan to pinkish gray, horizontally bedded, sandy siltstone that grades to a browner color, and has more crumbly weathering and a slightly coarser texture toward the top. The uppermost outcrop grades from a browner colored siltstone to a greenish yellow harder siltstone toward the top. In most of the study area the Chadron Formation lies between the Pierre Shale and the Rosebud

Fig. 7. A north-south Geologic cross section across Niobrara River at Meadville, Ne.  
 (After Skinner and others, 1972).



Formation. However, in some places the Rosebud Formation directly lies on the Pierre Shale. In the Highway 183 locality the Rosebud Formation is superposed directly on the Chadron Formation, with an abrupt local relief of approximately 8 meters, indicating that during post Chadronian times a period of erosion may have removed the Brule Formation before Rosebud rocks were deposited. The fine tan siltstones of the Rosebud Formation can be seen lapping against and over an erosional remnant of Chadron rocks. A maximum of 27 meters of Rosebud Formation is present along Highway 183; at Meadville the Rosebud Formation rests on the Pierre Shale about, and is approximately 57 meters thick. The Rosebud Formation is overlain by the Valentine Formation. There exists an erosional unconformity between the Rosebud and the overlying Valentine Formation, which creates an irregular contact and causes the Rosebud to vary from 25 meters to 45 meters in thickness. The Rosebud Formation is impermeable while the Valentine Formation is permeable.

The Valentine Formation, named for the town of Valentine, Nebraska, is widely recognized as the lower unit of the Ogallala Group in north-central Nebraska. The formation is Pliocene in age and lies unconformably on the Rosebud. The contact can be easily observed along the course of the Niobrara River. The Rosebud is a consolidated sequence and forms steep cliffs, whereas the Valentine is light in color and forms gentler slopes. The formation consists of friable, cross-bedded channel sand, semi-consolidated argillaceous sandstone, occasional beds containing silicified casts of fossil roots, massive sand and gravel. The Valentine Formation extends from south-central South Dakota (Skinner and Gooris,



1968) and northeast Nebraska through the type locality area in north-central Nebraska. Its occurrence in northern Nebraska is best observed along the Niobrara River and its tributary streams from Knox through Holt, Brown and Keya Paha counties. Its thickness varies along the Niobrara River from nearly 90 meters near the mouth of Coleman Creek in western Keya Paha County, to 66 meters in the type section near Valentine. The Valentine Formation unconformably overlies Arikaree rocks over much of the outcrop area in Cherry, Brown, and Keya Paha counties. In northeast Nebraska it lies on the Pierre Shale where the Chadron Formation and later sediments were removed by erosion before Valentine deposition. The Valentine Formation is divided into three members, but are difficult to distinguish due to similar lithologic character and color. The distribution of the Valentine Formation of the Ogallala Group was influenced and controlled by tectonic events of the Tertiary period.

The Keim Formation is not extensively exposed and is not a major formation in the main study area, but it is exposed on the southwestern part of the study area. The type section is near the Deep Creek, Brown County. The formation is composed of fine sand, silt, clay and limestone of latest Pliocene or earliest Pleistocene age unconformably overlying the Pliocene Valentine and Ash Hollow formations, and is also unconformably overlain by the Long Pine Formation. The Keim Formation is made up of fine sand, silt, carbonaceous lake clay and silts with many fresh water shells and limestones. Where exposed, the base of the formation rests with erosional

unconformity upon either the Valentine or Ash Hollow formations, depending on the location of the outcrop within the Paleovalley.

### 3.2 CENOZOIC HISTORY

A majority of the geomorphic features and landforms now existing in the study area are the product of Pleistocene time. As mentioned by Hearty (1978), the withdrawal of the Cretaceous sea and the onset of the diastrophic movements of the Laramide Orogeny occurred near the Mesozoic–Cenozoic boundary. The changes continued on through Paleocene and Eocene times, and subsequently several rejuvenating uplifts have occurred during the later Tertiary and in the Pleistocene period. Evidently when the first folds of the new Rocky Mountains were beginning to appear above sea level, the area of Nebraska was probably still below the shallow late Cretaceous sea. At first, folds were raised above the general level of the Cretaceous plain, and sedimentation was confined only to intermontane basins. Paleocene and Eocene deposits are mostly of this type. The Rocky Mountain area continued to rise, and with it the area under study also raised with decreasing rate of elevation towards the east. As the result of this eastward tilting of the plains, the eastward flowing drainages achieved sufficient sediment transporting competency. Sediments were transported not only from the mountain ridges but across and out of the intermontane basins onto the plains near the mountains. Sheet-like alluvial formations of early Tertiary age were thus formed east of the mountain area (Swinehard et al, 1985). With the continued uplift of the Rocky Mountains, the sediments were spread farther and farther eastward by streams and wind. In this way, a great apron of sediments, the wash

from the uplifting Rocky Mountains, was deposited farther and farther to the east, and eventually covered most of the plains. By Oligocene time (White River) the mountains and plains had been raised high enough so that the sands and silts were transported into western Nebraska. Later, Pliocene deposits (Ogallala) were spread extensively in Nebraska (Fig. 8). These later formations greatly overlap the older ones to the east, indicating increased elevation to the west, steeper gradients, and greater competency of the streams, which spread the sediments farther and farther eastward. The streams and rivers responsible for this sedimentation were broad, meandering, and sluggish. The channels of the streams, which accomplished the aggradation, were 10 to 15 meters deep and 30 to 70 meters wide, and were filled with material ranging in texture from coarse gravel to fine silt and clay. As deposition proceeded during each cycle of sedimentation, the main valleys became filled with channel and floodplain deposits, until the interstream areas were covered with fluvial sediments. In the later stages of deposition in each sedimentation cycle, the stream alluviation became widespread and extensive. The divides between streams were no higher than the depths of the channels, and were at the height at which the wind could drift the fine sand and silt into dunes on the plains. The coarser gravels and sands filled the old channels; the silts and clays settled in the quieter backwaters and over the wide floodplains. Upon these were deposited Pleistocene sediments. The Laramide Orogeny, associated by climatic fluctuations, controlled the sedimentation and drainage patterns throughout the Tertiary. The drainage was southeastward in the Mid-Tertiary; in Late-Tertiary, the Laramide Orogeny diverted this flow more

towards the east (Stanley, 1971). Broad, wide valleys with grades of 0.2 to 0.6 meters per kilometer spread Mid-Tertiary sediments over the plains (Lugn, 1935). There were no permanent valleys during this time as the shallow channels would fill and overflow into others as they aggraded the plain (Hearty, 1978). It is believed that the initial incision of the valleys in the High Plains began in the late Pliocene and continued into the Pleistocene with cooler and wetter climates (Brice, 1964). Alden (1924), Lugn (1935), Reed and Dreezen (1965) examined the terraces and concluded that major terrace formation occurred on the principal river systems in the plains during early to mid Pleistocene. According to Hearty (1978), the highest terrace plains adjacent to the Niobrara probably formed during mid Pleistocene and correlation may be established with the glacial events to the east. Simpson's (1960) work also supported the existence of the Niobrara during mid Pleistocene times.

According to Skinner and Hibbard (1972), the area comprising northern Brown and southern Keya Paha counties was a broad flat plain with gently degrading, shallow valleys, deprived of all the present day topographic features, such as the Sandhills or the Niobrara River drainage system and its tributaries, Plum, Long Pine, and Bone creeks. The formation of the Keim paleovalley resulted during late Hemphillian and early Blancan times. Streams in the Keim Valley were running primarily on middle Pliocene rocks, mainly on the Cap Rock Member of the Ash Hollow Formation. The Keim paleovalley had a broad trunk river with an approximate gradient of 0.3 meters to the km. Evidence indicates that the

competency of these streams was insignificant to carry particles greater than fine sand and silt, except during floods.

The beginning of the Nebraskan glaciation period initiated aggradation in the Keim paleovalley, mainly triggered by the plant growth, increasing stream load, decreased rainfall, and valley obstruction to the east. As the gradient of the paleovalley was reduced, meanders formed that could have produced oxbow lakes filled with fine sand, silt and clay. When filled the Keim paleovalley gradient was about 0.2 meters per km versus the original 0.3 meters per km before filling. These gradients are based on the elevations of the contacts as they exist today. As far as regional uplift is concerned, only the entrenchment of the Niobrara River suggests that uplift has taken place. However, the entrenchment of the Niobrara River may also be associated, in part, with the downcutting of the Missouri River system during the later part of the Pleistocene.

The first evidence of continental glaciation in northern Brown and southern Keya Paha counties is the fluvial gravel sheet (Long Pine Formation) that completely covered the deposits in the Keim paleovalley and the bordering Pliocene uplands. An interstadial phase of the first glaciation may be represented by the deposits of fine brown sand, silt, and clay, from 10 meters to 21 meters thick (Duffy Formation), that immediately overlies the gravel sheet. This formation is overlain by another thin gravel sheet i.e., the Pettijohn Formation, which extends eastward in Rock County along the south side of the Elkhorn Valley. Long after the deposition of these early Pleistocene sediments, the Niobrara River drainage system was initiated.





— suggested extent of White River Sedimentation   
- - - suggested extent of Ogallala Sedimentation 

Fig. 8. Extent of Tertiary Sedimentation in Nebraska.

### 3.3 PHYSIOGRAPHY

Rising in the high tablelands just across the state boundary line in Wyoming, the Niobrara River flows in an easterly direction across northern Nebraska and joins the Missouri River in Knox County near the town of Niobrara (Barbour, 1903). In its upper portions it flows in a wide underfit valley but in its middle reaches it flows in a narrow gorge until it is joined by the Keya Paha River, at which point the gorge broadens into a valley 800 to 1,200 meters wide. It is 560 kilometers in length. Throughout most of its length, except near the mouth, the valley is narrow and relatively deep in comparison with the width. Near its mouth its extreme width is 150 meters. Its current is exceedingly rapid, the channel is shallow and sandy, and in the eastern portion the banks are low and wooded. The bluffs of the Niobrara are peculiarly steep, modified by tributary canyons from which issue spring-fed streams. The bluffs are covered with a dense growth of shrubs and small trees, and in some places the valleys themselves are heavily wooded. In the main valley and tributaries, in the region of Valentine, a thick growth of pines and deciduous trees occurs. The chief tributary on the north is the Keya Paha River, which rises in South Dakota and is in all respects similar to the Niobrara River. On the south the Niobrara River has the most remarkable drainage system of any stream in the state (Fig. 9). The extensive Sandhill region stabilized dunes to the south constitutes a vast reservoir whose waters find their way into the Niobrara through numerous spring branches. These small streams have their sources in large springs in the Sandhills and flow through extensively narrow, precipitous canyons. In addition to the

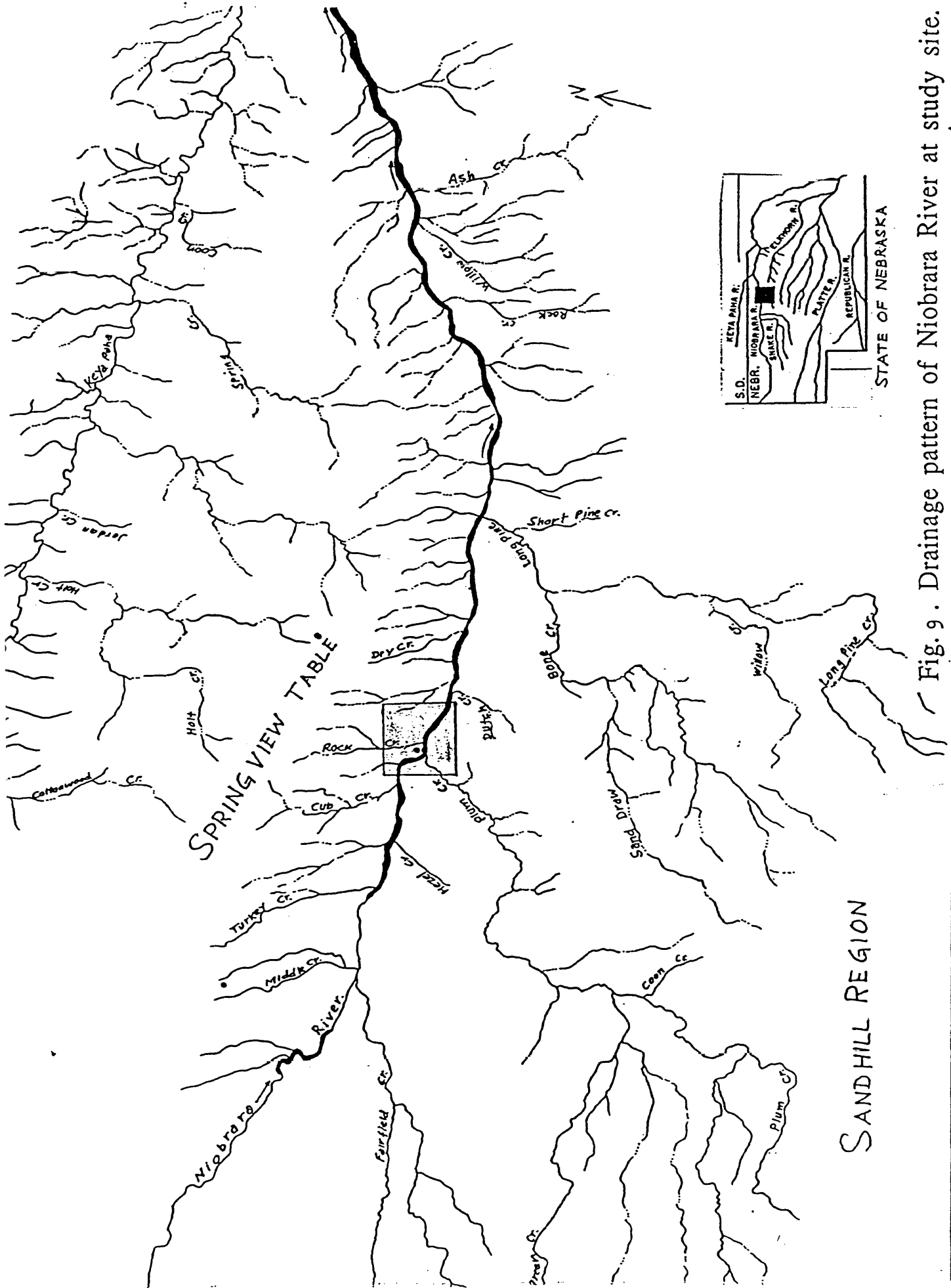


Fig. 9 . Drainage pattern of Niobrara River at study site.

SANDHILL REGION



west the river also receives several large tributaries, which, rising in marshes or ponds in the Sandhills, flow in their upper course through broad, marshy valleys bounded by high sandhills, and in their lower course through precipitous canyons.

The Tablelands south of the Niobrara are further dissected by young headward eroding streams in deep canyons. Plum Creek flows north and then diagonally northeast to the river through the western part of the area; Sand Draw, an intermittent stream, trends northeasterly to join Bone Creek, a tributary of Long Pine Creek. On the eastern side of the area, Long Pine Creek flows almost straight north to the Niobrara River after leaving its partially pirated southeasterly trending headwaters. The Niobrara River and its tributaries have cut through all the early Pleistocene and the Tertiary sediments and sedimentary rocks, therefore, its entrenchment could not have preceded or even paralleled early Pleistocene deposition. The initial entrenchment of the Niobrara River started in the medial Pleistocene. Piracies and diversions of minor headward eroding tributaries in the northern half of Brown County have profoundly changed the former east-trending drainage patterns to the present, extremely complex, north-trending pattern (Fig. 10). The early Pleistocene filling and later entrenchment reflects regional conditions that involved the entire Missouri River Basin to the east, as well as the local elevations. On the north side of the area a remnant of a former plain, locally known as the Springview Table, separates the Niobrara and Keya Paha rivers. On the south the Springview Table is dissected by small headward eroding streams in deep canyons that are cutting back from the Niobrara River. Many of

these valleys are oriented NW–SE and may be in part wind trained, whereby eolian erosion at their heads allows directional headward erosion. Gently graded valleys border the north side of the Springview Table and drain northward into the Keya Paha River. Outwash gravels from the Nebraskan glaciation, overlain by a thin mantle of Holocene soil, cover most of the Springview Table. The greatest elevation in the study area is 858 meters, on the sand dunes near the line between Brown and Cherry counties just north of Plum Creek. Elevational differences of stream drainages range from 590 meters on the Niobrara River at the eastern Brown County line to 818 meters on Plum Creek. This is a drainage drop of 227 meters in about 25 km and explains, in part, the erosion that produced the deep canyons and exposures in the region. Long Pine Creek drops from 721 meters to 584 meters at its junction with the Niobrara River, dropping 136 meters in about 11 km, an average of 0.8 meter per km.

Physiographically the whole Niobrara River basin can be divided into three distinct physiographic regions: (1) the Wyoming--Colorado Nebraska tablelands, (2) the Sandhills, and (3) the Dakota–Nebraska eroded tablelands. The study area can be placed within the Dakota–Nebraska eroded tableland region. The western part of the river basin is characterized by flat tablelands bordered on the north by the Pine Ridge and on the southeast by Sandhills. In the central and eastern portions of the basin, the steep, fast flowing river has formed a narrow valley with precipitous walls rising hundreds of feet to meet the adjoining uplands. Here the valley walls along the river and its major tributaries are covered

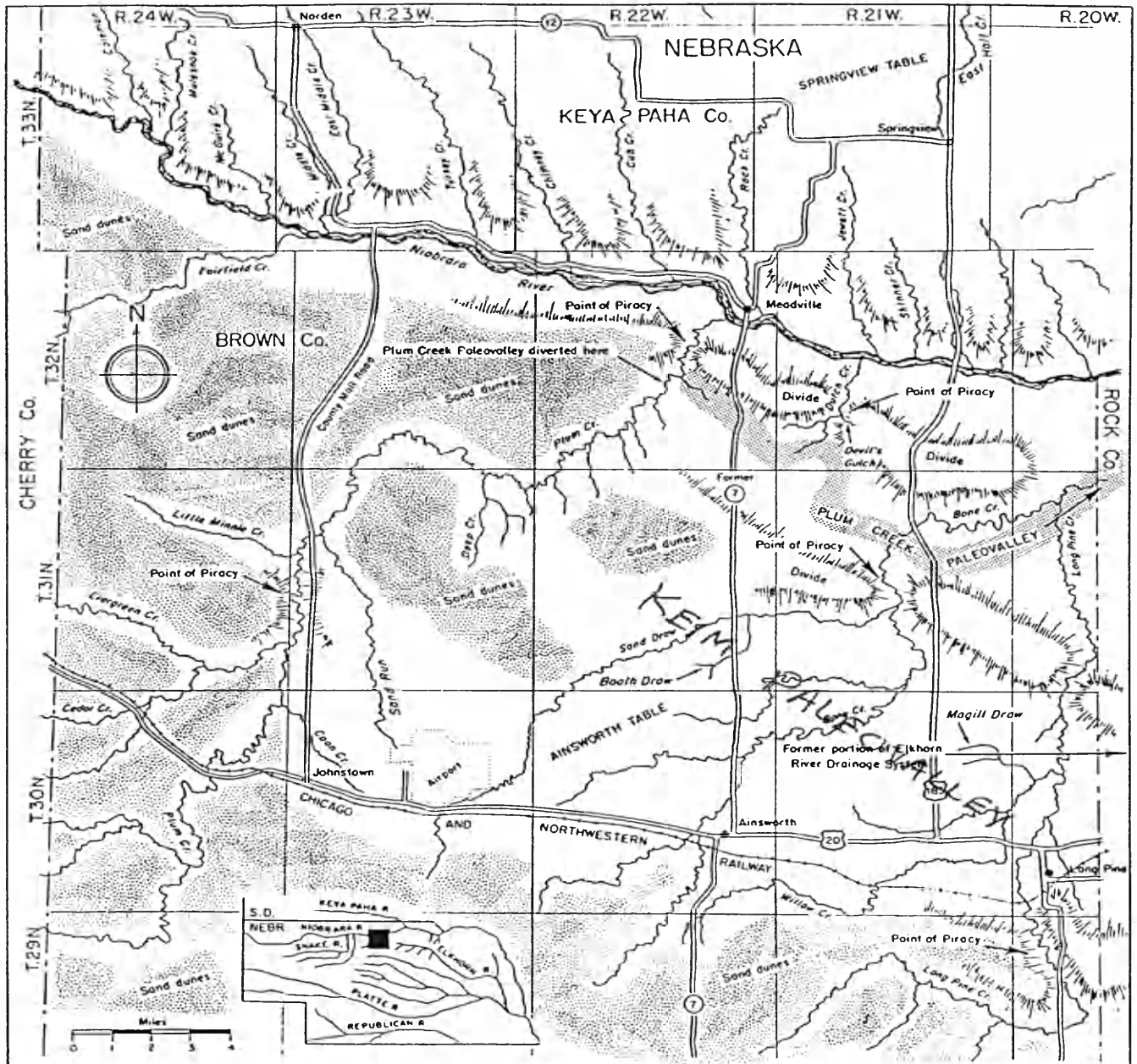


Fig. 10. Location map of the study area, showing stream piracies and diversions (Skinner and others, 1972).

by both eastern deciduous forest and Rocky Mountain forest, because the two ecotones meet and mingle in this area.

### 3.4 NATURAL VEGETATION AND CLIMATE

A general observation of the flora of the Niobrara River Basin as a whole and of the study area particularly revealed the following natural vegetation types: (1) mixed grass prairie, (2) eastern deciduous forest, (3) Sandhills prairie, (4) a mixture of Rocky Mountain and eastern deciduous forests, (5) Rocky Mountain forests, (6) short grass prairie, and (7) Dakota prairie. An area of overlap of the eastern deciduous and the Rocky Mountain Forests occur along the Niobrara River (Harrison,1980). The Rocky Mountain Forests species, particularly ponderosa pine (*Pinus ponderosa*), are found mainly on the fine, sandy loamy soils on both sides of the river. Pines also occur on the rim of the south bank. In the study area, pines overlap and intermingle with eastern deciduous forests which are generally confined to the south side of the river along more protected, spring-fed, north facing slopes and the deep canyons of tributary streams. Crosby, C. S (1988) identified twenty-five species of woody plants in the Niobrara River valley. These species may also be found in present study area. The species includes 11 trees and 14 shrubs. The list of these species is given in table 8.

Table. 8: Species of natural vegetation of Meadville slope failure

<i>Quercus macrocarpa</i>	(Bur oak)
<i>Pinus ponderosa</i>	(Ponderosa pine)
<i>Juniperus virginiana</i>	(Red oak)

<i>Ostrya virginiana</i>	(Ironwood)
<i>Betula papyrifera</i>	(Paperbirch)
<i>Tilia americana</i>	(American linden)
<i>Fraxinus pennsylvanica</i>	(Green ash)
<i>Ulmus americana</i>	(American elm)
<i>Celtis occidentalis</i>	(Hackberry)
<i>Acer negundo</i>	(Box elder)
<i>Juglans nigra</i>	(Black walnut)
<i>Populus deltoids</i>	(Cottonwood)
<i>Ribes odoratum</i>	(Buffalo currant)
<i>Prunus pumila</i>	(Sand cherry)
<i>Amorpha Canescens</i>	(Lead plant)
<i>Rosa arkansana</i>	(Prairie rose)
<i>Prunus americana</i>	(Wild plum)
<i>Amelanchier alnifolia</i>	(Saskatoon service berry)
<i>Rhus aromatica</i>	(Fragrant sumace)
<i>Zanthoxylum americanum</i>	(Prickly ash)
<i>Ribes missouriense</i>	(Missouri gooseberry)
<i>Rhus glabra</i>	(Smooth sumae)
<i>Prunus virginiana</i>	(Choke cherry)
<i>Symphoricarpos occidentalis</i>	(Western snowberry)
<i>Symphoricarpos occidentalis</i>	(Western snowberry)
<i>Viburnum opulus</i>	(Highbush canberry)

The climate of the area is semi-arid. The average annual precipitation in the Niobrara River basin ranges from about 57.5 cm in the eastern

end of the basin to approximately 42.5 cm in the Nebraska–Wyoming region. Most of the precipitation is received as rainfall during the spring and summer months. The majority of the precipitation falls as a result of cyclonic disturbances in May, June, and July (Friskopp, 1990). The annual temperature ranges are variable and extreme. These range from a minimum of 1.7° C (January) to 17.2° C (July) with an annual mean of 9.4° C.

## CHAPTER FOUR

### GEOMORPHOLOGY

#### 4.1 REGIONAL GEOMORPHOLOGY

Mass wasting, including slow and rapid movements as slopes fail, is the most dominant geomorphic features of the study area. Most of the geomorphological features of the study area have resulted, therefore, from mass movement. The types and factors responsible for these movements are described in detail in further sections of this chapter. Here in this section some major geomorphic features found in the study are explained briefly. It should be mentioned here that most of these geomorphic features, however, do not occur in the main part of the study area. But in regional context it was felt necessary to explain them since they constitute the general overall topography of the study area. The following geomorphological features can be recognized in the study area (see regional geomorphological map No.1 and geomorphological map No.2):

1. Low rolling hills, north of the Niobrara River.
2. Deeply dissected and entrenched canyons situated north of the Niobrara River.
3. Fluvial terraces that lie the south side of the Niobrara River.
4. Steep cutbanks and cliffs on the right bank of the Niobrara River.
5. Fluvial landforms as the result of river erosion.

Low rolling hills and depressions occur on the north side of the Niobrara River (Fig. 11). The area across the river comprising these low



Fig.11. Low rolling hills north of Niobrara River. The town of Meadville is visible in fore ground.



rolling hills gently slopes eastward and northward. These rolling hills also constitute tablelands capped by glacial material deposited as the result of Nebraskan glaciation.

The deeply dissected canyons are associated with the rolling hills, but such deep canyons are also found to the south of the Niobrara River. The region comprising these canyons has been greatly dissected by streams that are rapidly cutting into the Tertiary White River and Ogallala formations. The streams that drain these canyons are intermittent for most of the year; however, these streams get enough water as the result of summer storms and consequently alter their character significantly. These streams are also subject to headward erosion, because of the absence of vegetation on their scarps and the very steep inclination. The erosional processes are further accelerated by mass wasting in the form of rock falls and slides. The southerly exposed headwalls experience thermal expansion and freeze–thaw which accelerate the processes of mass movement as well as increase the effect of gullyng by producing regolith material.

The area on the south of the Niobrara River which is now covered by Pleistocene eolian deposits is underlain by terraces of the Niobrara River, probably of the Pliocene times. These terraces covered an extensive area. The deposits covering these terraces are in the form of stabilized sand dunes. The stabilization is the result of general climatic change and a rising water table. However, wind deflation is not uncommon in areas where the dunes have not sufficient vegetation cover.

Steep and bare cliffs exposing Pierre Shale and Rosebud formations are another dominant geomorphic feature in the study area. These cliffs

occur mostly on the right bank of the Niobrara River and are subject to considerable rapid type of mass movements and are also the sites of major slope failures. The steepness of these cliffs is the result of mass movements as well as river undercutting.

The Niobrara River in the study area is a graded river with a very smooth flowing river channel. The river channel is braided in part and sand bars of considerable size occur. The river also forms a floodplain of considerable size. The river channel and its associated floodplain are therefore an important geomorphic feature in study area. The river bed in the study area is basically Pierre Shale but above this is a thick layer of Pleistocene loose sandy material transported by the river. The Niobrara River here has a high concentration of suspended material, while sand and gravel particles also roll along the bed of the river. The fluvial deposition is mostly on the left bank, whereas the right bank is the subject of erosion. This is one reason that slope failures are not uncommon on the right bank of the Niobrara river throughout its course. The width of the river channel in study area is approximately 150 meters.

#### 4.2 MASS WASTING

The Valentine Formation and the Pierre Shale of the Cretaceous period are the two most important lithological units involved in almost all kinds of landsliding and mass wasting activities along the Niobrara River. The major underlying factor is their extremely unstable and cohesionless nature. The Valentine, which unconformably lies on the Rosebud and forms gentler slopes, consists of cross-bedded channel sand and gravel. Under normal conditions the formation is fairly stable, and slopes are

stable up to a certain degree. Slope failure occurs when this material is highly saturated with water. The movement is usually in the form of flow, slumps and sand runs. The underlying formation (which is Rosebud) of the White River group is also not of appreciable strength. Both of these formations have shown many instances of failure in this area. The other most dominant and conspicuous formation is the Pierre Shale. The Pierre shows instability and failure when it is wet. The weathered mantle of shale absorbs water readily and swells considerably and the shale becomes a plastic mass, and consequently the surface shale flows downslope, even on a very gentle gradient. It is highly susceptible to deformation and movement. In South Dakota at the type locality it has been observed that nearly 75% of all Pierre Shale outcrop areas had been displaced by sliding, flowing and deformation (Crandell, 1958). This outcrop mobility and vulnerability to slope instability made the proposed Meadville dam site unfavorable, where a huge outcrop of Pierre Shale occurs along the right bank of the Niobrara River in the form of steep cliffs. The mobility of Pierre Shale is not only limited to slopes; it also suffers deformation from overburden pressure where it lies below the surface. This subterranean deformation of the Pierre Shale in several localities proved its inability to provide frictional resistance to movement, and its very poor response to stresses.

Landslides are always the result of two causes. To the first cause belong the category of slides that are the result of pure mechanical factors, for example, an increase of hydrostatic pressure, erosion, or freezing, with no change in the chemical properties of the soil. The second type of causes

result in the category of slides that are caused by a change in the physical or chemical properties of the soil. As the result of this, severe landslides can occur, because the soil loses its original strength in part or as a whole. The slope failure of the Pierre Shale is the result of the second cause. The Pierre Shale starts flowing down the slope when it loses its original strength and physical properties. The high content of clay minerals also makes the Pierre Shale susceptible to mobility, because the minerals cause a gradual or sudden decrease of shear strength in a soil (Hilbert, 1979). In Pierre Shale, montmorillonite, illite and bentonite are the main clay mineral constituents. These three clay mineral constituents have the largest plastic and liquid limits of all clays. The clay minerals are responsible for the effects and the mechanism of water absorption and desorption, ion exchange, swelling, and plasticity. Clay minerals that increase their volume by swelling due to water absorption, and simultaneously decrease in shear strength, are mainly responsible for landslides; particularly the montmorillonites and illites. After sedimentation these minerals may be dehydrated, compacted, and consolidated by heavy pressure from superimposed soil or rock layers. When the load is removed, water can be taken up again. This water gets bonded to the colloid particles, in part physically and in part chemically. Water penetrates between the platlet particles, causing a large increase of volume and a large reduction of the bonding force between particles. Dry montmorillonite already absorbs so much water from water saturated air that its volume increases by 30% and it becomes plastic; in the process, one gram of montmorillonite absorbs about one gram of water. When in contact with water, the water content

increases up to 5 gram of water for every grams of montmorillite, the volume increases up to 20 times, and shear strength becomes almost zero; the result is a substance that flows almost like water.

In the study area the outcrops of Pierre Shale and the loose sandy Valentine Formation are largely responsible for slope failure and other types of mass wasting. High and steep shale cliffs subjected to very rapid types of landsliding and slope failure can be observed all along the right bank of the Niobrara River at the Meadville site (Fig. 12). Along the river the failure of steep shale slopes and cliffs is confined to the reaches of the river, where steep slopes are up to  $55^\circ$ . Therefore the landsliding activity appears to be occurring in conjunction with the lateral and vertical cutting of the river.

To go further into the details of the landslide triggering mechanisms is behind the scope of this study. The main purpose for which the methodology herein was adopted was the identification of different types of landslides, their classification being based primarily on morphology and origin, and their presentation on a geomorphological map with the aid of different types of symbols. However, the processes responsible for failure as well as the role of lithology have not been left without explanation. Therefore, data were collected from all major landslide areas, both active and potential. Tape and Abney level measurement were performed to determine the degree of slope and the breaks of slope. Sections and profiles were drawn using the tape and level measurement data. Photographs were taken during different times and seasons of the year, especially after the rainy season, to see the role and effects of water on the slope. Significant



Fig.12. The steep shale cliffs along the Niobrara River. A site of severe slope failure. Fresh shale is dark grey in color, while the weathered shale is light brown. (Photo taken in 1989).



Fig. 13. Photographs taken in 1988. Note the large approximately 5 x 10 meter shale block separated from cliff presumable as the result of recent rainfalls and under cutting by the river. The range pole shows scale in feet's.

results have been obtained by such time lapse photography (compare figures 12 and 13). Aerial photographs were also consulted, and proved very useful for mapping purposes.

In this study an effort has been made to discuss only those slides present on the right bank of the Niobrara river near the town of Meadville. Otherwise, on a regional basis, some slides and slope failures can be observed along the Niobrara River down stream from Meadville and also on west of Plum Creek. The slope failure on the other two formations can be seen in the form of the big white scar of the main Scarp in sharp contrast to the surrounding thick cover of coniferous and deciduous vegetation cover (Fig. 14). Here we have the most severe displacement and damage of vegetation.

Besides unstable geological formation exposed in the study area, river under cutting and saturation of the soil also greatly accelerate the rate of slope failure and reduce soil stability. Because of the impermeable nature of the Rosebud Formation the overlying Valentine Formation gets saturated. Groundwater flows easily through the Valentine Formation and cause stability on slopes. All these processes produce different types of slides slow to rapid such as block slide, debris slide. Slides and falls are common on the steep shale cliffs along the river bank and overlying Rosebud and Valentine formations. The slides on steep and vegetation covered slopes sometimes include woody vegetation. The vegetation roots often bind the mass together during the slide. Trees become often tilted or dislodged from the soil material. Other forms of mass wasting mostly derived from Valentine and Rosebud formation are Sandruns which usually



flow in dry state but may also flow wet. A big landslide scar above the “Lost Lake” is a major site of sandruns (Fig. 15). Earth creep, earth flow and other slow types of mass movements are also recognized. Arched and toppled trees commonly occur and serve as an indication of this and other types of movements (Fig. 16).



Fig. 14. Main Scarp of Meadville slope failure. The slope is located on the south bank of the Niobrara River. Underlying formations are Pierre Shale, Rosebud and Valentine.



Fig. 15. A landslide scar above the "Hidden Lake." a site of major sandrun activities (photograph 1989).



Fig. 16. Tilted and dislodged trees as the result of earth creep and sliding (Photograph 1989).

## CHAPTER FIVE

### GEOMORPHOLOGICAL MAPPING

#### 5.1 TECHNIQUES AND METHODOLOGY

As has already been mentioned earlier, the main objective of this research was to prepare a large scale geomorphological map. Before taking any steps in this direction, it was necessary to develop a quality large scale topographic map. Therefore, field excursions and laboratory research were conducted to produce a topographic map on a scale of 1:1578, with a contour interval of 3 meters. In the field most work was completed using standard surveying techniques. A plane table survey, using a transit telescopic alidad surveying instrument, was conducted during the summer of 1988. A number of triangulated control points covering the entire study area were established shot in. Their angular distance and height were also measured. After shooting and acquiring these control points, several cross sections or profiles were taken using the hand-held Abney level instrument. These profiles were later fixed between control points to adjust the contours. The techniques implied for the preparation of the topographic map can be summed up in the following steps:

- (1) The USGS 7.5 minute existing maps were blown up.
- (2) The blown up maps were used with color IR slides and a 35mm slide projector to prepare a general map showing prominent landforms and cultural attributes.
- (3) The plane table map of site was created.

- (4) Tape and Abney level surveying of north–south slope profiles was conducted.
- (5) A historical search for old air photographs in the archives of the Nebraska Conservation and Survey Division was carried out.

The surveying techniques were utilized only to map the study area on the south side of the Niobrara River, which is a main area of study. The river channel and the associated features of the floodplain were later transcribed on the surveyed map, from color IR and black and white transparencies. The completion and acquisition of the topographic map, which was to serve as a base map for the geomorphological map and also to study the general topography of the Meadville area, ended the first phase of this study. The second phase, which included the preparation of the geomorphological map, was mostly fieldwork; however, it was greatly supplemented by laboratory work. The geomorphological and morphological features were observed, identified and measured to determine the areal extent and then transformed and delineated on the base map. Dozens of slope profiles were measured using tape and Abney level to determine the types and shape of the slope as well as the steepness of the slopes. The different landforms are shown on map by symbols. The visual and instrument field work data was also supplemented by field photography. The field photography was very useful for keeping track of the geomorphological events occurred in different times of the year, and also for the identification of the sites of some particular landforms at the time of plotting them on the geomorphological map. A legend of geomor-

phological mapping symbols was prepared for this purpose (appendix A). The task of fieldwork for the preparation of the geomorphological map was completed during the summer of 1989.

A good quantity of black and white, color infrared (IR), transparencies and prints, covering the time periods of 1939, 1954, 1968, and 1984 were available. These photographs and transparencies were extensively used to prepare small scale geomorphological and physiographic maps and also to interpret the geomorphic history of the area. Standard photogrammetric techniques were used for this purpose. The information from these air photos were transformed on a map using the stereo zoom transfer scope, and also by overlaying the transparencies of different time periods to determine and detect the changes as the result of time exposure. The air photographs on a scale of 1:24,000 and color IR on a scale of 1:50,000 proved to be very useful in the preparation of the small scale map of the study area, and also for the interpretation of geomorphic history of the study area. However, they are not of much use for large scale geomorphic mapping. Their usefulness was limited by the obscurity of landforms under dense and thick vegetation cover. The previous work on geomorphological mapping was consulted and a comprehensive legend based on several geomorphological maps was prepared. In most of the cases when no symbology from the previous work was available, new symbology was adopted, keeping in consideration the scale and nature of the present map. It should be mentioned here that almost all previous work on geomorphological mapping has been on a very small scale. Therefore, the symbols and legends adopted for small scale

maps could not be exploited significantly for the present mapping effort. This difficulty was faced because of the following reasons:

- (1) The symbols designed for small scale maps on which only the major categories of landforms are illustrated can not be used for large scale maps. For example on small scale maps only one symbol of one centimeter in size can be used to show a landslide scar covering an area of considerable size. Therefore, if one had to prepare a small scale map of the Meadville landslide, then only two symbols should be enough to show the sites of the two major landslides; one that is below the Noon Ridge and the other landsliding on the Pierre Shale cliffs along the river, because on small scale air photographs Noon Ridge slide is merely a scar (Fig. 17); but if we blow this scale up to study these feature on the micro level then we have numerous microfeatures e.g., slumps, breaks in slope, tension cracks etc. (Fig. 18)
- (2) The maps prepared so are mostly color maps. On such color maps, when it is not possible to exhibit some particular landform by symbol, then different colors and shades have been used. Also on such maps it is always easy to show the morphology as well as the genesis of that particular landform by using color and symbol combination. So keeping these factors in mind, a suitable legend was prepared which could fulfill the purpose of large scale mapping.



Fig. 17. A 1968 air photograph showing the location of study area. Note the narrow meander curve of the Niobrara River which is the site of severe lateral undercutting of steep shale cliffs.





Fig. 18. Landslide scar above lake. Note numerous microfeatures e.g., slumps, tension cracks and breaks in slope at the top of the scar (photograph 1989).

## 5.2 EXPLANATION OF MAP LEGEND

The legend for the geomorphological map of the Meadville slope area is derived partially from several different geomorphological maps prepared both on medium and small scale. Where symbols suitable for large scale type maps were not available, new symbols were adopted. All landforms and geomorphic features found in the study area were classified into seven classes or categories, also including cultural features such as settlements and roads. The classification of these landforms is primarily based on both genesis as well as morphology. An effort has been made to adopt the symbols that best express the actual morphology as well to give an idea of its origin and the material involved. The following is the list of classes and the landforms of each class exhibited on the geomorphological map of Meadville landslide:

- (1) Morphology– This class is comprised of those landforms and morphological features which gave an area its general outlook, but not designating the genesis or origin:
  - a. Angular convex break of slope
  - b. Angular concave break of slope
  - c. Smoothly concave change of slope
  - d. Angle of slope (degree of slope is shown on top of the slope)
  - e. Change of slope
  - f. Convex slope unit
  - g. Concave slope unit
  - h. Cliffs

- i. Steep shale cliffs (combination of two symbols is used)
  - j. Ridges
  - k. Scarp
  - l. Graben
  - m. Benchland (or relatively flat surface also called tableland)
- (2) Fluvial landforms– Includes landforms originated as the result of the river action or flowing water:
- a. River channel (the main channel of the river)
  - b. Stream (stream with water flowing throughout the year, but does not have a channel like a river with sandbars, etc)
  - c. Seasonal stream
  - d. Spring or wet areas
  - e. Swamp
  - f. Permanent and temporary water bodies or lakes
  - g. Floodplains of the river
  - h. Areas susceptible to flooding
  - i. Erosion caused by running water on slopes
  - k. Major river incision
  - l. Gullies
  - m. Sand bars found inside the river channel
  - n. Sand bars covered by vegetation

- (3) Lithology– Lithology, which includes both consolidated and unconsolidated material, is shown by symbols generally used for this purpose. Where it was not possible to use any kind of symbol color is used to express the material found in that locality. The lithology is mostly shown on the physiographic map of Meadville and adjoining areas. The nature of the geomorphological map, however, did not allow the use of lithological symbols except on exposed shale cliffs along the river.
- (4) Eolian landforms– Eolian landforms or those formed as the result of wind action, in the main part of the study area. However, these symbols were used to show some eolian features on the medium scale physiographic map which covers the surrounding area. On the basis of information derived from air photos, the following types of eolian landforms were recognized and shown on the physiographic map by different symbols:
- a. Wind blown sandplain
  - b. Sand dunes
  - c. Sand dunes covered by vegetation (stabilized sand dunes)
  - d. Deflation area
  - e. Deflation hollow
- (5) Slope stability/instability– This class include all those landforms and other geomorphic features which are associated

with slope stability and instability. Slope instability or failure has produced the following different types of landslide features:

- a. Unstable slope (slope which has been determined unstable and has active mass wasting activities on it)
- b. Potentially unstable slope (the slope which was determined potentially unstable due to its degree of steepness, surficial or superficial material and also the vegetation cover)
- c. Talus slope (mostly composed of loose unconsolidated material derived from upper slope failure)
- d. Slumps (slumps due to mass wasting are found almost everywhere and are mostly longitudinal to the slope)
- e. Small or isolated slumps
- f. Earth creep
- g. Earth flow
- h. Sand run
- i. Fall
- k. Slide block
- l. Glide block
- m. Landslide scar
- n. Mudslide

- o. Tension cracks
  - p. Earth flow in gullies
  - q. Steps in unconsolidated deposits (mainly where mass wasting is in progress on very gentle slopes)
- (6) Depositional landforms– This category of landforms is comprised of landforms produced as the result of depositional processes, mostly colluvial or fluvial:
- a. Talus slope (fall both in depositional as well as slope instability features)
  - b. Weathered shale deposits
  - c. Colluvial deposits
  - d. Fluvial deposits
- (7) Anthropogenic landforms– This class includes all those landforms produced due to the result of human activities. Although human activities do not seem to be predominant in the study area, it is believed that some of the slope instability could be the result of road construction and digging for electric poles and underground cables. There is no historical record in the form of air photographs available prior to such activities so that such comparison could not be made precisely.

### 5.3 DESCRIPTION OF REGIONAL GEOMORPHOLOGICAL MAP NO.1

A regional geomorphological map on a scale of 1:24,000 is prepared, using aerial photographs from 1939 to 1968. The color IR imagery of 1984 was also used. The map includes major geomorphic and morphological features. The map legend is very clear. Information is arranged into three main groups, namely (i) accumulative features, (ii) the accumulative-denudative features, and (iii) the fluvial features. The division of these features is mainly based on the material origin, structure, etc.

Both colors and signs are used to present information in cartographic form. Colors range from dark, for the highest relief class, to light for the lowest. The altitude of various places is also indicated. Following are some major geomorphic features shown on this map:

Low rolling hills

Sand Dunes

Wind blown deposits (eolian plain)

Ridges

Shale cliffs

Slope failure and other mass movement activities

landslide scars

Floodplain (older and recent floodplain deposits)

Areas subject to flooding.



FIG. 19. Air photograph of study area taken in 1939. Low rolling hills south of Niobrara River are drained by deeply entrenched canyons. River channel has been changed considerably. This change has been caused by the construction of dams and irrigation canals upstream areas.



The region north of the Niobrara River mostly consists of rolling hills, the hills are traversed by deep entrenched canyons, which are vegetation covered (Fig. 19). Their extension is generally east-west and serves as a watershed boundary between the Keya Paha River on the north and the Niobrara River on the south. The brown color shade is used to show these hills on the map. The region on the south of the Niobrara River consists of a plain of wind blown sandy material. On the west, the plain merges into the Sand Hills region of Nebraska. The wind blown sand plain is characterized by pirated streams, divides, depressions, sand dunes, and table lands. The Anisworth table is located approximately 30 km south from the right bank of the Niobrara River. The area east of Plum Creek and to Bone Creek on the south and Dutch Creek on the east is poorly drained. Except for Plum, Bone and Dutch creeks, all other streams disappear into the plain. The region on the east of Plum Creek has smooth low rolling topography, and gently grades towards the north. The region on the west of Plum Creek is extensively covered by sandy dunes (Fig. 20). Majority of them have been stabilized, and wind deflation occurs only where the protective vegetation cover has been removed. Geological formations underlying the wind blown deposits are Valentine, Rosebud of Tertiary, and Pierre Shale of the Cretaceous period. Further south, deposits of Keim Formation overlying Ash Hollow Formation are also found.



Fig. 20 Air photograph, showing the area west and east of Plum Creek, a right bank tributary of Niobrara River. The area west of Plum Creek (right above the study area) is mostly irrigated and is under cultivation, while the area east of Plum Creek is mostly occupied by sand dunes and other eolian features; however, it is stabilized and wind deflation is not very common.

Slope failure and various other mass movement activities are mainly restricted to the right bank of the river, where unstable geological formations form very steep slopes and cliffs (Fig. 21). Sites of some old slope failures are noticed along Plum Creek. The scale of air photographs and imagery does not however allow to observe all the details and minor features associated with mass movement activities; therefore, only landslide scars and other landslides of undetermined types were mapped on the regional geomorphological map. Color and symbols are used to show the sites of slope instability. Shale cliffs along the river are shown in orange color, while the yellow colors express the landslide scars.

All fluvial relief features associated with river channel are shown by symbols. The channel of the Niobrara River in study area is graded and flows smoothly in a wide channel (Fig. 22), and in study area it forms a meander curve. Large size sand bars are present and some have been intact for a long time and are covered by thick vegetation. Old and recent floodplain deposits are mapped on either side of the river. Recent development of the flood plain has been on the left bank. On the right bank, a little further down from the bridge, deposits of the old floodplain were mapped, which are also mixed up with old coluvial deposits (Fig. 23). Various other features such as seasonal streams, natural vegetation, agricultural areas, and roads are also mapped using appropriate symbols.



Fig. 21 1968 air photograph, showing the areas along the Niobrara River affected by landsliding. The cohan plain behind these cliffs is internally drained and gently slopes towards north. The internal seepage of water on this plain and the flow towards unstable geologic formations exposed along the river may be one cause of slope failure and also the large water body "Lost Lake" below Noon ridge.

0-68

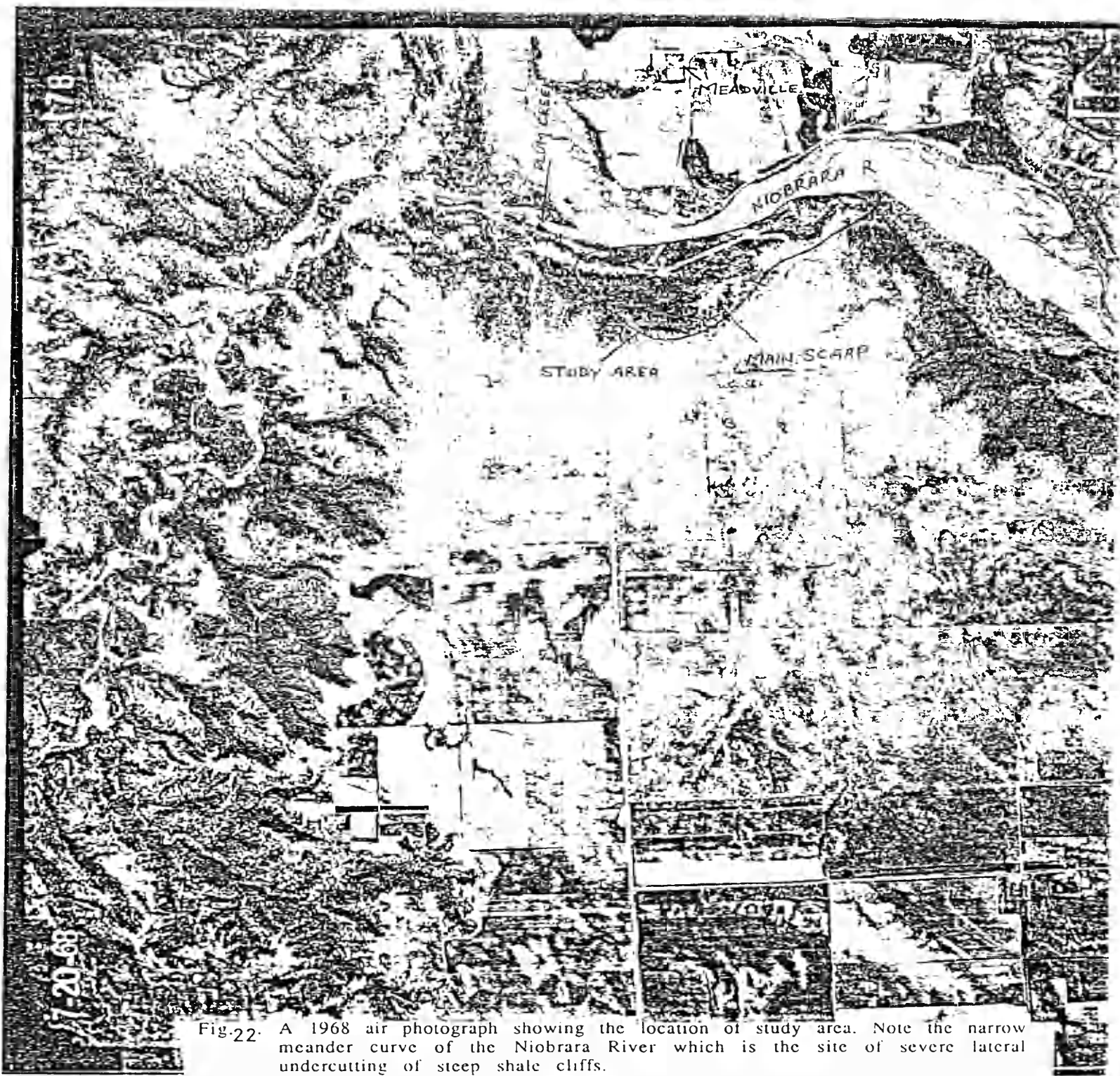


Fig.22. A 1968 air photograph showing the location of study area. Note the narrow meander curve of the Niobrara River which is the site of severe lateral undercutting of steep shale cliffs.



Fig. 23. Air photograph taken in 1968 showing the area north and south of Niobrara River, Approximately 2 km downstream from study area. Steep shale cliffs on the right bank face lateral erosion and undercutting. River deposition mostly takes place on the left bank.

#### 5.4 DESCRIPTION OF THE DETAILED GEOMORPHOLOGICAL MAP NO.2

The detailed geomorphological map of the Meadville slope failure emphasised the definition and mapping of both the slope failures themselves and the factors responsible for slope failures. This has been based on two main principles; (a) dynamic geomorphological processes, and (b) the response of the slope to processes. The slope may respond to these processes in form of movements, the nature of these movements may depend on many other factors such as material, angle of slope, vegetation cover and also the climate of the area. The slope responses to the geomorphological processes may also be influenced by anthropogenic activities. Mapping efforts have been concentrated on defining and describing and also plotting the position as well as areal delineation of all these factors (i.e., lithology, angle of slopes, and other geomorphic features) likely to have bearing on slope stability/instability (i.e., slope failure or landslides), and also the features produced as the result of slope failure. The determination of the areal extent or distribution is the main objective of slope failure mapping. The geomorphological map of the Meadville slope failure not only illustrate these objectives but also other geomorphic features both on macro and micro which may have bearing on slope movements are mapped and are areally delineated.

Mapping landform stability/instability is derived from landform activity analysis, different kinds of slope failure processes, such as landslides, downslope creep, flow and fall initiated by different geomorphoic processes are recognised and the intensity of these geomorphic processes is evaluated to map thses stability/instability features representing individual geomorphic processes, or different state of equilibrium or areal stability. For example fluvial processes may cause unstable areas of low instability or high instability. Likewise slope processes and related unstable areas may cause slope units subject to debris accumulation (talus) and also the areas of low instability and high instability or we can say active or potentially unstable slopes. The landslide inventory for this map is detailed, showing deposits and areas that appear to have failed because of slope failure processes.

The channel of the Niobrara River forms a very narrow meander curve in the study area, where on its left bank the steep shale cliffs are exposed. Here we have a severe slope failure processes in progress. The highly unstable shale cliffs are prone to failure because of erosion and undercutting by river, which is although not very significant because the river channel already is graded and has less degradational capability because of heavy concentration of suspended sediment load (Fig. 24). But seepage of water through overlying formations, the effects of rainfall and north facing exposures of these shale





Fig24. A view of Niobrara River. Plum Creek joins the right bank 1 km above the bridge. Note the smooth and graded river channel (photograph 1989).

cliffs cause failures. Severe failures on these cliffs have been observed especially after the rainy period. The types of failure mapped here includes falls, in which the blocks of shale usually slightly wet were separated from the cliffs and fall down under the action of gravity. The sliding movements were also noticed in which the fallen blocks of shale rested on lower surfaces for some period and then gradually slid down towards the river. The shale cliffs exposed along the river are actually glide block fronts of the main slide (Fig. 25). Glide block fronts and the main scarp are clearly visible across the river.(see figure 14). Minor mud slides were also noticed where the shale slopes are not so steep. The shale mixed with other materials derived from overlying formations flows in a shallow gorge carved in these cliffs. The area west of cliffs experienced slow type of movements. The evidence of these flow movements are deformed pine trees. Various slumps, tension cracks, depressions and mass movement related features have been observed and mapped in this area (Figs 26 and 27). The juniper vegetation is severely disrupted in this locality. The area west of the bridge has not been affected by landsliding or slope failures, only landforms which are mapped in this locality are few potentially unstable slopes and rest of the area is floodplain of the Niobrara River. The dark tone areas shown on map above glide block fronts are the glide blocks, they resemble benchlands, their surfaces is plain and have numerous tension cracks and minor



Fig. 25. Glide block front in Pierre Shale (photograph 1989).

depressions. The glide blocks are separated by deep graben. Between these glide blocks and the main scarp on the Valentine Formation just below the Noon Ridge (Fig. 28), is located the "Hidden lake," which presumably is the result of accumulation of water seeping through overlying formations into a depression produced as the result of separation of glide blocks from the main scarp. The lake is quite large in size and the surface is covered by algae scum (Fig. 29). Significant damage to vegetation has occurred in this vicinity. Numerous trees have been deformed and uprooted on the lower portion of the slopes of the main scarp above the lake (Fig. 30). The slopes of the main scarps on Valentine Formation are bare surfaces. Sand runs, numerous minor slumps and tension cracks are present. A series of sharp longitudinal sharp ridges in the Valentine Formation are also mapped right below the main scarp. Their formation may be the result of downward sliding movements. The area above the Noon Ridge experienced slow types of mass movement activities. Numerous indications of earth creep (Fig. 31), tension cracks, steps and breaks on the slope are also mapped (Fig. 32). Several sites are marked as potentially unstable (Fig. 33). Earth flows that are usually slightly wet occur in many gulleys on the west of Noon Ridge.

The area on the east of road to Anisworth and south of Niobrara River is comparatively stable. The gradient is very smooth, although some old landslide scars were recognized and

mapped. The legend of the map illustrates many other geomorphic features associated with the mass movements and slope failures.



Fig. 26. Slope failure along the Niobrara River. (1) Flow portion with deformed pines  
(2) Pierre Shale glide blocks (photograph 1989).



ig. 27. Photograph taken in the summer of 1989, showing the slope failure along the river right of the bridge on the right bank of the river. Sliding and flow is mostly the result of undercutting by water. Although backward tilts of the juniper trees indicate the sliding slumps. The movement is slow but noticeable.



Fig. 28. Main Scarp above the Noon Ridge (photograph 1988).





Fig.29. Views of "Hidden or Lost Lake." (a) uprooted and displaced coniferous vegetation on the slope above the lake (b) algae scum covered surface of the hidden lake (photograph 1989).



Fig-30. Tilted and uprooted trees on slopes above the "Lost Lake." The lake itself may be the result of depression produced due to slope failure, which probably later filled with water seeping through Valentine Formation.



Fig. 31 .A zone of weakness. Area in this picture is potentially susceptible to failure and can occur any moment. The writing pad in the extreme left indicates the extent of this zone of weakness. The location of this photograph is right of the Noon ridge facing north.



Fig. 32. Deformed and damaged vegetation. The most common slope failure features here (above the lake) are slumps and tension cracks. The arrow indicate the direction of failure (photograph 1989).



Fig. 33. Note the "steps in slope," an indication of slope failure. The size of the steps is one to one and half meter (photograph 1989).

## CHAPTER SIX

### CONCLUDING DISCUSSION

The geomorphological aspects and mechanics of slope failures and other forms of mass movement have been and continue to be a matter of great concern to geomorphologists, ecologists, land managers, highway engineers, and to those living in landslide-prone areas. The destruction of communication systems, public property and private property, and the loss of life associated with mass movement throughout historic times have been very significant. The geomorphological aspects of the landsliding are important for the identification of landsliding areas and the stabilization of landslides. It is important to distinguish between those physical characteristics of a site which make landsliding possible and the actual cause which initiates movements, such as the underlying geological formations, steepness and nature of the slope exposure, vegetation cover, and also the ground and surface runoff. The Meadville failure is one of the largest in Nebraska and has affected the plan for dam and reservoir, a highway bridge, the roads, power lines, houses, and buried telephone lines. Analysis of this failure is important in reducing further hazards. Geomorphological mapping has proven to be very useful for such purposes. The through study and indepth scientific analysis of this type of geomorphological hazards

demand multi-disciplinary approach which may include mapping of the landslide affected areas, geotechnical and slope stability studies to determine the zones of weakness. Dendrochronological studies may also prove useful, especially in areas where the underlying geological formations are unconsolidated, to determine the age of movements. The aim and objective of this research work was two fold: (1) to prepare a large scale as well as small scale geomorphological maps, and (2) to describe the geomorphological history which has developed in this area during the Quaternary period. An account of the physical environment of the study area may be cursory in nature. However, an efforts have been made to prepare a detailed map of geomorphic features which may serve as a geomorphological tool in future for such type of studies.

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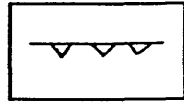


APPENDIX A  
LEGEND FOR DETAILED GEOMORPHOLOGICAL AND  
REGIONAL GEOMORPHOLOGICAL MAPS OF MEADVILLE  
SLOPE FAILURE

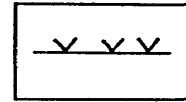
LEGEND FOR GEOMORPHOLOGICAL AND PHYSIOGRAPHIC MAPS  
OF MEADVILLE LANSLIDE, NEBRASKA.

1. MORPHOLOGY

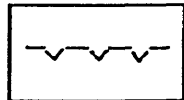
Angular convex  
break of slope



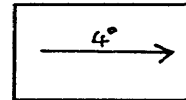
Angular concave  
break of slope



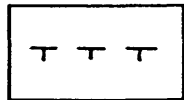
Smoothly concave  
change of slope



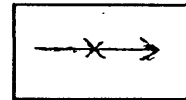
Angle of slope (degrees)



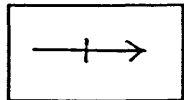
Change of slope



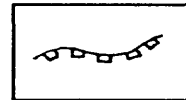
Convex slope Unit



Concave slope Unit



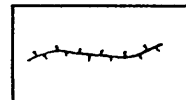
Cliffs



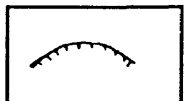
Steep shale cliffs



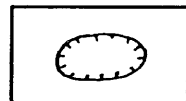
Ridges



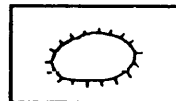
Scarp



Graben

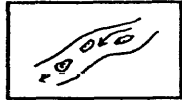


Benchland

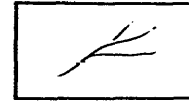


## 2. FLUVIAL LANDFORMS

River channel



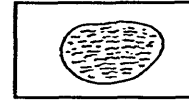
Stream



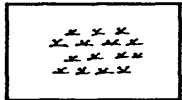
Seasonal stream



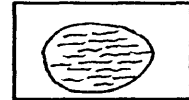
Spring or wet areas



Swamp



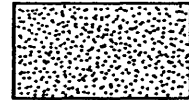
Permanent lake



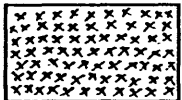
Temporary lake



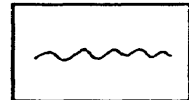
Floodplains



Area susceptible to flooding



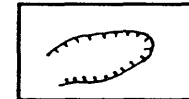
Rill erosion



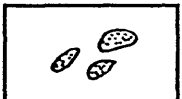
Major river incision



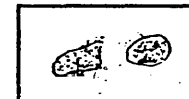
Gully



Sand bars

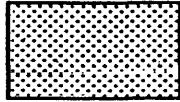


Sand bars  
(vegetation covered)

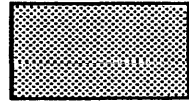


### 3. LITHOLOGY

Sand



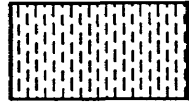
Silt



Clay



Alluvium



Shale

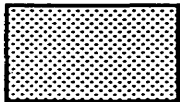


Weathered shale

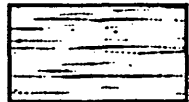


### 4. AEOLIAN (EOLIAN) LANDFORMS

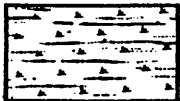
Wind blown sandplain



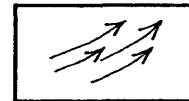
Sanddunes



Sanddunes (vegetation covered)



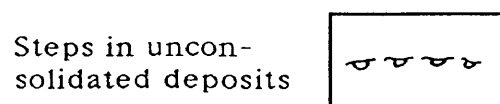
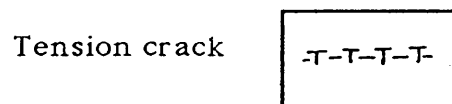
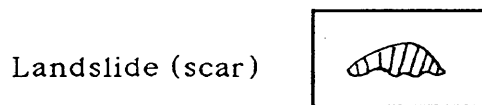
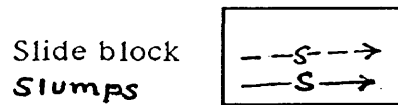
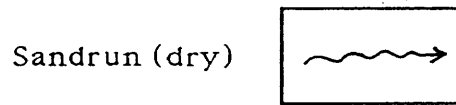
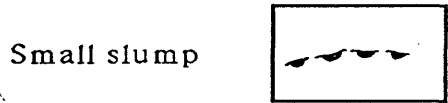
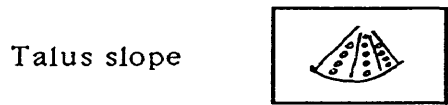
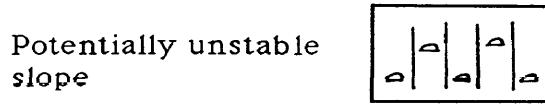
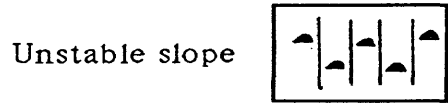
Deflation area



Deflation hollow



### 5. SLOPE STABILITY/INSTABILITY



### 6. DEPOSITIONAL LANDFORMS

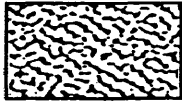
Talus slope



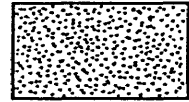
Weathered shale deposits



Colluvial deposits

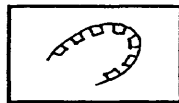


Fluvial deposits



### 7. MAN-MADE LANDFORMS

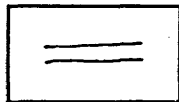
Quarry



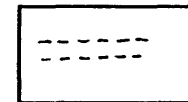
Settlement area



Transport route (paved)



Transport route (unpaved)



# REGIONAL GEOMORPHOLOGICAL MAP OF MEADVILLE LANDSLIDE

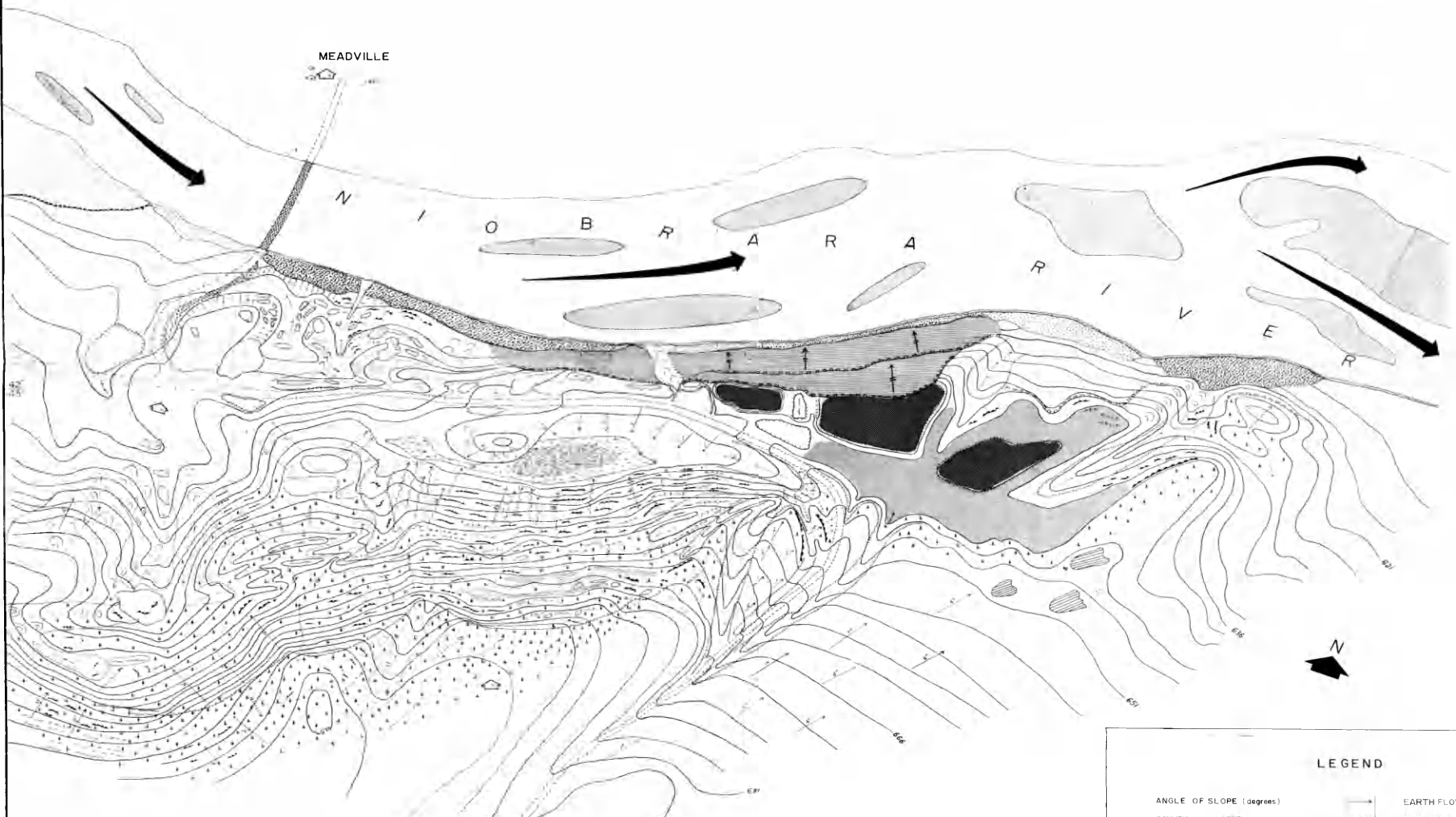
## LEGEND

- LOW ROLLING HILLS 
- SAND DUNES 
- WIND BLOWN DEPOSITS 
- RIDGES 
- SHALE CLIFFS 
- MASS MOVEMENT 
- DEPRESSIONS 
- LANDSLIDE SCARS 
- FLOODPLAIN 
- AREAS SUBJECT TO FLOODING 
- RIVER CHANNEL 
- SEASONAL STREAMS 
- SAND BARS 
- SAND BARS COVERED BY VEGETATION 
- AGRICULTURAL AREA 
- CONIFEROUS VEGETATION 
- ROADS 

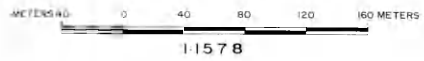
SCALE: 1:240



# GEOMORPHOLOGICAL MAP OF MEADVILLE LANDSLIDE, NEBRASKA



42  
45



**LEGEND**

ANGLE OF SLOPE (degrees)		EARTH FLOW ON SLOPES	
CONVEX SLOPE UNIT		MUD SLIDE	
CHANGE OF SLOPE		SANDRUN (DRY)	
UNSTABLE SLOPES		FALL (FAST)	
POTENTIALLY UNSTABLE SLOPES		GLIDE BLOCK	
CLIFFS		LANDSLIDE SCAR	
STEEP SHALE CLIFFS		GULLY	
TALUS SLOPE		EARTH FLOWS IN GULLYS	
RIDGES		COLLUVIAL DEPOSITS	
ISOLATED LONGITUDINAL RIDGES		WEATHERED SHALE DEPOSITS	
DRABEN		FLUVIAL DEPOSITS	
DEPRESSIONS		SAND BARS	
BENCH AND (GLIDE BLOCK)		RIVER EROSION	
TENSION CRACKS		LAKE SWAMP	
SLUMPS			
STEPS IN UNCONSOLIDATED CLIFFS			
EARTH CREEP (very slow movement)			
SETTLEMENT AREA		TRANSPORT ROUTE	
		QUARRY	