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LANDSLIDE PHENOMENA IN SHELL, AND TENSLEEP CANYONS, BIGHORN MOUNTAINS, WYOMING.

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Landslide phenomena in Shell, and Tensleep

Canyons, Bighorn Mountains, Wyoming

by

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1978

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INTRODUCTION

Landslides are defined as: the downward and outward movement of slope forming materials--natural rock, soils, artificial fills, or combination of these materials (Eckel, 1958). They are one of the processes by which slopes adjust themselves to a particular set of environmental conditions. During the Quaternary, the environment has undergone repeated changes. Work by Carson (1976) indicates that landslides are controlled by changes in their environment. A significant contribution to geology is to determine how the landslides are distributed in space and time in response to these environmental changes.

Knowledge of the distribution of landslides in time and space will enable a better prediction of regional slope stability. An important economic need exists for this type of information. It is estimated that total economic losses in California alone due to landslides between 1970 and the year 2000 will total almost 10 billion dollars. A systematic evaluation of landslides on first a regional basis, then a tract or community basis, and finally on a site basis has been estimated to reduce the damage that will be caused by landslides by 95 to 99 percent (Leighton, 1976).

This dissertation deals primarily with landslide phenomena on a regional scale. In the dissertation the word region is used to denote an area of the earth's surface ranging in size from a first order drainage basin to a physiographic province. As the region being dealt with becomes larger in size the level of detail at which it is studied must decrease. The time span over which the various environmental factors affecting that region are considered, on the other hand, must increase (Schumm and Lichty, 1965).

The purpose of this dissertation is threefold: first, to evaluate the important environmental factors which should control slope stability; second, to conduct a detailed field investigation to determine those environmental factors which actually control regional slope stability in a specific area; and third, to develop a series of models, based in part on the field study, which will better predict regional slope stability.

This dissertation is limited to the study of landslides that are likely to be caused by long term environmental changes. Landslides which can be definitely attributed to sudden intense periods of rainfall are excluded as are creep and solifluction phenomena.

ENVIRONMENTAL FACTORS CONTROLLING SLOPE STABILITY

In this section the factors controlling slope stability are discussed using published literature. The primary concern is the distribution in space and time of landslides occurring on the earth's surface. The factors that control the distribution of landslides have been dealt with by Terzaghi (1950) and Varnes (1958), and are: topography, mechanical properties of materials involved, presence or absence of earthquakes, climate, structural configuration of the material involved, and the stratigraphy (homogeneity or inhomogeneity) of the material involved. As these factors vary either through time or space the relative stability of the slopes involved will change accordingly.

More recent work has tended to confirm that of Terzaghi and Varnes and will be briefly summarized in the succeeding pages. While the factors controlling landslides are discussed individually the reader must keep in mind that landslides are seldom triggered by one single factor (Varnes, 1958).

Slope Stability Factors

Topography

All other factors being equal, landslides are more common in areas of high relief than low relief. On a regional scale, the steeper the slope the more likely a landslide is to occur (Cooke and Doornkamp, 1974), and as the slope angle increases both the size and number of landslides increase (Rice et al., 1969). For example, on the Cumberland Plateau of Tennessee where local relief is low (approximately 15 meters) landslides are rare. In contrast, along the Cumberland escarpment where local relief is 183-366 meters landslides are common (Royster, 1973).

On a site specific scale, unstable slopes are characterized by topographic profiles parallel to slope that are more concave than stable areas. Profiles at right angles to slope are less convex in the downslope direction than stable areas (Waltz, 1972).

Mechanical properties

On any slope, regardless of the topography, when the forces that drive a landslide become greater than those resisting it, failure occurs. The magnitude of the force necessary to cause failure is described by the Mohr-Coulomb criterion for failure, modified for effective stress (Terzaghi, 1950). The criteria is:

$$s = c + (p - hw) \tan \phi$$

where

s = shearing resistance per unit of area at the observation point

c = the cohesion value

p = pressure per unit of area at a given point P of a potential surface of sliding, due to the weight of the solids and the water located above the surface

h = the piezometric head at the point

w = the unit weight of the water

ϕ = the angle of sliding friction for the surface of sliding

Whenever the actual shearing stress on a failure surface becomes greater than s failure will occur. It is critically important to evaluate hw in determining slope stability. Most slope failures involve at least a partial saturation (a rise in hw) of the slide material (Spangler and Handy, 1973). A more unstable situation exists if artesion conditions are present in the slope, that is, (p - hw) becomes a negative value.

Once the slope begins to fail, the manner in which it fails depends on the physical behavior of the material involved. This recognition is important because, in certain situations, slopes may fail with little prior warning. Likewise, the rate at which a landslide moves downslope is determined in part by the physical behavior of the material involved.

Where slopes are made of hard, unweathered rock (sandstone, limestone, marble, granite, etc.) the stability of the slope is determined by physical defects in the rock, such as joints and faults and not by the strnegth of the rock itself (Terzaghi, 1962). Cohesion between joints is zero and the slope will behave mechanically as a mass of angular, irregularly, shaped blocks (Terzaghi, 1962). Failure in these slopes will be by sliding and the rate of movement may range from slow to very rapid (Varnes, 1958).

Where interstratified sedimentary rocks are oriented into a valley, catastrophic landslides which go through a period of slow movement followed by sudden rapid movement of the material downslope may occur. This type of failure is a time dependent phenomenon and commonly passes through two stages in its development (Hsu, 1969). The first stage is characterized by creep of the material (Figure 1, A to D). The driving force must overcome both cohesive strength and internal friction at the base of the sliding mass. The second stage is characterized by rapid movement of the material where the driving force must only overcome sliding friction

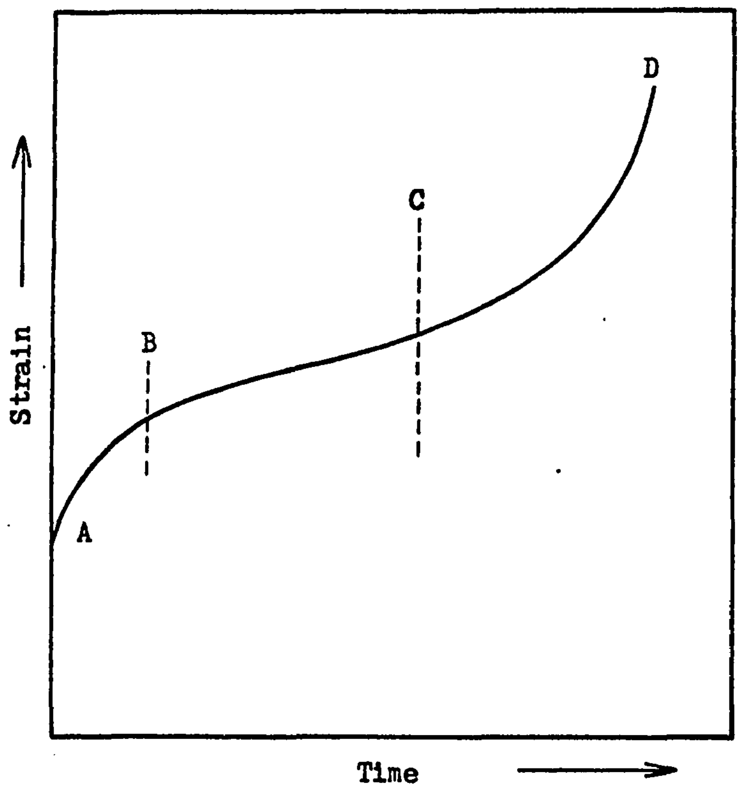


Figure 1. Typical strain-time (creep) curve for a rock under constant differential stress. Instantaneous elastic strain to A; transient (decelerating) creep from A to B; pseudoviscous (steady) creep from B to C; teritary (accelerating) creep leading to rupture at D (after Handin, 1966).

(Figure 1, D). This phenomenon is very sensitive to changes in pore pressure (Hsu, 1969).

Where low strength materials (soils, shales, etc.) are involved in landslides a conceptual model based on laboratory investigations of material behavior has been developed by Komamura and Huang (1974). The rheological state of the material involved changes gradually from a visco-plasto-elastic (solid) stage through a visco-plastic (plastic) stage to a viscous (fluid) stage with increasing water content (Figure 2). Material in the visco-plastic-elastic stage will theoretically not move rapidly. Sliding type movements (slumps, block glides) occur when the material is moving in this stage. When the material is in the viscous stage rapid movement (debris flows) may take place. For a discussion of landslide terminology see Appendix A.

Earthquakes

The effect of an earthquake on hillslopes is to increase the incidence of landslides. The ground accelerations during an earthquake increase the shearing stress along potential failure surfaces and landslides may result (Terzaghi, 1950). Surficial sediments, because of their lower strength, will fail more readily than bedrock (Leggit, 1939).

In surficial sediments, the most susceptible areas are those with a geometrical configuration which tends to accentuate earthquake vibrations. Ground motions of large amplitude and long duration have been observed on thick, water-saturated, unconsolidated sediments (Borcherdt, 1970). The amplitude of the ground motion generally increases with increasing thickness of the unconsolidated material. The greatest effects are on hori-

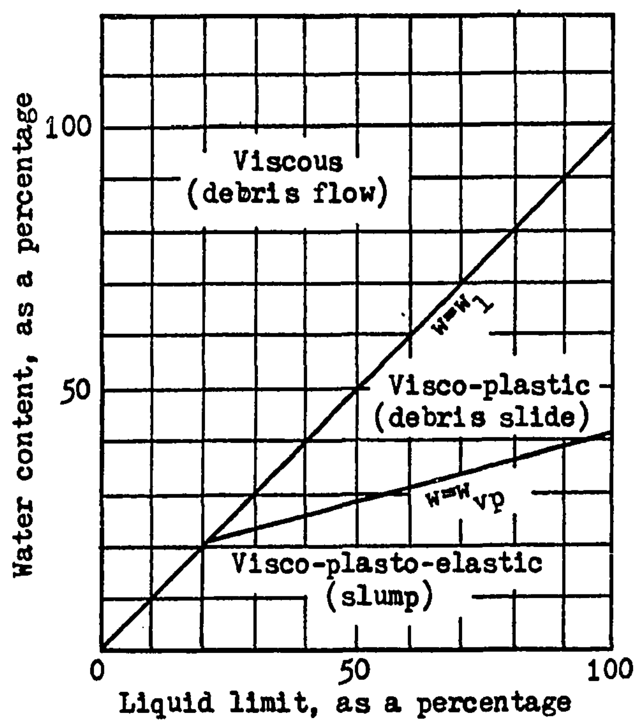


Figure 2. Rheological state of soil in accordance with water content (modified from Komamura and Huang, 1974; Carson, 1976).

zontal ground motion rather than vertical ground motion. Horizontal ground motion causes most earthquake damage (Borcherdt, 1970). The most susceptible of all materials to high amplitude ground motions are loose, saturated sands and highly sensitive clays. Both are very susceptible to liquefaction during earthquakes (Seed, 1967).

At the present time, only relatively simple response models have been developed to explain the effects of valley shape on the amplification or attenuation of earthquake vibrations. No analytical solutions for three-dimensional problems exist, even for cases where the topography may be described by relatively simple geometric forms (Singh and Sabina, 1977). Simple two-dimensional models for SH waves (S waves horizontally polarized) have been developed, however. In a narrow, steep-walled bedrock valley the amplitude of the SH waves is greatest on the side of the valley nearest the source of the SH waves, provided the SH waves strike the valley at a relatively shallow vertical angle (Trifunac, 1973). Therefore, the most severe risk of landsliding will be on the side of the valley nearest the source of the earthquake. In a bedrock valley filled with alluvium the pattern of vibrations during an earthquake is complex but standing waves may develop (Trifunac, 1971; Wong and Trifunac, 1974). This will make the valley areas particularly susceptible to liquefaction. In a valley cut into alluvium, the maximum amplitude for SH waves occurs at the edge of the valley. The thickness of the alluvium appears to be more important in controlling the amplitude than the surface topography of the valley (Wong et al., 1977).

Climate

Climatic changes affect hillslopes in two ways. First, the seepage forces within the slope change. Second, the climatic change may trigger base level changes at the toe of the slope. This will alter the stresses on that slope.

The western U.S. has undergone numerous climatic changes during the Pleistocene, and periods of glaciation in that area appear to be associated with periods of increased landslide activity. This is due to increased effective precipitation and/or glacial oversteepening of valley sides during glaciation. Howe (1909), after studying Pleistocene landslides in the San Juan Mountains of Colorado, states that the landslides took place "during or immediately after the first stage of glaciation." Waldrop and Hyden (1963) found three periods of landslide activity in the Gardner, Montana area and indicated that they were associated with glacial advances from the Yellowstone area. Pierce (1968) found two distinct periods of landslide activity in the Carter Mountain area near Cody, Wyoming. The older landslide deposits are associated with a glacial till of probable Bull Lake age. He attributes both periods of landslide activity to periods of increased precipitation which "may be associated with glaciofluvial events."

Most types of landslides are controlled by their geologic or topographic setting, rather than by the present day climate (Carson, 1976). However, landsliding as an agent of erosion is most effective in humid climates (Blumenstock and Thornthwaite, 1941).

<u>Structure</u>

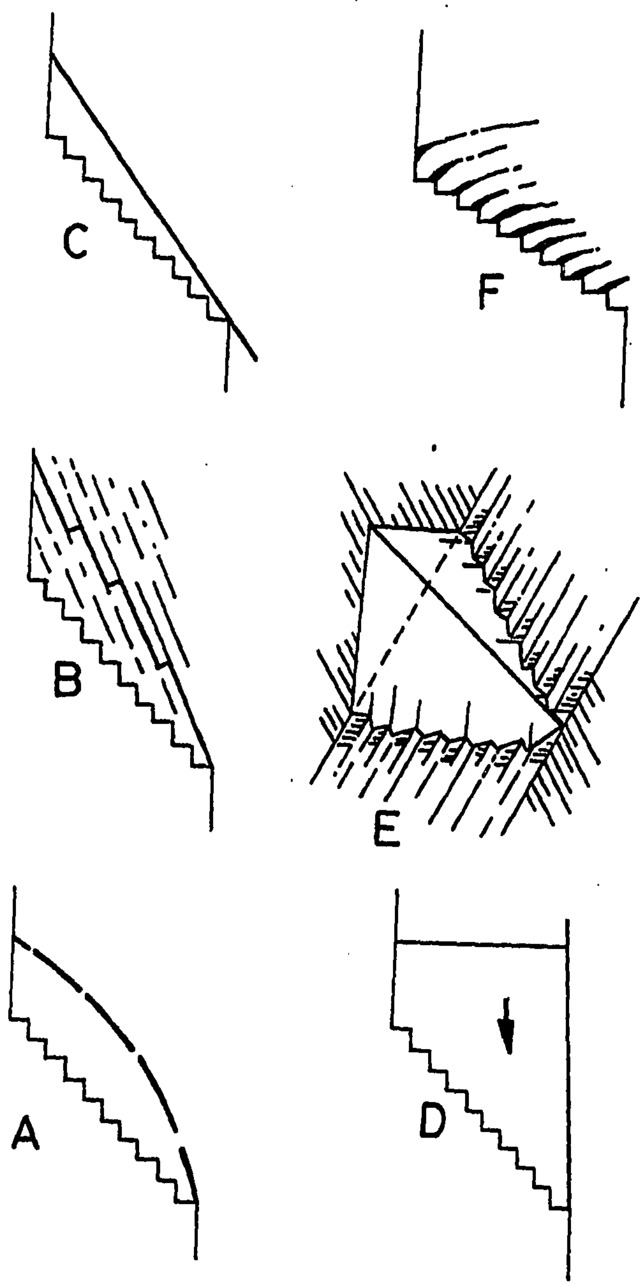
The structural orientation of discontinuities (bedding planes, joints, foliation, etc.) in slope forming material will control both the location and type of landslides occurring. As pointed out earlier, where slope forming materials are jointed, they are less stable than unjointed material because the joints reduce the overall strength of the material and allow easier access of ground water to the material (Varnes, 1958). The stable slope angle depends on the nature of the joint pattern, whether random or regular, and the orientation of the joints relative to the slope (Carson and Kirkby, 1972). Where the joints have a regular pattern, slopes become unstable when the joints dip downslope (Zaruba and Mencl, 1969). Block glides, debris slides, rock avalanches, and rockfalls are the type of landslides that occur. The presence of other discontinuities, such as faults, shear zones, etc., in hillslopes will also make them more susceptible to landslides (Zaruba and Mencl, 1969; Cooke and Doornkamp, 1974).

Where slopes consist of interstratified beds of material of differing strengths, the orientation of the beds relative to the slope determine the type of landslide (Figure 3). In such a case, the dip of the beds becomes the maximum angle at which the overlying slope is stable (Zaruba and Mencl, 1969). Where the beds dip steeply, greater than 20°, sudden catastrophic landslides result (Hsü, 1969), i.e., rock avalanches, soil avalanches, etc.

<u>Stratigraphy</u>

Landslides will occur more often on hillslopes composed of weak materials than on slopes in homogeneous, high strength materials. Where the slope material is weak and relatively homogeneous, slumps occur along

Figure 3. Type of landslide that occurs in relation to structural orientation of bedding planes, joints, or faults (modified after Brawner, 1977). (A) Slump occurring in homogeneous rock, rock with random localized jointing, or in interbedded sedimentary or metamorphic rocks where the bedding is horizontal or dipping gently away from the bank. (B) Debris slide with movement along joints or bedding planes. (C) Debris slide on the plane of a continuous fault, shear zone or joint. (D) Block glide on a weak layer bounded at the back by a joint or tension crack. (E) Failure as a wedge on two or more intersection discontinuities. (F) Failure by toppling. Most frequent where the major structure dips steeply.


C
F
B
E
A
D

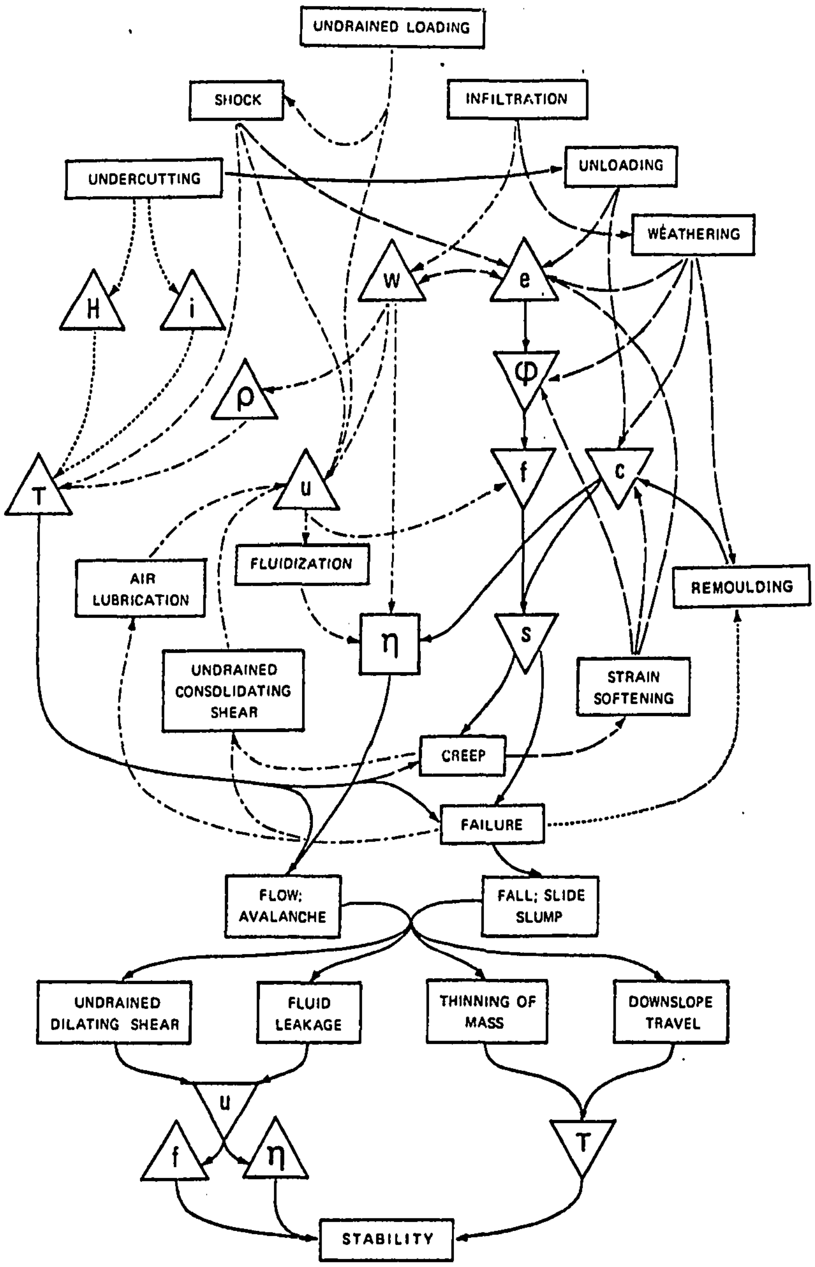
deep-reaching, curved surfaces (Zaruba and Mencl, 1969). Where a thick layer of high strength material overlies a layer of low strength material rockfalls or soilfalls will occur. These conditions favor overhanging or oversteepened slopes (Ritchie, 1958). Slopes in heterogeneous materials of contrasting strength are susceptible to landslides due to the presence of the weak layers. The type of landslides that occur in this situation has already been covered in the section on structure. Slopes in homogeneous, high strength materials are relatively stable except when jointed. Where the joints are randomly oriented, the slopes are stable to an angle of about 70° (Terzaghi, 1962). If the joints form a continuous pattern in the high strength material then it will behave the same as the heterogeneous material of contrasting strength (Terzaghi, 1962).

The complex interaction of the various environmental factors controlling slope stability at a site are summarized in a model proposed by Carson (1976) (Figure 4). Landslides can seldom be attributed to any single cause, but are due to the complex interaction of the various environmental factors controlling slope stability. Although the short term environmental changes illustrated in Figure 4, such as rainstorms, earthquakes, etc., often trigger sudden, rapid landslides, their effectiveness is largely controlled by slow, cumulative changes over a longer period of time.

In the next two sections the variation in time and space of the environmental factors controlling regional slope stability is evaluated. Variations of the factors in time determine when a region is characterized by widespread slope stability or instability. Variations in space deter-

Figure 4. Interaction of environmental factors that control slope stability (Carson, 1976). Conventional triangle denotes increase in value of variable represented by symbol within triangle; inverted triangle denotes a decrease; dotted line denotes sudden, irreversible change; dashed line denotes slow, irreversible change; alternation of dots and dashes denotes sudden reversible change; solid line denotes change undifferentiated by type. The symbols used are:

H = slope height
i = slope angle
ρ = bulk density
T = shear force
u = pore pressure
w = intake of water
e = void ratio
φ = frictional component of strength
f = friction developed on potential shear surfaces
c = cohesion
η = viscosity
s = strength


UNDRAINED LOADING
SHOCK
INFILTRATION
UNDERCUTTING
UNLOADING
WEATHERING
W
e
H
i
φ
ρ
T
u
f
c
AIR LUBRICATION
FLUIDIZATION
η
s
REMOULDING
UNDRAINED CONSOLIDATING SHEAR
STRAIN SOFTENING
CREEP
FAILURE
FLOW; AVALANCHE
FALL; SLIDE SLUMP
UNDRAINED DILATING SHEAR
FLUID LEAKAGE
THINNING OF MASS
DOWNSLOPE TRAVEL
u
T
f
η
STABILITY

mine what parts of a region are characterized by slope instability at a particular point in time.

STUDY AREA

Shell and Tensleep Canyons are located on the west side of the Bighorn Mountains of north-central Wyoming (Figure 5). This mountain range is a broad anticlinal uplift flanked by Paleozoic sedimentary rocks with Precambrian igneous and metamorphic rocks exposed in the core (Darton, 1906). Each canyon is bounded by cliffs of massive Paleozoic carbonates. Landslides in each canyon have occurred both in intact bedrock and in the brown colluvium derived from these cliffs. Both canyons contain deposits of glacial till in the upper reaches of the respective study areas.

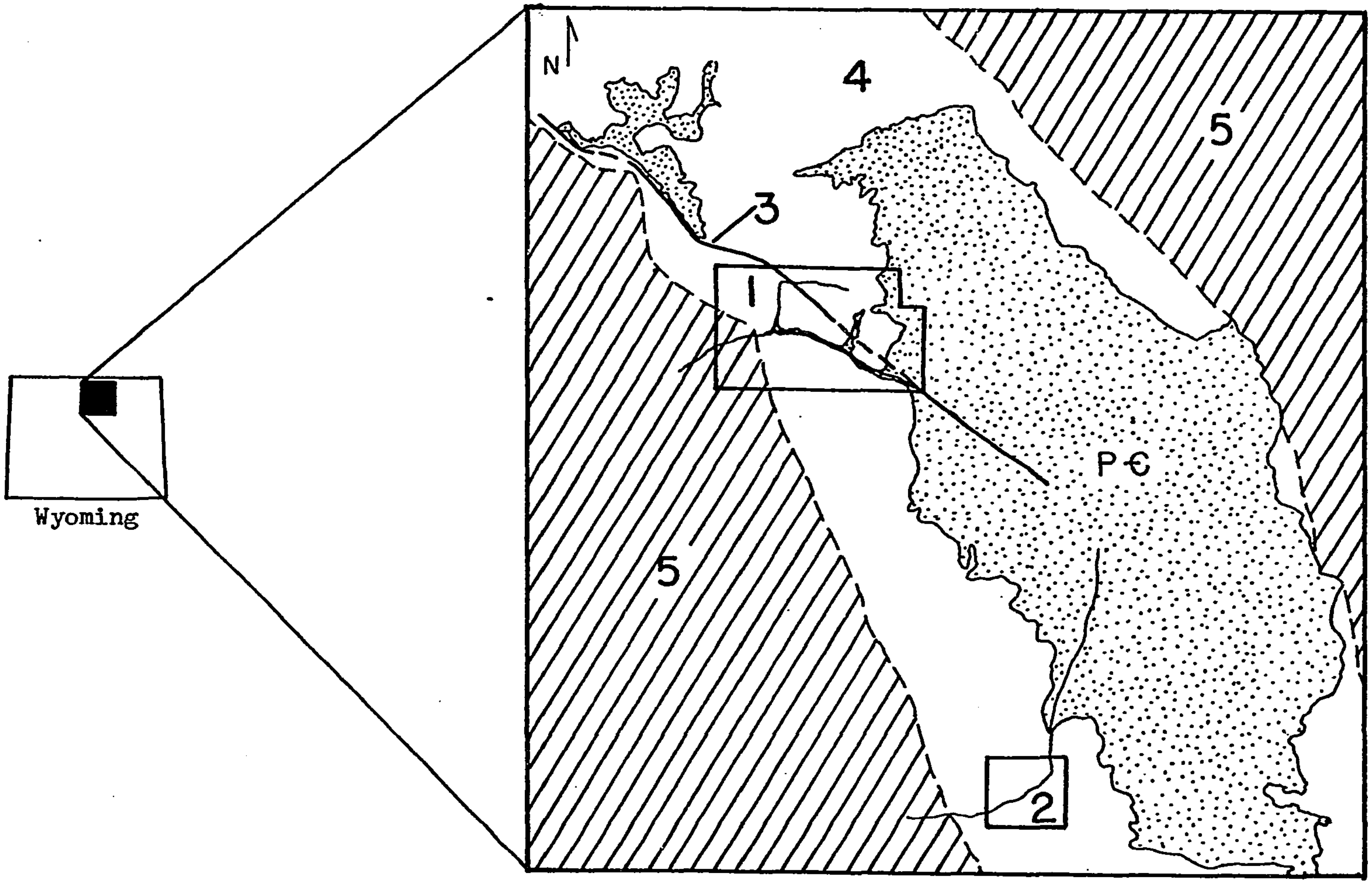
The present climate ranges from semiarid in the lower portion of each canyon to alpine in the upper portions. South facing slopes tend to be covered with a mixture of sage, prickly pear, and bunch grass at lower elevations. At higher elevations south facing slopes are covered by grass, sage, and generally "open" stands of pine trees. North facing slopes are generally covered by pine forests.

Several reasons exist for choosing Shell and Tensleep Canyons for this type of study. Both areas have seen relatively little human development. Both canyons have the same lower Paleozoic rocks exposed. Because of an inner Precambrian gorge, large areas of landslides, roughly 840 km^2 in Shell Canyon, are not affected by base level changes. Here the effect of climatic changes may be studied. However, Tensleep Canyon lacks an inner Precambrian gorge and the landslides there may have been affected by base level changes. Both canyons have landslides occurring in the same type of material.

Figure 5. Sketch map of the Bighorn Mountains.

5 = Mesozoic and younger age bed rock
4 = Paleozoic age bed rock
PC = Precambrian age bed rock
3 = Hunt Mountain lineament
2 = Tensleep Canyon study area
1 = Shell Canyon study area

Scale
0 — 20 km


Wyoming
N
4
5
3
1
P€
5
2

The dominant types of landslides developed in the study area are slumps, block glides, and debris slides. Slump is defined by the A.G.I. GLOSSARY OF GEOLOGY (Gary et al., 1974) as:

> A landslide characterized by a shearing and rotary movement of a generally independent mass of rock or earth along a curved slip surface (concave upward) and about an axis parallel to the slope from which it descends, and by backward tilting of the mass with respect to that slope so that the slump surface often exhibits a reversed slope facing uphill.

Block glide is defined by the A.G.I. GLOSSARY OF GEOLOGY as:

> A translational landslide in which the slide mass remains essentially intact, moving outward and downward as a unit, most often along a preexisting plane of weakness, such as bedding, foliation, joints, faults, etc. In contrast to rotational landslides, the various points within a displaced block-glide landslide have predominantly maintained the same mutual difference in elevation in relation to points outside the slide mass.

Debris slide is defined by the A.G.I. GLOSSARY OF GEOLOGY as:

> A landslide involving a slow-to-rapid downslope movement of comparatively dry and predominantly unconsolidated and incoherent earth, soil, and debris in which the mass does not show backward rotation (as in a slump) but slides or rolls forward, forming an irregular hummocky deposit resembling a moraine (Sharpe, 1938, p. 74). It is often called an earth slide but this is incorrect because the moving mass of a debris slide is greatly deformed or consists of many small units.

For a more detailed discussion of landslide classification see Appendix A.

Slumps, debris slides, and block glides are types of landslides that are triggered by long term environmental changes, undercutting, unloading, and weathering, shown in Figure 4. They are listed as slides and slumps in Carson's (1976) nomenclature.

Structure and Stratigraphy

Structure

The structure of Shell Canyon is relatively simple. The major structural feature in Shell Canyon is a monocline located at the mouth of the Canyon (Figure 7). Upstream from the mouth of the Canyon, Shell Creek flows diagonally across the strike of both the Paleozoic rocks and the Precambrian surface which have a regional dip from four to eight degrees to the southwest (Figures 6 and 7).

Two important minor structural features occur in Shell Canyon. The first, herein named the Hunt Mountain lineament, extends a distance of 80 kilometers from the headwaters of North Paint Rock Creek to a point approximately eight kilometers northwest of Five Springs Canyon along a line trending N55W (Figure 5). Where Precambrian crystalline rock is exposed at the surface the lineament shows up as a fault or fracture zone. Where Paleozoic sedimentary rocks are exposed at the surface the lineament appears as a monocline.

The second minor fetaure is a fault, herein named the Cedar Creek Fault (Figure 7) trending along a line N90E following Cedar Creek. The south side is uplifted relative to the north.

The effect of these two structures is to tilt a large area of Paleozoic bedrock, known as Copeman's Tomb, towards Shell Creek (Figure 9). This provides an ideal geometry for recurrent landslide activity.

Tensleep Canyon has a simpler structural setting than Shell Canyon. The major structure is a homocline with an average dip of five degrees to

Figure 6. Structure contour map of the top of the Precambrian rocks in Shell Canyon. Contour interval is 61 meters.

Scale

0 km. 4

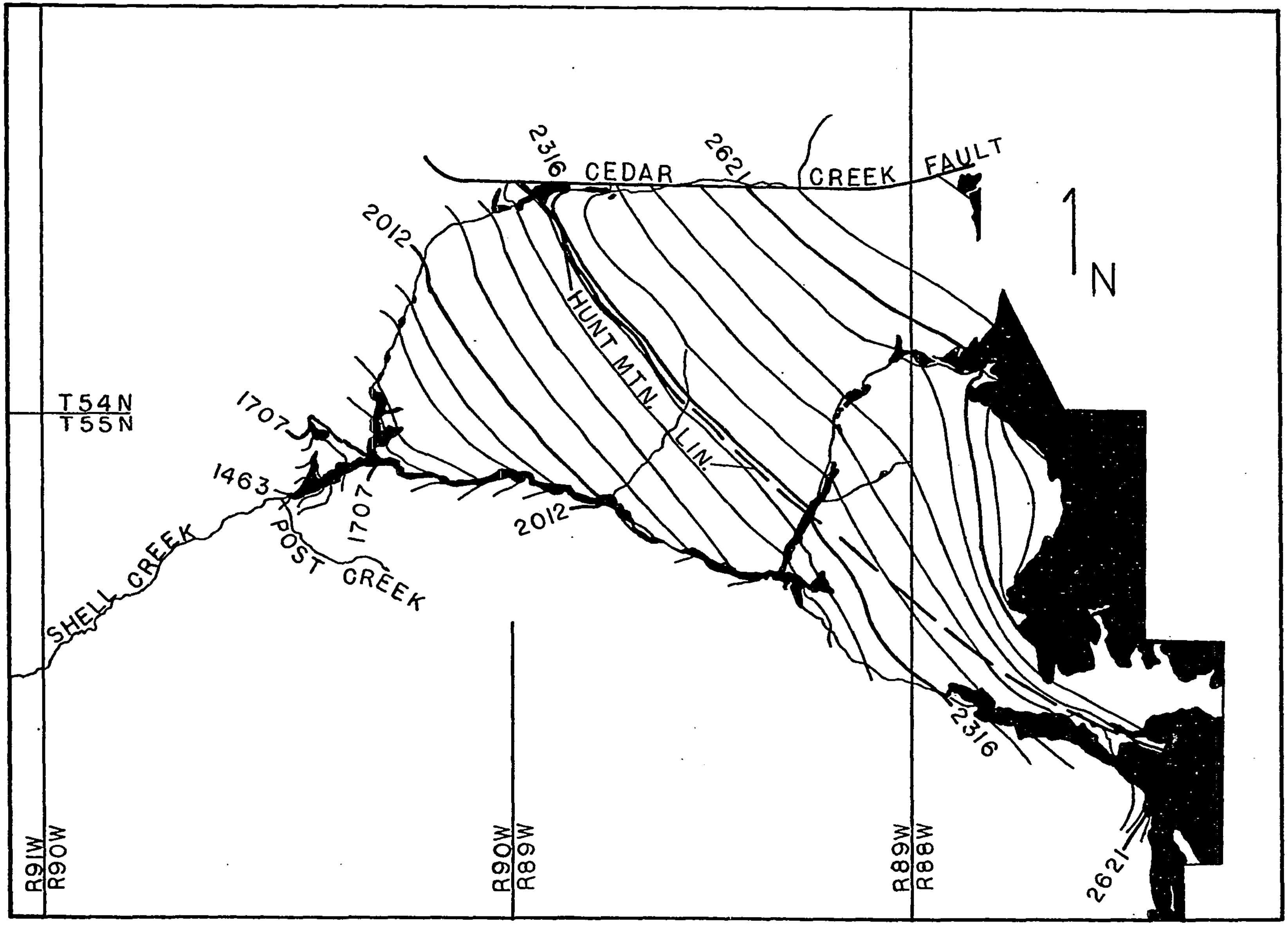

CEDAR CREEK FAULT
2316
2621
2012
HUNT MTN. LIN.
N
T54N
T55N
1707
1463
1707
2012
SHELL CREEK
POST CREEK
2316
2621
R91W
R90W
R90W
R89W
R89W
R88W

Figure 7. Structure contour map of the top of the Steamboat Point Member of the Bighorn Formation in Shell Canyon. Contour interval is 61 meters.

Scale

0 km. 4

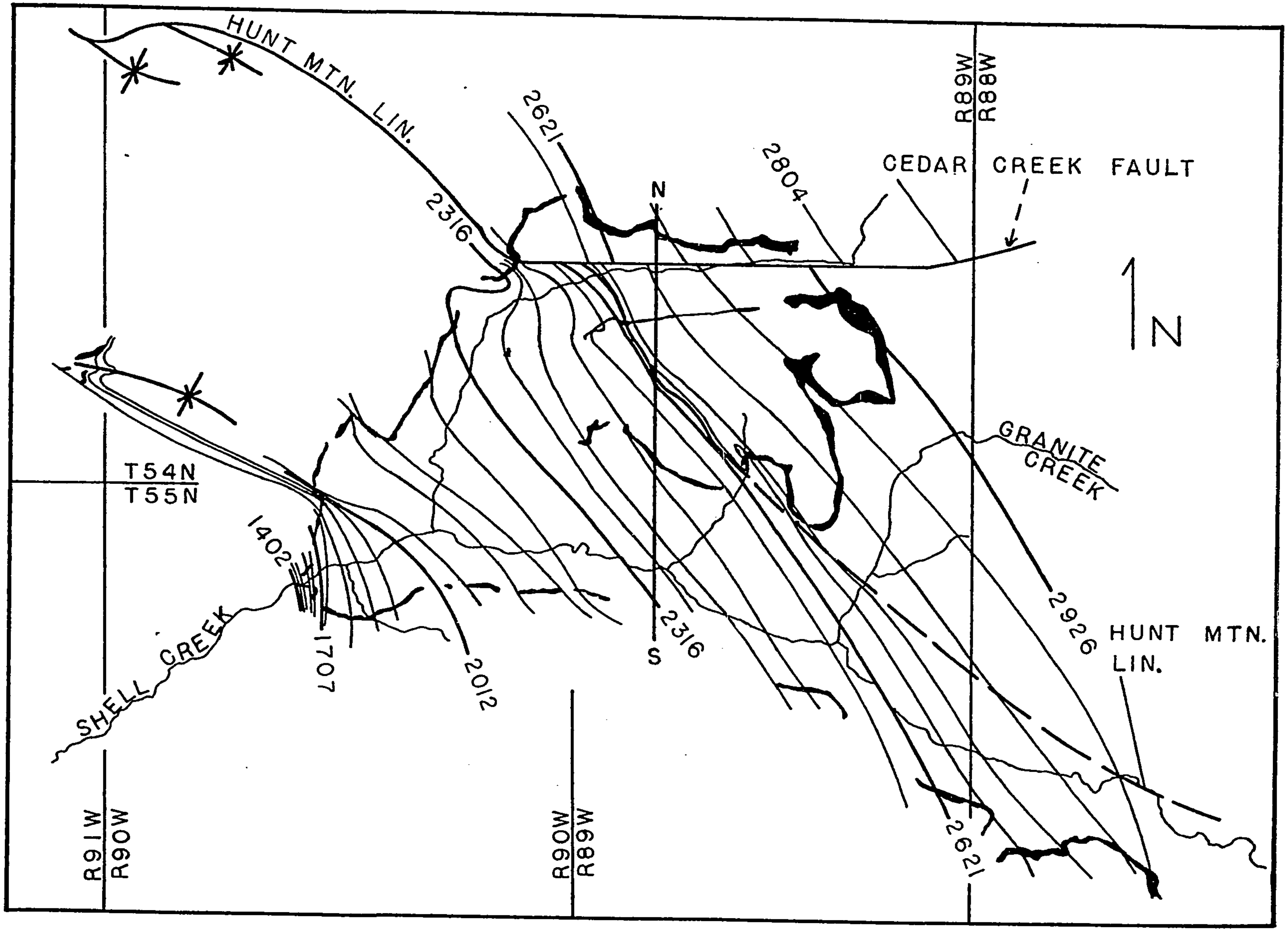

HUNT MTN. LIN.
2621
2804
CEDAR CREEK FAULT
R89W
R88W
N
2316
N
S
GRANITE CREEK
T54N
T55N
1402
1707
2012
2316
2926
HUNT MTN. LIN.
SHELL CREEK
R91W
R90W
R90W
R89W
2621

Figure 8. Structure contour map of the top of the Steamboat Point Member of the Bighorn Formation in Tensleep Canyon. Contour interval is 61 meters.

Scale
km
0 3

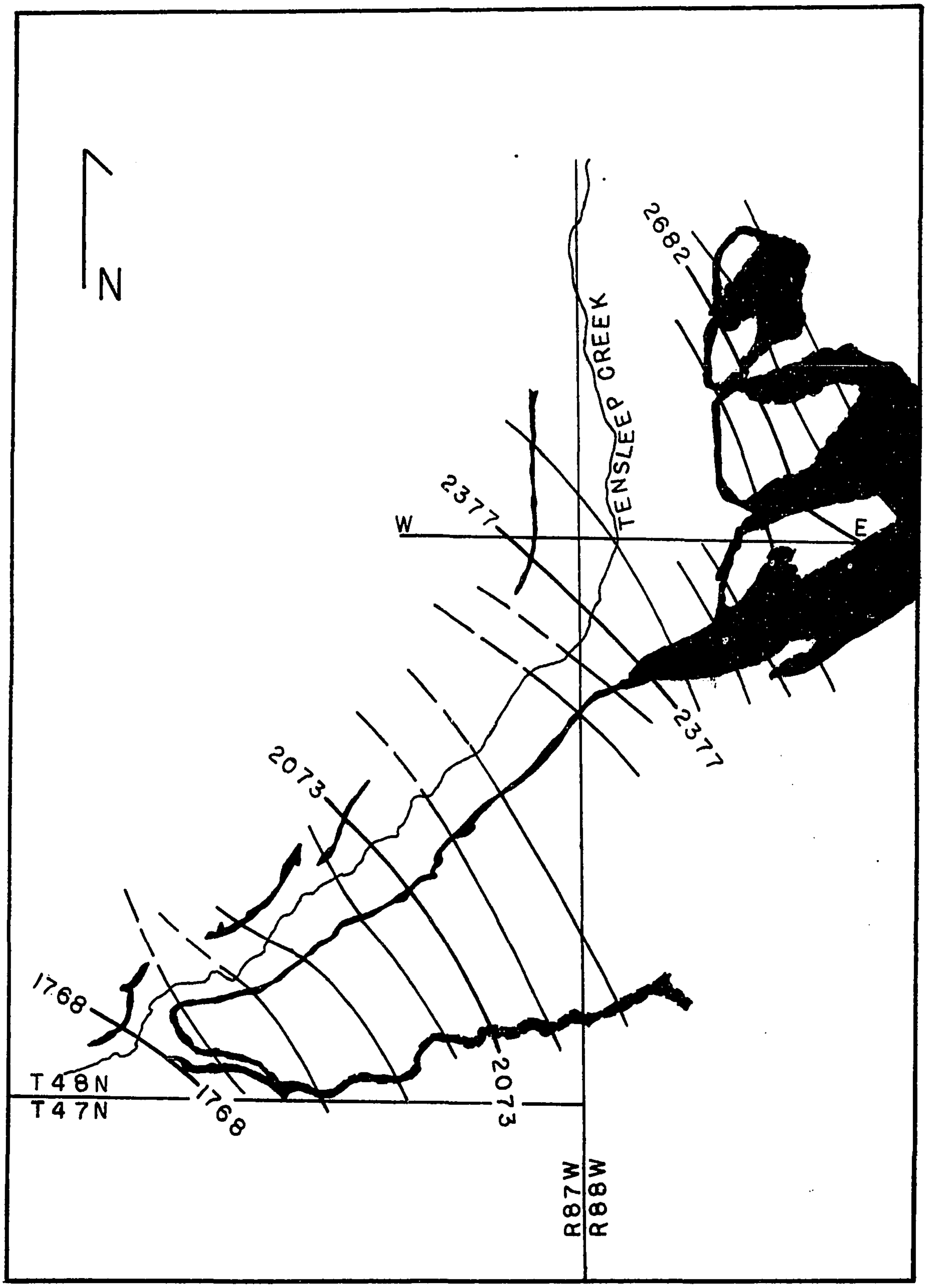

N
TENSLEEP CREEK
2682
2377
W
E
2377
2073
2073
1768
1768
T48N
T47N
R87W
R88W

Figure 9. Cross section across Shell Canyon. See Figure 7 for location of traverse line N - S.

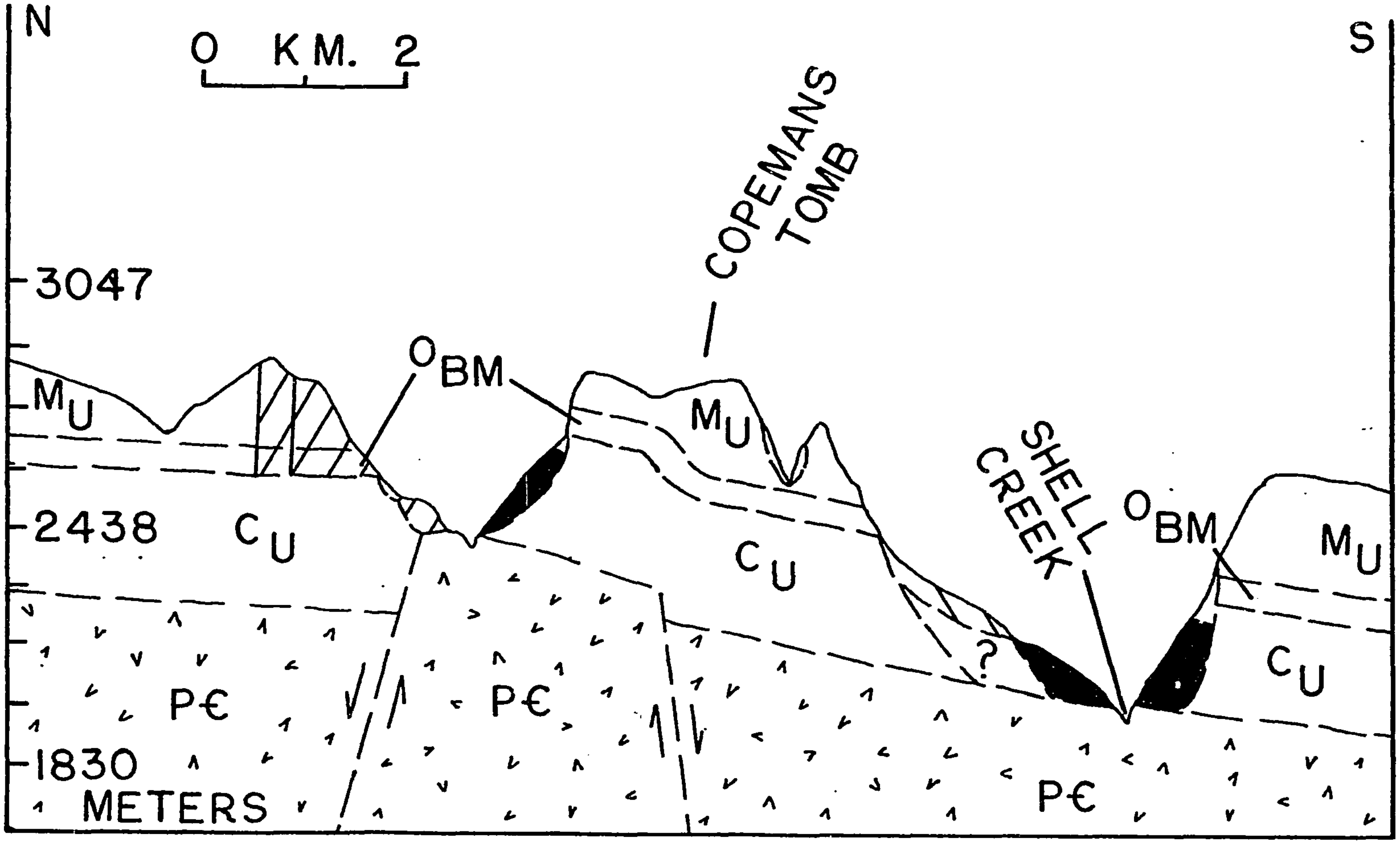
PC = Precambrian rocks undifferentiated
C_U = Cambrian rocks undifferentiated
O_{BM} = Ordovician, Bighorn Fm., Steamboat Point Member
M_U = Ordovician, Bighorn Fm., Leigh and Horsehoe Mtn. Members, Devonian, Jefferson Formation, and Mississippian, Madison Formation

= Block glide

= Slump

= Debris slide

= Talus


N
S
0 KM. 2
COPEMANS TOMB
SHELL CREEK
3047
2438
1830
METERS
M_U
O_{BM}
C_U
PЄ
?

the southwest. Tensleep Creek in the lower part of the study area flows directly down dip (Figure 8).

Stratigraphy, bedrock

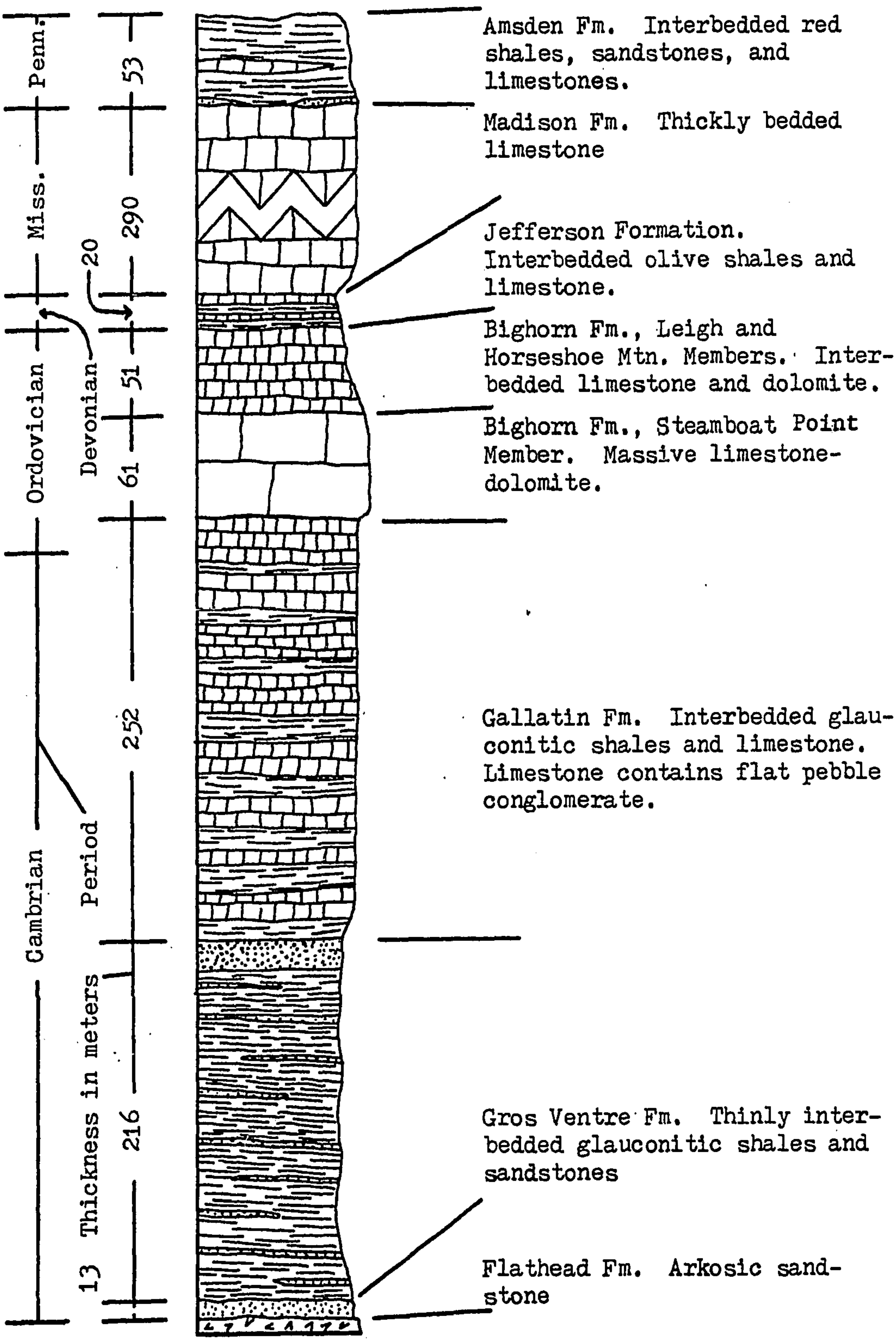
A composite section was measured in the area of Cottonwood Creek in the lower part of Shell Canyon (Figures 10 and 51). The basal sedimentary unit at this locality is the middle Cambrian age Flathead Formation. It consists of thirteen meters of well-indurated, arkosic sandstone. Where not covered by landslide debris the Flathead Formation forms a low scarp.

The middle Cambrian age Gros Ventre Formation overlies the Flathead Formation. It is made up of 216 meters of thinly interbedded green, glauconitic shales and sandstones. The formation is capped by an eighteen meter thick sandstone unit. Where not covered, this sandstone unit is found throughout the Shell Canyon area. The formation as a whole is poorly indurated and a slope former.

The Gros Ventre is overlain by the Gallatin Formation. The Gallatin ranges in age from upper Cambrian at the base to oldest Ordovician at the top (Cygan and Koucky, 1963). It consists of 252 meters of interbedded glauconitic shales (poorly indurated) and limestones (moderately well-indurated). The limestones frequently contain layers of flat pebble conglomerate. Individual beds of limestone gradually become thicker and shales thinner towards the top of the formation. The upper twenty-five meters of this formation frequently form a cliff whereas the remainder is poorly exposed.

The overlying Ordovician age Bighorn Formation is separated from the Gallatin Formation by an unconformity. The Bighorn is composed of 112

Figure 10. Generalized stratigraphic column for the lower end of Shell Canyon, thickness of the units is in meters. For location see Figure 51.


Penn.
Miss.
Devonian
Ordovician
Cambrian
Period
Thickness in meters
53
290
20
51
61
252
216
13
Amsden Fm. Interbedded red shales, sandstones, and limestones.
Madison Fm. Thickly bedded limestone
Jefferson Formation. Interbedded olive shales and limestone.
Bighorn Fm., Leigh and Horseshoe Mtn. Members. Interbedded limestone and dolomite.
Bighorn Fm., Steamboat Point Member. Massive limestone-dolomite.
Gallatin Fm. Interbedded glauconitic shales and limestone. Limestone contains flat pebble conglomerate.
Gros Ventre Fm. Thinly interbedded glauconitic shales and sandstones
Flathead Fm. Arkosic sandstone

meters of extremely well-indurated limestone-dolomite. The Steamboat Point Member of this formation is the first major cliff former encountered and is well exposed throughout the study area.

Of the Devonian age rocks, only the Jefferson Formation is present in Shell Canyon (Sandberg, 1967). It overlies the Bighorn along a prominent unconformity. In places in Shell Canyon the relief on this unconformity reaches one and one-half meters. The formations consist of twenty meters of interbedded olive shales and limestones. Above the lowest five meters the shales thin to the point where they become shaley partings between the limestone beds. This formation is not as well indurated as the Bighorn and forms a noticeable break in slope at the base of the Madison cliff.

Only the thickness of the overlying Mississippian age Madison Formation was determined in Shell Canyon. The formation has previously been described by Darton (1906). It is made up of 290 meters of well-indurated limestone. This formation is well-exposed and is the major sedimentary rock, cliff former in the entire Bighorn Mountain Range (Darton, 1906).

In places along the rim of Shell Canyon the Madison Formation is capped by the Pensylvanian age Amsden Formation (Figure 10). Only the thickness of the Amsden was determined. The formation has previously been described in the Shell Canyon area by Darton (1906). It is separated from the underlying Madison Formation by an unconformity. Where the entire formation has not been removed by erosion it consists of a discontinuous basal sandstone overlain by interbedded red shales and cream colored limestones. The Amsden has a total thickness in the Shell Canyon area of 53 meters.

The bedrock stratigraphy in Tensleep Canyon is similar to that in Shell Canyon with two exceptions. The Jefferson Formation is thinner, a maximum of 1.7 meters thick. In the lower reaches of Tensleep Canyon the Tensleep Formation caps the Canyon rim.

The Pennsylvanian age Tensleep Formation was described by Darton (1906). In the area of Tensleep Canyon it consists of over 90 meters of white to buff colored sandstone. Individual layers are cross-bedded, and the formation weathers to irregular pinnacled forms (Darton, 1906).

Stratigraphy, surficial, glacial

Moraines of four different ages are recognized in Shell Canyon. The moraines are differentiated on the basis of surface morphology, relative position in the valley with respect to other moraines, and soil profile development. The till making up the moraines consists of crystalline rock fragments in a sandy matrix.

The oldest moraine recognized in the Canyon consists of one small deposit which is herein informally referred to as the Ruble Creek Moraine (Figure 52). No morainal surface morphology remains, rather the deposit consists of a bench developed on a till composed of crystalline boulders set in a sandy matrix. The Ruble Creek Moraine is located down valley from the outermost recognizable morainal ridge.

The soil developed on the Ruble Creek Moraine is an Inceptisol. The A, B, and C horizons have developed under a grass-sage vegetation. The horizons may be distinguished from each other on the basis of color and structural development. The A horizon is dark greyish brown in color (10YR3/2) and has a granular structure. The B horizon is colored brown

(10YR4/3) and has a medium to coarse angular blocky structure. The C horizon is olive brown (2.5Y4/4) in color and massive. Little textural difference exists between the three horizons (Table 1).

The next moraine upvalley is herein informally referred to as the Shell Creek Moraine. It lacks a distinct hummocky morainal topography, but the lateral moraines are still preserved as ridges. The soil horizons are similar in thickness and development to those on the Ruble Creek Moraine (Table 1).

The next oldest moraine is herein informally referred to as the Ranger Station Moraine. It is located upvalley from the Shell Creek Moraine and has a well preserved hummocky surface morphology. Some of the depressions still contain lakes and ponds but they are at least partially filled with sediment. The end moraine of the Ranger Station Moraine has been breached by Shell Creek. The soils of the Ranger Station Moraine are texturally similar to the Shell Creek and Ruble Creek Moraines. However, the A horizon is somewhat thinner (Table 1).

The youngest moraine in the study area in Shell Canyon is herein informally referred to as the Crooked Creek Moraine. The portion of the moraine under a grass-sage vegetation has a well-preserved hummocky surface morphology. Several of the depressions contain lakes, which show some evidence of filling. The lateral moraine in the area for which it is named has been breached by Crooked Creek. This moraine is located upvalley from the Ranger Station Moraine. The texture of the soil profile is similar to those of the older moraines. However, the Crooked Creek

Table 1. Summary of soil profile characteristics of glacial moraines in Shell Canyon; all soil pits were dug in areas of grass-sage vegetation

Property	Crooked Creek Moraine	Ranger Station Moraine	Shell Creek Moraine	Ruble Creek Moraine
A horiz. thickness in cm	13	18	22	23
% sand	70	66	69	66
% silt	23	28	27	21
% clay	5	6	4	13
B horiz. thickness in cm	absent	32	32	28
% sand	absent	82	79	89
% silt	absent	13	13	7
% clay	absent	5	8	5
C horiz. thickness in cm	undetermined	undetermined	undetermined	undetermined
% sand	88	92	99	88
% silt	9	7	0	8
% clay	1	2	1	5

Moraine may be easily distinguished from the older moraines by its lack of a B horizon (Table 1).

The moraines in Shell Canyon have been correlated on the basis of topography, position in valley, and soil profile development with those in West Tensleep Canyon (Burggraf, 1978), and with the regional model proposed by Richmond (1965) (Table 2). However, a regional correlation is at best speculative and subject to interpretation (Nelson, 1954).

Table 2. Correlation of Shell Canyon moraines with those of West Tensleep (Burggraf, 1978) and with the regional model

Shell Canyon	Tensleep Canyon	Regional Model	Sources
	Mistymoon Moraine	Late Pinedale	Richmond, 1965, pp. 224-225
Crooked Creek Moraine	Tyrrell Moraine	Middle Pinedale	Richmond, 1965, pp. 224-225
Ranger Station Moraine	Squaw Creek Moraine	Early Pinedale	Richmond, 1965, pp. 224-225
Shell Creek Moraine	Bald Ridge Moraine	Bull Lake I	Mears, 1974, pp. 23-24
Ruble Creek Moraine	Borrow Pit Drift	Bull Lake II or older	Mears, 1974, pp. 23-24

Stratigraphy, surficial, colluvial

There are 42 different lithologic types of material in the colluvial landslides (key for Figures 18-26, pages 67-68). However, the two dominant materials consist of brown colluvium and green colluvium. Deposits of brown silt are also found but are not as abundant as the brown colluvium. For detailed descriptions of all colluvial materials see Appendix C.

The brown colluvium makes up the bulk of the colluvial landslide deposits. It is formed from the weathering debris of the Bighorn, Jefferson, and Madison Formations. The material contains 30 to 70 percent, angular, gravel to boulder size carbonate rock fragments in a loamy sand size matrix of carbonate rock fragments (Table 3).

Table 3. Summary of soil textural data for less than 2 mm fraction of C horizon for colluviums and for depressional fills; for raw data see Appendix D

Texture	Green colluvium n = 3	Unstratified brown colluvium n = 49	Stratified brown colluvium n = 1	Stratified brown silt n = 2	Depression fill modern n = 2
% sand	31	78	75	2	65
% silt	43	15	17	70	24
% clay	26	7	8	28	11

Along the north side of Tensleep Canyon (Figure 53) the brown colluvium is crudely stratified (Figure 11). The stratification is due to textural differences, some layers contain a higher percentage of rock fragments than others (point A, Figure 11), and to the presence of buried C_{Ca} horizons (point B, Figure 11). It is inferred that the deposits of brown colluvium along the north side of Tensleep Canyon have not been involved in landslide activity because the extensive deformation during landsliding would destroy the stratification. However, the stratification of the colluvium is horizontal and undisturbed, and no landslide surface morphology exists on the north side of Tensleep Canyon.

The brown colluvium along the south side of Tensleep Canyon and in most of Shell Canyon is unstratified (Figure 12). The material is similar texturally to the stratified brown colluvium (Table 3). However, it lacks

Figure 11. Roadcuts making up switchbacks along north side of Tensleep Canyon. TC77 - 6 is located near point A. (A) stratification due to presence of C_{Ca} horizon. (B) stratification due to textural differences. For location see Figure 53.

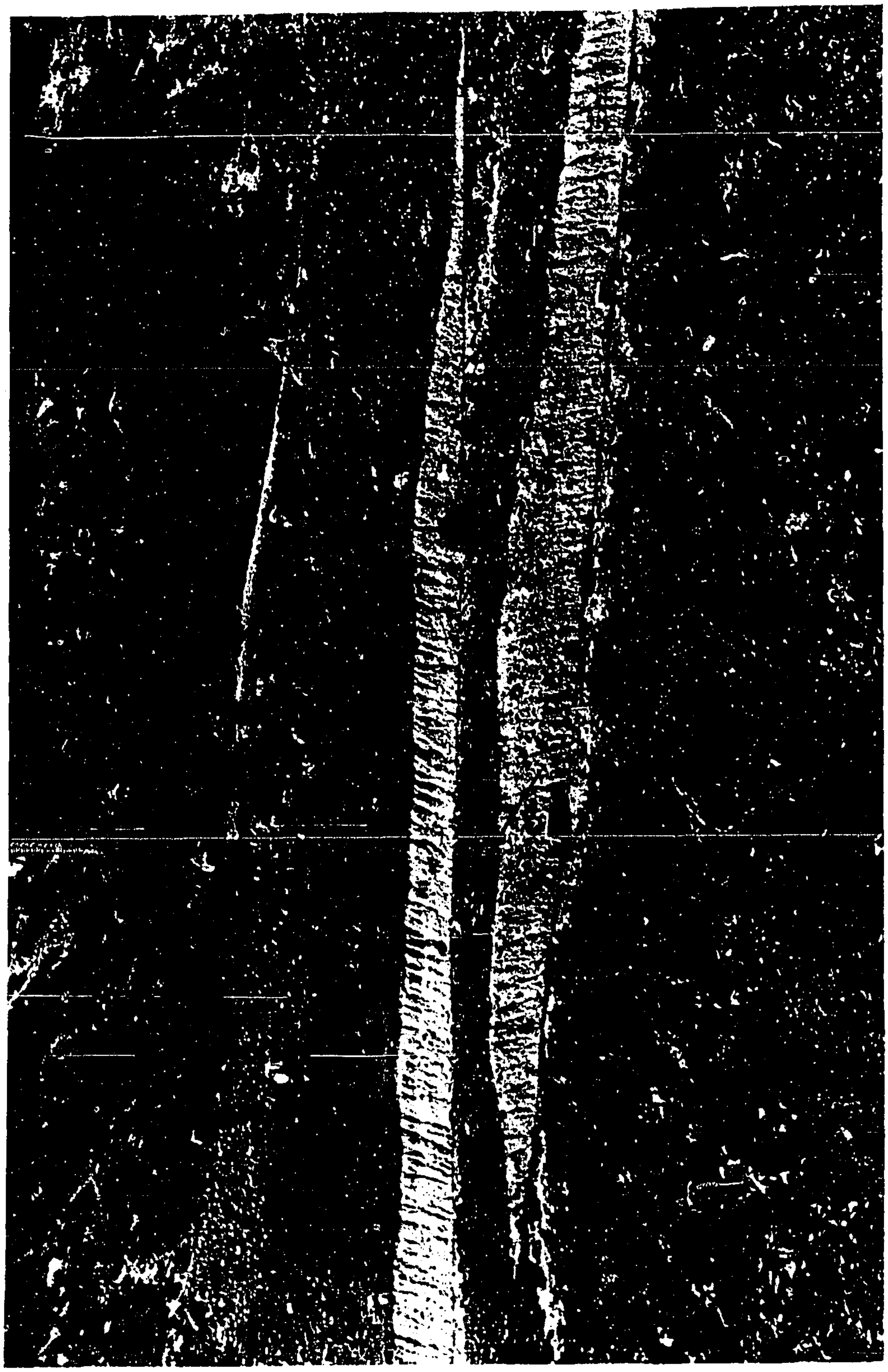
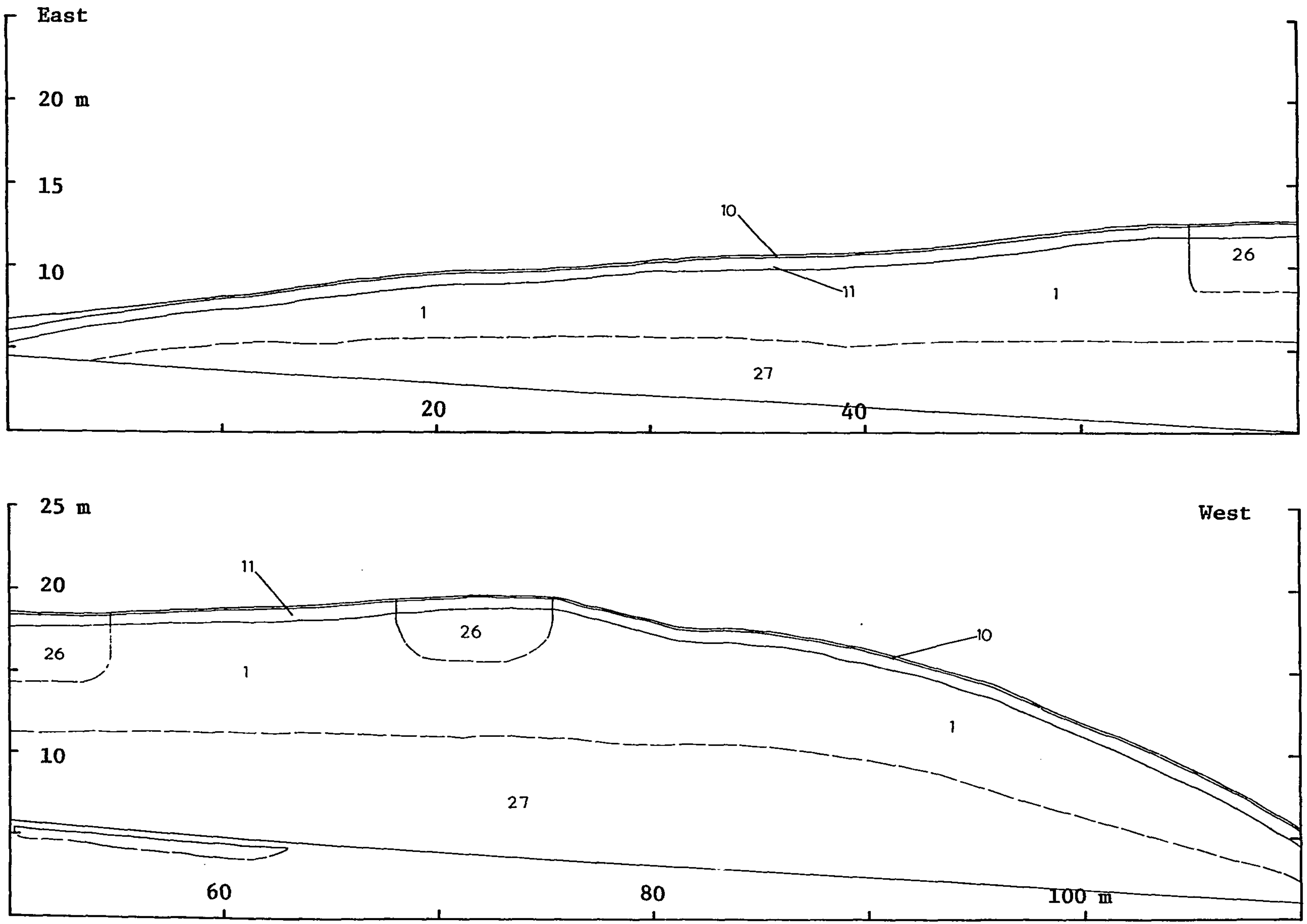


Figure 12. RC4-76. The brown colluvium in this roadcut has no apparent stratification. For location see Figure 51.


East
20 m
15
10
10
11
1
26
1
27
20
40
25 m
West
20
11
26
26
1
10
1
10
27
60
80
100 m

any C_{Ca} horizons, except for that forming in the present surface soil horizon. The lack of apparent stratification in this material is inferred to result from landslide activity, probably debris slides, and the consequent mixing action.

The soils developed on the unstratified brown colluvium below 1890 meters elevation are sandy, skeletal, carbonitic, mesic, typic torriorthents. For descriptions of individual soil profiles see Appendix E. The limestone parent material contains very little acid insoluble residue to provide clays for profile development. No statistically valid textural or depth to horizon differences exist between the soils developed on surfaces of different ages in this material. The average texture of the C horizon is listed in Table 3. The A horizon averages 11.5 cm in thickness and the B 20 cm. The only consistent soil difference is the presence of a C_{Ca} horizon on landslides that are pre-Bull Lake in age. Younger landslide deposits lack these C_{Ca} horizons.

Above 1890 meters the soils on the unstratified brown colluvium may be ustic torriorthents. Vegetation is noticeably better developed than at lower elevations. However, the moisture regime of the soil during the summer growing months is unknown at present.

Layers of stratified brown silt are often found interstratified with layers of brown colluvium. The stratification consists of laminations less than 0.5 cm thick, fine layers predominate. While somewhat finer textured than material accumulating in closed depressions on the modern surface (Table 3) the thickness of the laminations are similar. It appears that the brown silts also accumulated in closed depressions and were subsequently buried.

The green colluvium is derived from the weathering of the Gros Ventre and Gallatin Formations. It consists of rock fragments of flat pebble conglomerate set in a clay loam size matrix. The amount of rock fragments varies widely (10 to 80 percent of the total) but the longest dimension of the fragments is less than 50 cm.

When involved in landslides, the green colluvium is found in two different situations. Where the canyons are bounded by cliffs of Bighorn and Madison limestone, landslides composed dominantly of unstratified brown colluvium occur. The green colluvium is found as individual layers of irregular masses within the brown colluvium. Where the Bighorn and Madison cliffs are not present, landslide deposits composed predominantly of green colluvium are found. Soils developed on these landslides are clay loamy, skeletal, carbonitic ustic torriorthents.

Due to the highly friable nature of unstratified brown colluvium only field engineering tests were conducted on both the unstratified brown and the green colluvium. This was done to gain a better understanding of the physical properties of the materials.

Penetrometer tests were run on both colluviums over a wide range of moisture contents (Figures 13 and 14). While some scatter in the data exists it is clear that as percent saturation for both materials increases, the resistance to penetration decreases. Resistance to penetration and cohesion can only be related in a qualitative manner but the data indicates that the effective cohesion also decreases with increasing moisture content. This is an indication that hill slopes will be less stable during an interval of greater available moisture.

Figure 13. Penetrometer blows normalized for dry bulk density, N/γ_d, vs. percent saturation, S, for brown colluvium in Shell Canyon. R^2 of N/γ_d vs. S line is 0.57.

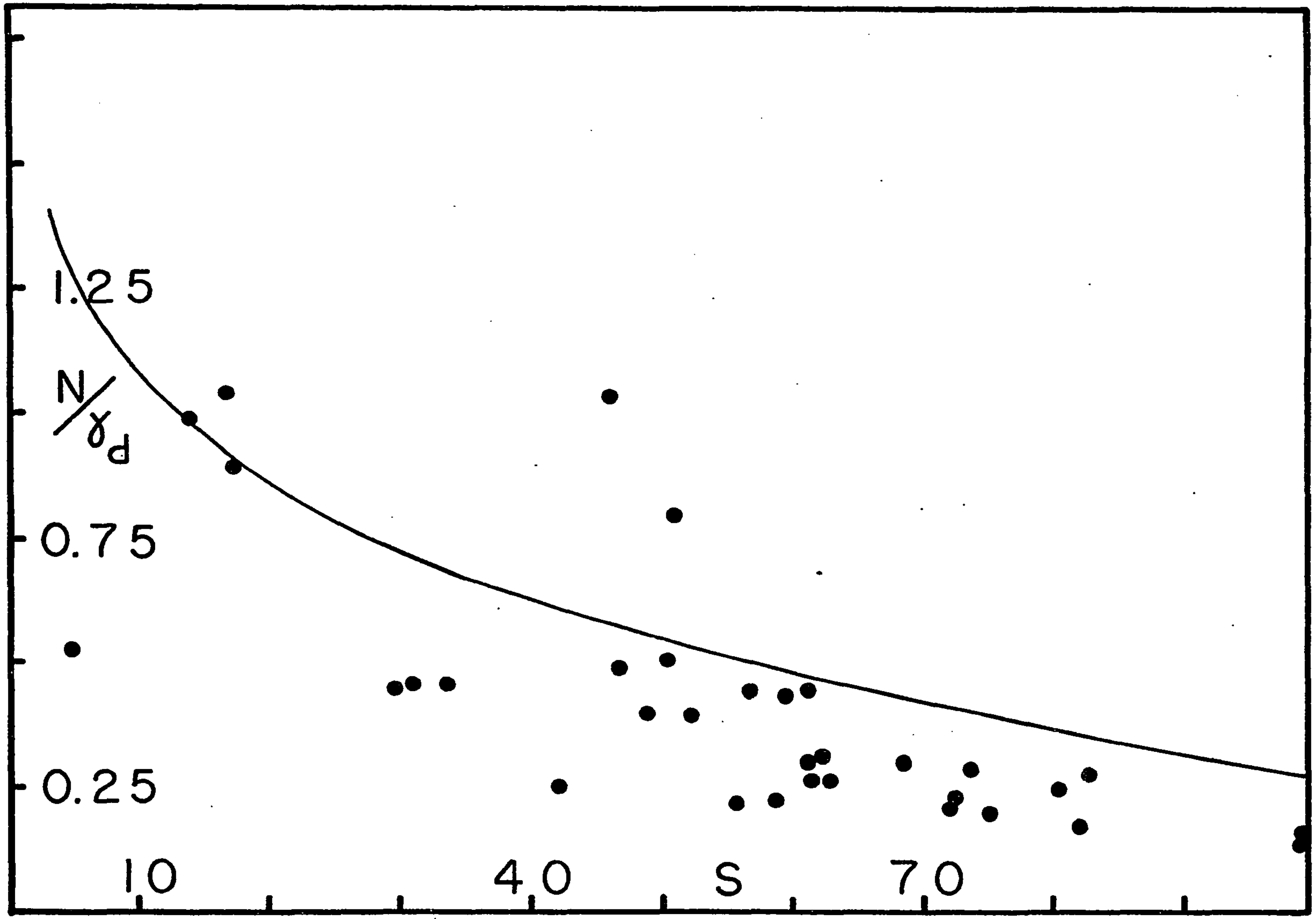
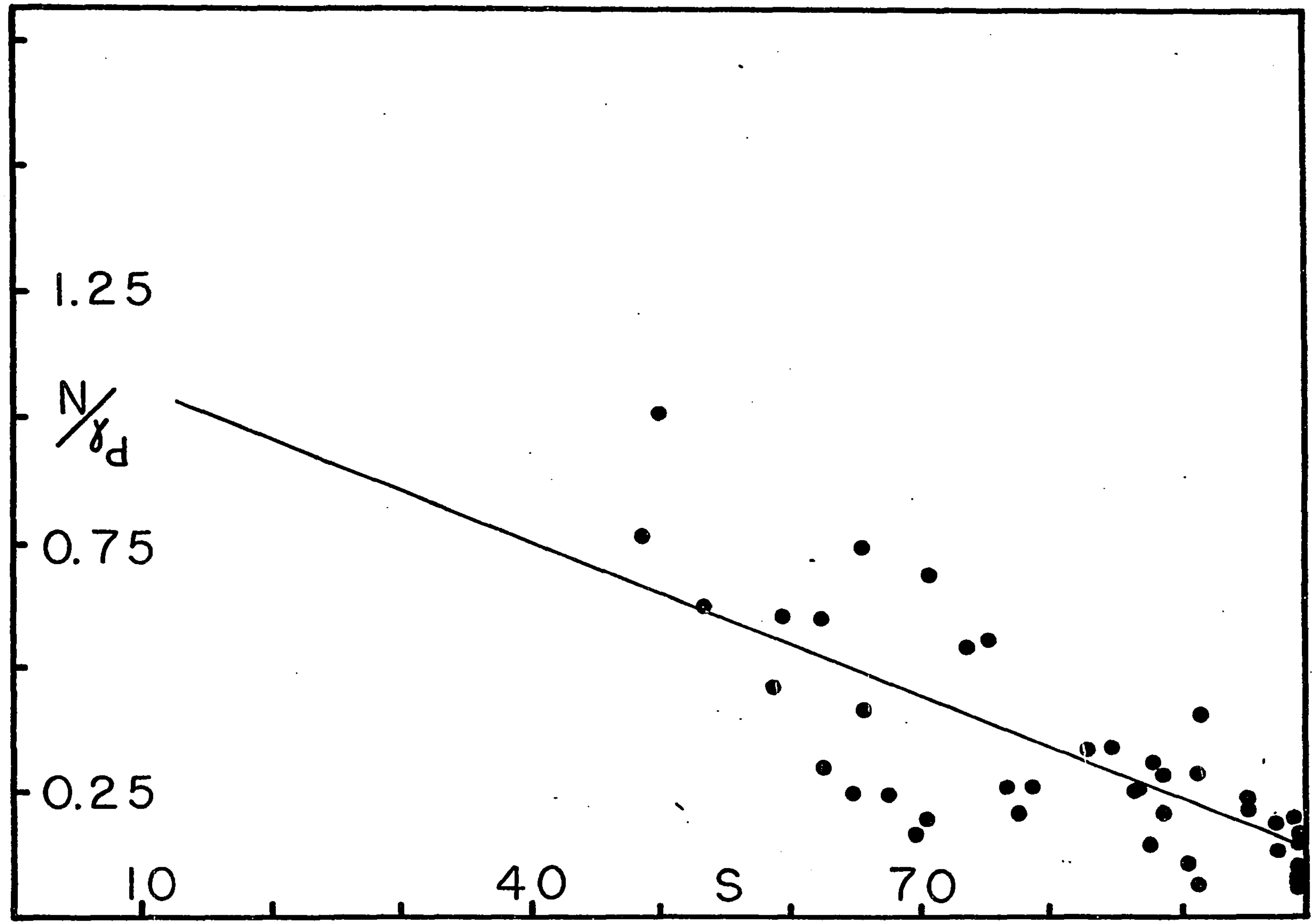

1.25
N/γd
0.75
0.25
1.0
4.0
S
7.0

Figure 14. Penetrometer blows normalized for dry bulk density, N/γ_d, vs. percent saturation, S, for green colluvium in Shell Canyon. R^2 of N/γ_d vs. S line is 0.57.



1.25
N/γ_d
0.75
0.25
10
40
S
70

The green colluvium is essentially impermeable while the brown colluvium is highly permeable. Field percolation tests showed that the green colluvium has a percolation rate less than 2.5 cm/60 min. The brown colluvium has a percolation rate of 2.5 cm/6 min. Since these two materials are frequently interlayered (Figures 18-26) perched water tables can be expected beneath the slopes of Shell Canyon.

The high percolation rate of the unstratified brown colluvium is also demonstrated by the nature of many of the small tributary streams and springs in both canyons. For example, in the area of Post Creek (Figure 51), several springs issue from the top of the Bighorn Formation which here makes up the lower part of the canyon wall. However, they flow for a distance of less than three meters across the soils before the entire discharge has seeped into the ground. Post Creek itself has no surface flow below the Bighorn cliff either. Many of the other tributary streams in the canyons also appear to be influent, their discharge being noticeably less when they enter the main stream than when they flow over the cliffs surrounding each canyon. It thus appears that the high percolation rate of the unstratified brown colluvium allows the streams to become influent and causes the moisture falling on the uplands surrounding the canyons to rapidly build up seepage forces in the colluvial slopes below the limestone cliffs.

Stratigraphy, surficial, landslides

The landslide deposits in Shell Canyon have been subdivided into seven morphostratigraphic units based on the degree of preservation of their surface morphology. The relative age ranges from active, youngest, to inactive-3, oldest. The material making up the landslide deposits consists of either intact Paleozoic bedrock, or colluvium derived from the Paleozoic bedrock. The morphostratigraphic units will be described in greater detail in the section Activity of Landslides in Shell and Tensleep Canyons.

Stratigraphy, volcanic ashes

Several deposits of airfall volcanic ash occur both in Shell Canyon and Tensleep Canyon (Figures 12, 15A,B,C,D, 20, 22B and 25B). The ash deposits are white in color and appear to contain very little foreign material. For a detailed description see Appendix C. Since the ash deposits occur among landslide, colluvial, and terrace deposits their correlation is important in working out the quarternary history of the area.

Two stream terraces associated with volcanic ashes occur in the area of Shell Canyon (Figure 51). Both were deposited by Shell Creek. The basal gravels in each terrace have compositions similar to those of the modern Shell Creek gravels.

The terrace deposit opposite the Wagon Wheel Cafe was first described by Heroy (1941) as a sequence of ashy sediments overlying a basal conglomerate (Payton conglomerate). However, when this exposure was examined in detail it appears that there are three separate beds of volcanic ash present. They are separated by other types of surficial sediments, gravely sand, and red silts (Figure 15A).

The base of the terrace deposit is 67 meters above the present Shell Creek floodplain. A projection of the approximate gradient of the Pre-

Figure 15. Volcanic ash deposits:

A = Wagon Wheel exposure (RC17-76), along Shell Creek

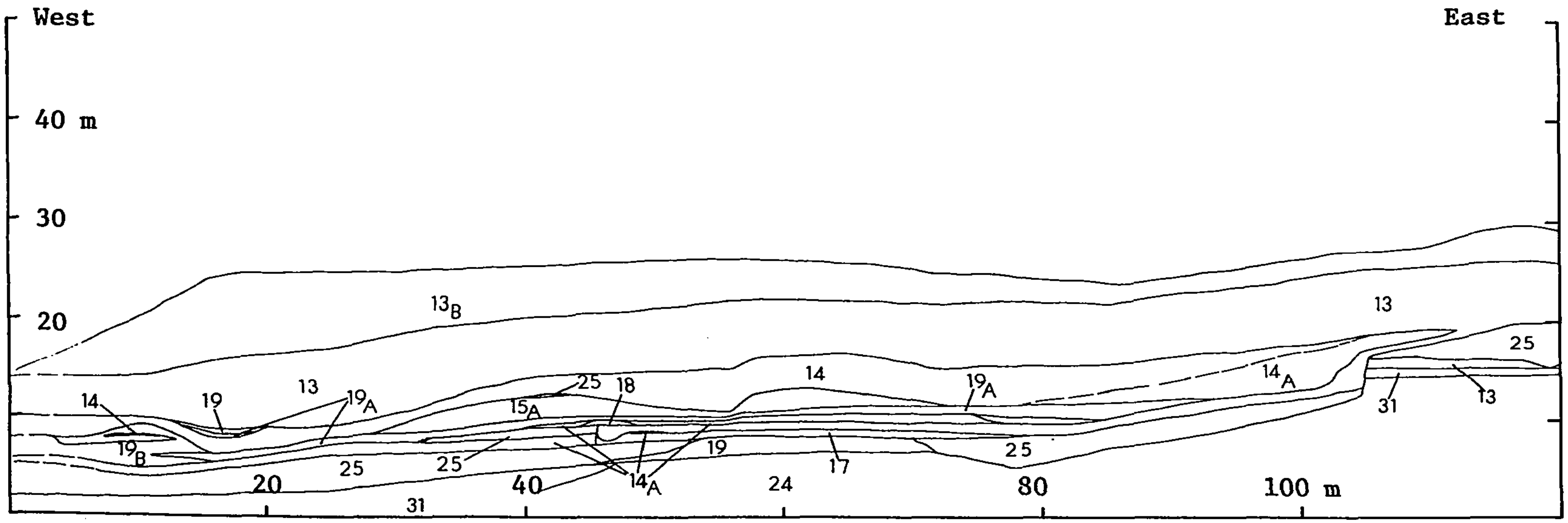
B = Field Camp exposure, along Shell Creek

C = Tensleep Canyon exposure (TC5-77), along Tensleep Creek

D = Tensleep Canyon exposure (TC6-77), along Tensleep Creek

See also Figures 12, 20, 22B, and 25B. For locations see Figures 51, and 53. For key to units see pages 67-68.

A


West
East
40 m
30
20
20
40
80
100 m
13B
13
14
19
19A
19B
25
15A
18
14A
17
24
31

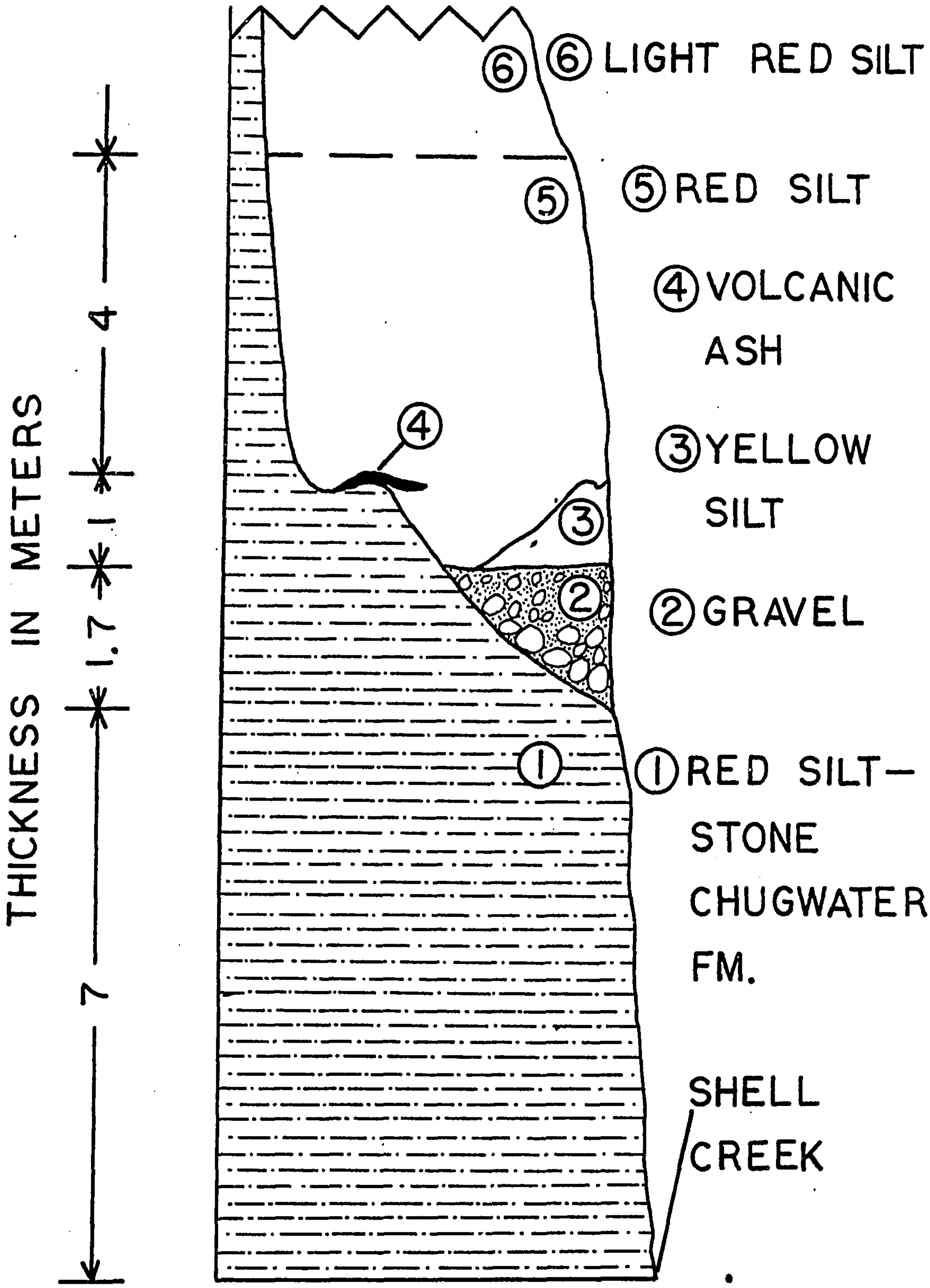
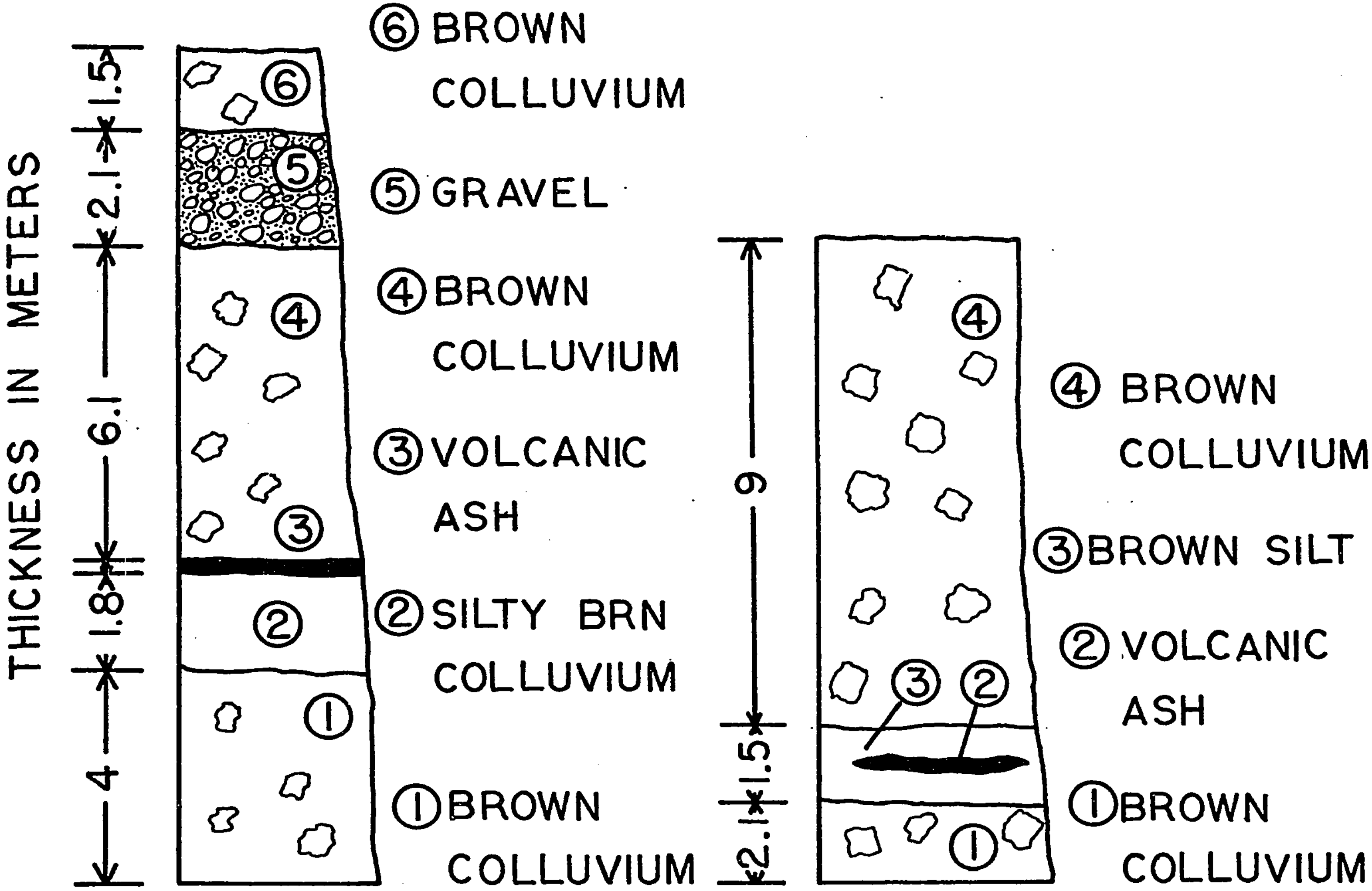


Figure 15. (Continued) B



C

D

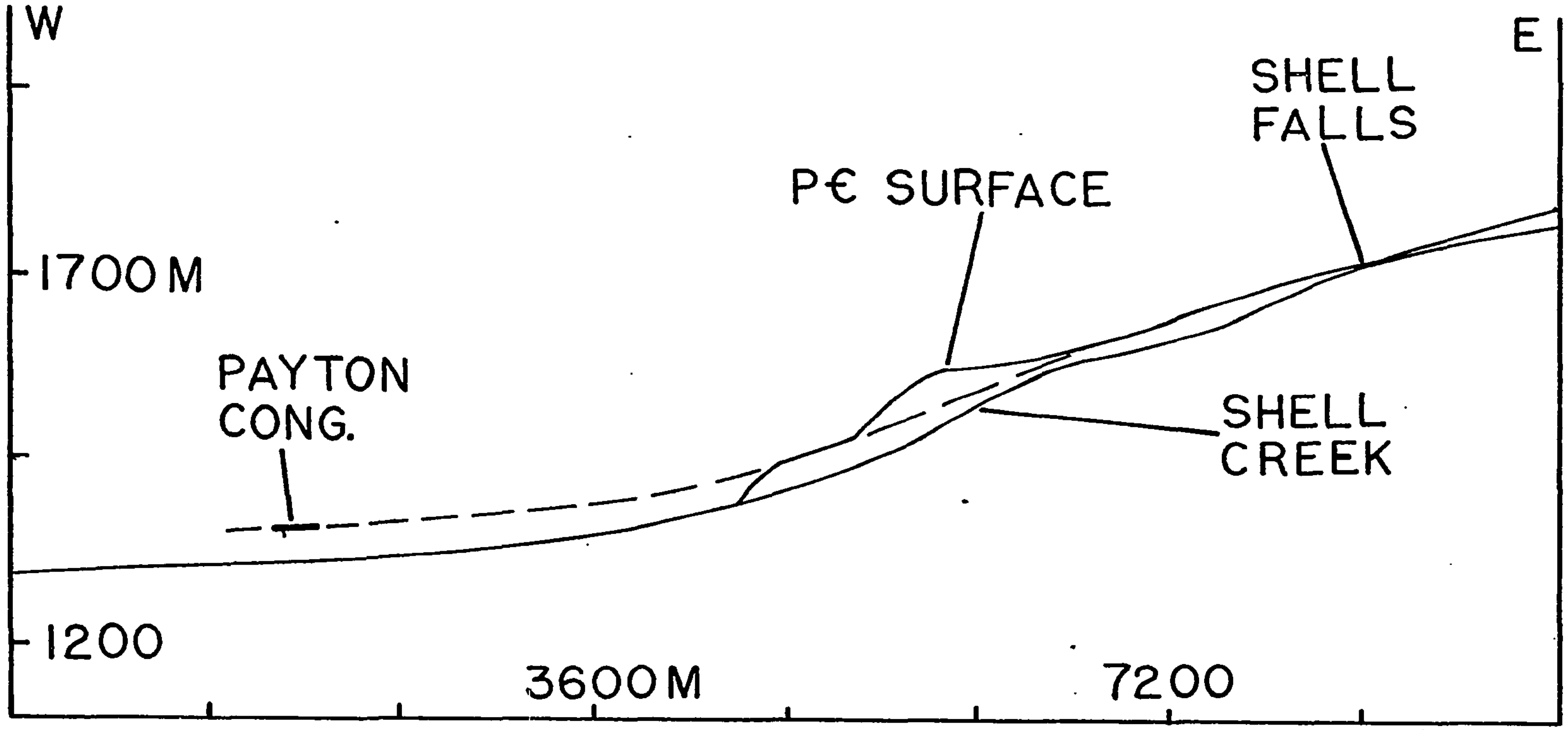
Figure 15. (Continued)

cambrian surface in Shell Canyon into the Bighorn Basin intersects the base of the terrace (Figure 16). This relationship is interpreted to indicate that Shell Creek had cut down to the Precambrian surface within Shell Canyon prior to the deposition of the lowermost ash at the Wagon Wheel and that the base level of Shell Creek was stable in this locality until after the deposition of the uppermost ash. After the deposition of the upper ash Shell Creek again downcut. At this time the inner Precambrian gorge was cut and base level for the landslides was frozen above the first 1.2 kilometers of Shell Canyon (Figure 52).

The youngest terrace deposit associated with volcanic ash is found near the I.S.U. Field Camp (Figure 51). The base of this terrace is only seven meters above the level of the modern Shell Creek, and it contains a single deposit of volcanic ash (Figure 15B). Since this terrace is only 2.4 kilometers from the one at the Wagon Wheel, and is in a topographically lower position, the Field Camp ash deposit must be younger than the three ashes at the Wagon Wheel.

The relative ages of the ashes associated with the landslide and colluvial deposits cannot be determined on the basis of their stratigraphic position as those among the terrace deposits can. The crystalline gravels found in Figures 15C and D and 25B can only be assumed to be Bull Lake or older. They occur topographically above the oldest Pinedale moraines. The ashes in Figures 12, 20, and 22B are found among landslide deposits which have no surface expression. They cannot be independently correlated with other ash deposits.

Figure 16. Profile of Shell Creek and Precambrian surface of Shell Canyon from Shell Falls to the Payton Conglomerate. For location see Figure 51.


W
E
SHELL
FALLS
P€ SURFACE
1700 M
PAYTON
CONG.
SHELL
CREEK
1200
3600 M
7200

In order to be able to correlate the ash deposits in the landslides and colluvial material with those found in the terrace deposits at the Wagon Wheel and the Field Camp, the indices of refraction of the glass shards and the weight loss of ash samples on heating were determined for all known outcrops of ash in the study area. It has not yet been determined whether this technique is applicable outside a local area. However, the technique has the advantage of being both rapid and inexpensive.

Indices of refraction of the glass shards indicate that all ash deposits in Shell and Tensleep Canyons are Pearlette type ashes (Table 4). Unfortunately the Yellowstone Caldera has produced three Pearlette ashes (Izett et al., 1971; Naeser, 1973) and nine younger ash beds (Richmond, 1976).

Table 4. Comparison of indices of refraction of glass shards from ash deposits in Shell and Tensleep Canyons with those of the type Pearlette ash (Swineford and Frye, 1946) and the Bishop ash (Izett et al., 1971)

Shell and Tensleep Canyon ashes	Type Pearlette	Bishop ash
range 1.499-1.50	range 1.498-1.50	range 1.492-1.499
avg. 1.499	avg. 1.499	avg. 1.495-6

The ash samples collected in Shell and Tensleep Canyons plus samples from Lovell and Riverton, Wyoming supplied by Richard Birdseye and classed as Type O Pearlette by Roy Wilcox were dried at 110°C for 24 hours and weighed. They were then heated at 1000°C for 30 minutes, cooled in a desiccator and reweighed. This allowed the calculation of a percent weight loss (Table 5). The fusion temperature at atmospheric pressure was also determined (Table 5). Even though part of the weight loss may result from the loss of volatile elements, K, Na, etc., the losses in the ash samples from the Wagon Wheel and the Field Camp are consistent and reproducible. This is in agreement with the stratigraphic evidence which indicates that the four ash beds must be of different ages. Steen-McIntyre (1975) found that all other factors being equal, the water content of volcanic glass shards increases with increasing age, the weight loss upon heating of the glass shards then will also increase with increasing age. The only problem encountered in using this method occurred in the two lower ash beds at the Wagon Wheel (Figure 15A). The ash in these beds has been nearly completely altered to clay. This evidently produces overlapping weight losses and fusion temperatures. Based on weight loss and fusion temperatures a correlation chart (Figure 17) for the ash deposits was drawn.

The upper ash at the Wagon Wheel correlates with the ash deposit at Lovell, Wyoming which Izett and and Wilcox have informally named the Kane ash (G. A. Izett and R. E. Wilcox, U.S.G.S., Denver, personal communication, 1978). It is classed by them as type O Pearlette of the Midwest. The intermediate ash bed is informally named the Bluejacket ash. The lowest ash at the Wagon Wheel is informally named Dirty Sally's ash (after Dirty Sally's Wagon Wheel Cafe). Dirty Sally's ash and the Bluejacket ash are correlated with the type B and type S Pearlette ashes of the Midwest, respectively, based on their stratigraphic position below the Kane ash.

Table 5. Weight loss on heating in % and fusion temperature of ash deposits in Shell and Tensleep Canyons, Riverton and Lovell[a]

Location	Weight loss %	Fusion temp. in °C
I.S.U. Field Camp	4.68	900-1000
TC 76-1	4.24	900-1000
TC 77-5	4.45	900-1000
RC17-76 Lower Ash at base	8.41	1050+
RC17-76 Lower Ash .66 m above base	9.90	1000-1050
RC17-76 Middle Ash	8.83	1050+
RC17-76 Upper Ash at base	4.65	1000-1050
RC17-76 Upper Ash 1.3 m above base	4.69	1000-1050
RC4-76	4.37	1000-1050
RC8-76	3.91	1000-1050
RC6-76 .3 m above base	3.92	1000-1050
RC6-76 2.6 m above base	5.00	1000-1050
RC6-76 5 m above base	7.83	1000-1050
TC77-6	5.94	1000-1050
Riverton	4.68	1000-1050
Lovell	4.45	1000-1050

[a]For location of ash deposits see Figures 51 and 53.

Figure 17. Correlation chart for ashes in Shell and Tensleep Canyons with the Pearlette ashes of the Midwest. T-C stands for thermal correlation. S-P stands for correlation by stratigraphic position. Date stands for location already dated.

correltion	Lovell	Riverton	TC 76-1	TC 77-5	TC 77-6	Field Camp	RC 8-76	RC 6-76	RC 4-76	RC 17-76
			Tensleep Canyon			Shell Canyon				
?			T-C	T-C		T-C				
Pearlette Type O (0.6 my)	Date				T-C		T-C	T-C	T-C	T-C
Pearlette Type S (1.2 my)										S-P
Pearlette Type B (1.9 my)										S-P

The ash deposit found at the I.S.U. Field Camp is informally referred to as the Field Camp ash. It correlates with two of the deposits of ash found in Tensleep Canyon (Figure 17). Since Pearlette time there have been at least nine different pumice and rhyolite flows deposited in Yellowstone National Park ranging in age from 266,000 years b.p. to 70,000 years b.p. (Richmond, 1976). Any one of these eruptions could be the source of the Field Camp ash. The Field Camp ash in Tensleep Canyon is overlain by crystalline gravel deposits interpreted to be glacial outwash (Figures 15C and 25B). The Pinedale I terminal moraine is at the level of the modern Tensleep Creek. The gravels overlying the ash deposits are 37 meters above stream level. Therefore, the youngest they can be is Bull Lake in age. Pierce et al. (1976) date the Bull Lake in Yellowstone National Park as older than the West Yellowstone Rhyolite flow (114,500± 7,300 years b.p.). This would make the Field Camp ash either 266,000 or 219,000 years old. These are the dates of the next two older ash deposits. However, Richmond (1976) dates the Bull Lake moraines as ranging from pre-West Yellowstone rhyolite (114,500±7,300 b.p.) to post-Pitchstone Plateau rhyolite (70,000 years b.p.). Therefore, no date can as yet be assigned to the Field Camp ash.

Heavy mineral analysis or chemical analysis of volcanic ashes are commonly used as means of correlating ash deposits in the published literature. In the ash deposit at RC6-76 (Figure 20), it was observed in the field that there were alternating layers of coarser and finer ash. Also some individual layers had a noticeably higher content of dark mafic minerals than others. There may be significant variations in the heavy mineral content and chemical composition vertically through an ash bed. This may be due either to changes during the airfall or to the introduction of foreign material during later reworking (R. E. Wilcox, U.S.G.S., Denver, personal communication, 1978). The most useful data for the correlation of ash deposits comes from the microscopic and chemical analyses of each specific primary constituent, not the analyses of the bulk sample. This requires a careful preparation of each sample, including cleaning, gravimetric and magnetic separation to isolate the constituents (R. E. Wilcox, U.S.G.S., Denver, personal communication, 1978). Time did not permit this; therefore, these methods were not used.

Internal Structure of Landslides

Two basic types of material behavior, brittle and plastic, are shown by the internal structures of the landslides in Shell Canyon. The internal structures of the landslides are interpreted from detailed roadlogs of roadcuts in Shell Canyon. Most of the roadcuts appear to be oriented at right angles to the long axis of the landslides. Roadlogs located near the heads of former landslides indicate brittle behavior. Roadlogs indicating plastic behavior are probably located near the toes of former landslides. Analysis of the roadcuts indicate, especially where volcanic ashes are present, that at least three distinct episodes of landslide movement occurred, none of which have any relationship to the present landslide surface morphology.

Where the material is characterized by brittle behavior little internal deformation of the landslide takes place. The word brittle is used here in the sense that deformation is restricted to failure along a few discrete surfaces and the bulk of the deposit is undeformed. This type of behavior is best demonstrated by the roadcut in Figure 23. The key for Figures 18-26 is on pages 67-68. For detailed descriptions see Appendix C. The material in the landslide has moved along the "fault" at 130 meters but the original crude stratification of the brown colluvium has been preserved. In Figure 20 there has been sufficient rotation of the landslide so that the original stratification of the brown colluvium between 120 and 160 meters is nearly vertical but still preserved.

Where bed rock is involved in brittle behavior, the bedding planes of the rock making up the landslide are preserved. This is shown in Figure 21, where the stratification of the shales and sandstones has been rotated but is still intact. This roadcut is located at the base of a bedrock slump. Here, at 80 meters, bedrock has actually been "thrust" out over brown colluvium. The bedrock at 260 to 320 meters in Figure 24 has also remained intact and shows the characteristic backwards rotation of slump.

Where the failure surface of a landslide consists of a zone rather than one distinct surface several different materials may be "sheared" together. This is seen in the western half of Figure 18. The long thin outcrop pattern of many of the bodies of green and brown colluviums indicates that they are being "sheared" along several failure surfaces. A similar pattern is seen in the western half of Figure 26.

Based on these roadcuts it appears that brittle behavior in the form of slumping is characteristic of at least some of the landslides.

Key for Figures 15A and 18-26

No. or symbol	Unit
A	Buried A horizon
1	Brown colluvium
1A	Washed brown colluvium
1B	Very rocky brown colluvium
1C	Brown colluvium with gray M_u boulders
1D	Fine brown colluvium
2	Green colluvium
3	Green shaley colluvium
3A	Green bouldery colluvium
4	Mixed green and brown colluvium
5	Brown silt
5A	Brown silt with pebbles
5B	White silt
6	Dark brown silt
7	Gray silt
8	Orange gravel
9	Cobble size M_u fragments in a gray silt matrix (50-50)
10	A horizon
11	C_{Ca} horizon
11A	C_{Ca} horizon poorly developed
12	Red colluvium
13	Red silt
13A	Light red silt
13B	Red silty gravel
13C	Massive sandy silt
13D	Red silt
14	Volcanic ash
14A	Ash-lithified

14B	Ash-slightly lithified
14C	Volcanic ash
15	Ashy silt
15A	Ashy sand
16	Yellow silt
17	Olive sand
18	Sand
19	Gravel
19A	Gravely sand
19B	Sandy gravel
20	Interbedded green shale and sandstone
20A	Interbedded green shale and sandstone-strongly oxidized
21	Green sandstone
21A	Green shale
22	Brown sandstone
22A	Shattered brown sandstone
22B	White sandstone
23	Red sandstone
24	Red siltstone
25	Conglomerate
25A	Conglomerate
25B	Sandstone
26	Modern slump
27	Talus deposits
28	Gros Ventre-Gallatin Formation
28A	Highly fractured Gros Ventre-Gallatin Formation
30	Igneous and metamorphic clast gravels
31	Limestone
O_B	Bighorn Fm. rock fragments
M_u	Madison Fm. rock fragments

Figure 18. RC1-76. The westernmost half of RC1-76 shows material in the process of being mixed together. Here at least eight different types of colluviums and silts form a complex association. The long thin shape of many of the deposits indicates that they are being sheared together. This situation would exist if the failure surface of a landslide consisted of a zone of several failure surfaces rather than one discrete failure surface. Or if during several periods of movement of the landslide different failure surfaces had formed. For location see Figure 51.

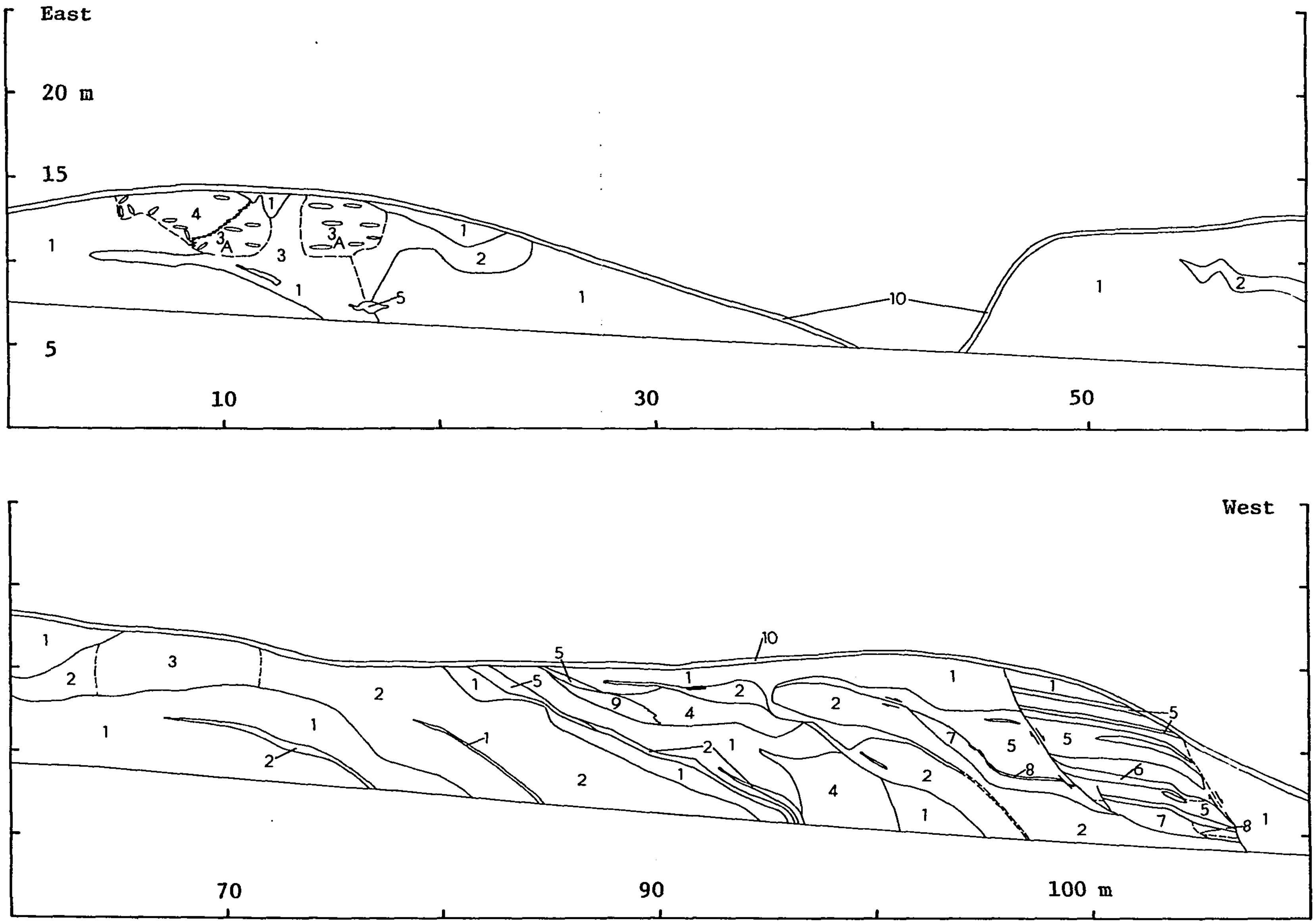

East
20 m
15
5
10
30
50
West
70
90
100 m

Figure 19. RC2-76 and Rc3-76.

A. The deposits here are not extensive enough to enable any detailed structures to be worked out. The silts appear to be a series of deposits filling in a depression on the surface of a landslide. For location see Figure 51.

B. The brown colluvium both above and below the bedded brown silts shows no apparent stratification; however, the brown silts are not deformed. Possibly, the silt accumulated in a closed depression on the surface of a debris slide and was covered by a later debris slide in which the green colluvium formed the failure surface. Each end of the silt deposit has been terminated by faults formed during a later period of movement. For location see Figure 51.

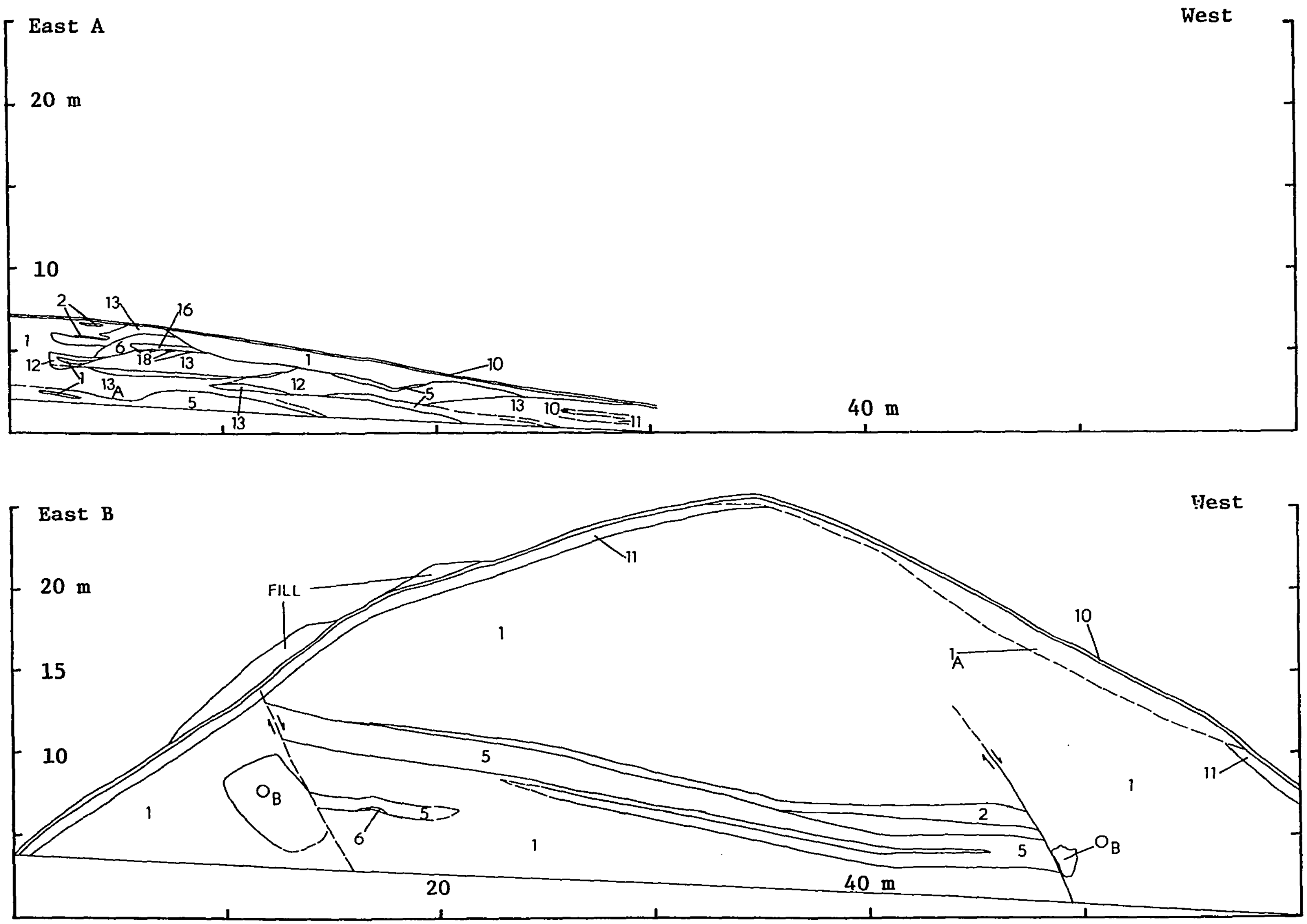
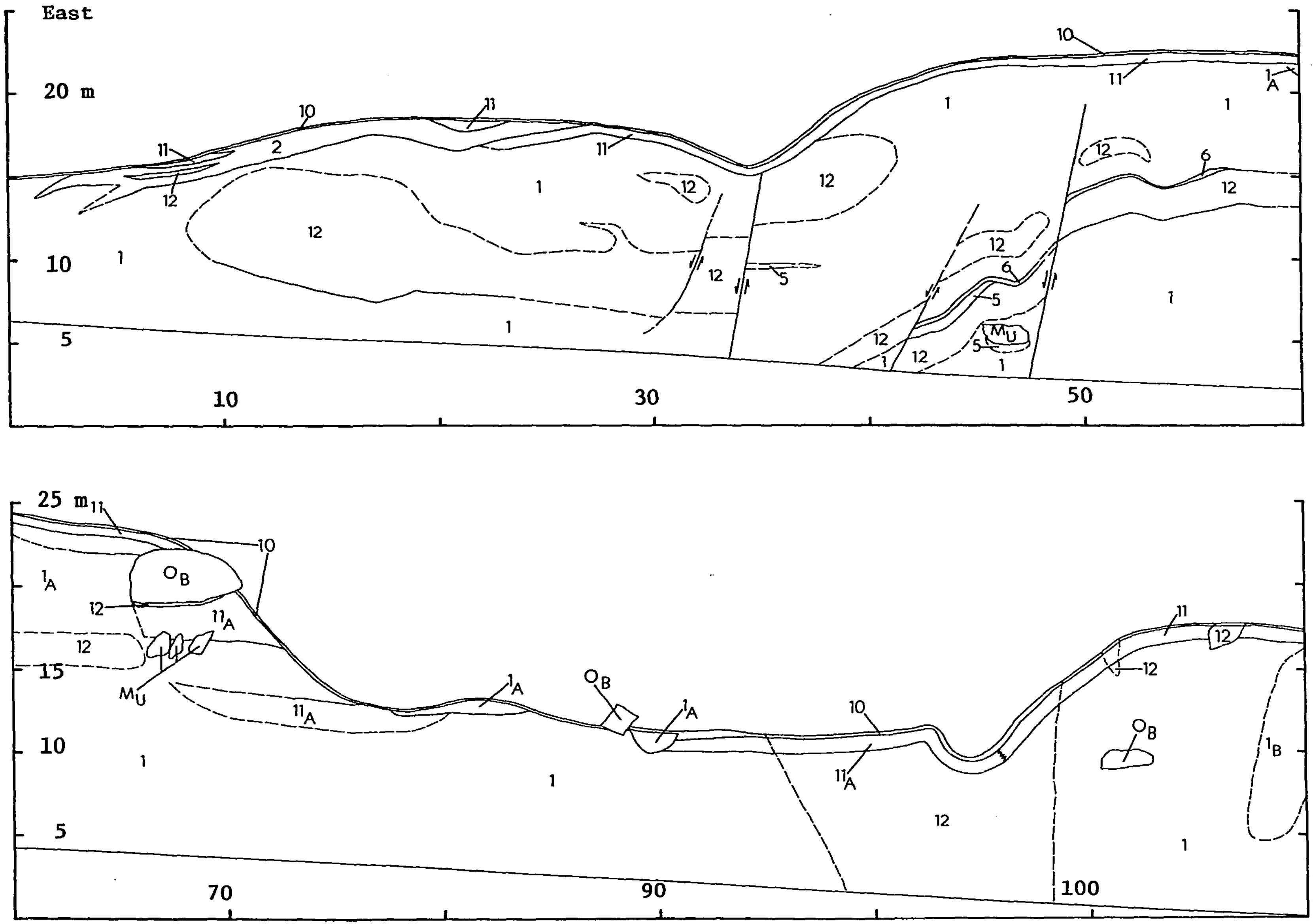

East A
West
20 m
10
40 m
1
2
6
10
11
12
13
13A
16
18
5
East B
West
20 m
15
10
20
40 m
FILL
1
1A
2
5
6
10
11
O_B

Figure 20. RC5-76. The material in this roadcut shows a complete range from rigid to plastic behavior. West of 160 meters there is no apparent stratification in the brown colluvium, and the green colluvium at 220 meters has a highly contorted contact with the brown colluvium indicating a plastic behavior. Between 120 and 160 meters the material is crudely stratified but the stratification is nearly vertical. The failure surface for this landslide is in the green colluvium located at 120 meters. Clasts of flat pebble conglomerate are aligned parallel with the contacts between the green and brown colluviums. The material between 120 and 160 meters has been rotated by a later movement; the ash bed is now dipping at approximately 45°. This later period of movement would account for the steeply dipping stratification of the ash bed. For location see Figure 51.


East
20 m
10
5
10
30
50
25 m
15
10
5
70
90
100
1
2
5
6
10
11
12
1_A
1_B
11_A
O_B
M_U

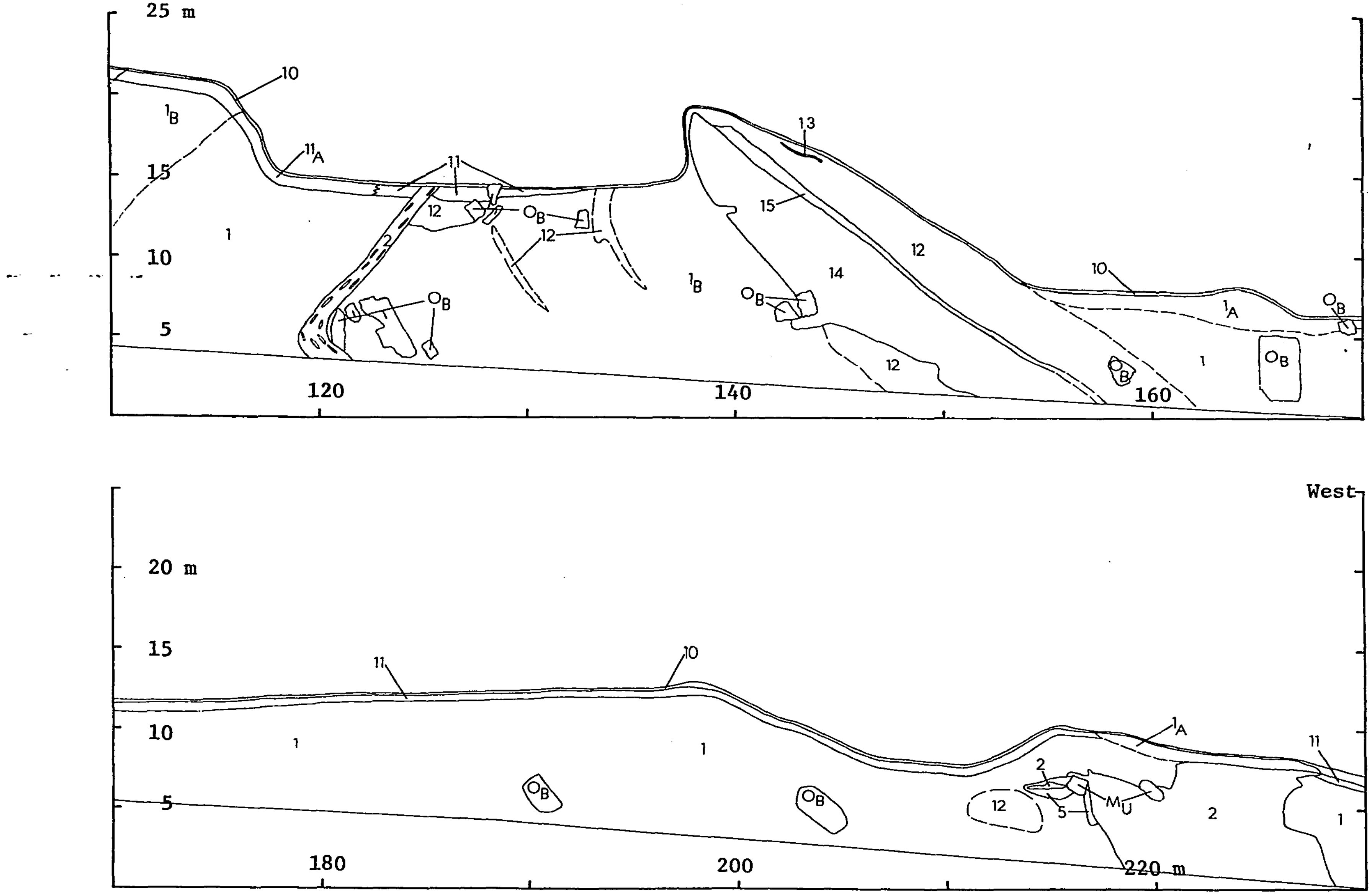


Figure 20. (Continued)

Figure 21. RC6-76. Part of the toe of a bedrock slump is still intact. Since the bedding in the westernmost 30 meters of the roadcut is intact the landslide must have moved as a rigid body along a discrete shear surface. This is further substantiated by the fact that at 80 meters intact bedrock has been "thrust" out over brown colluvium. For location see Figure 51.

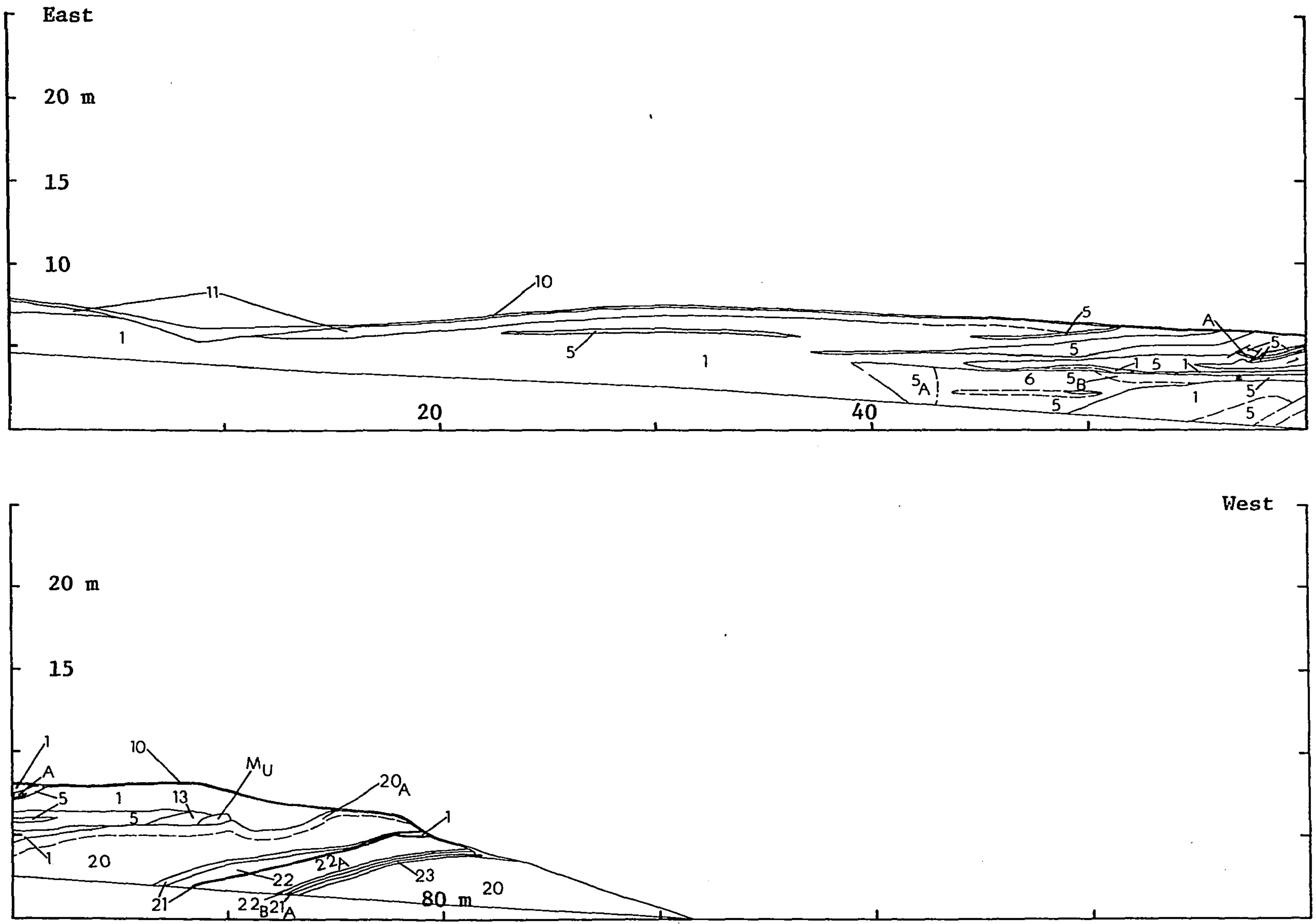
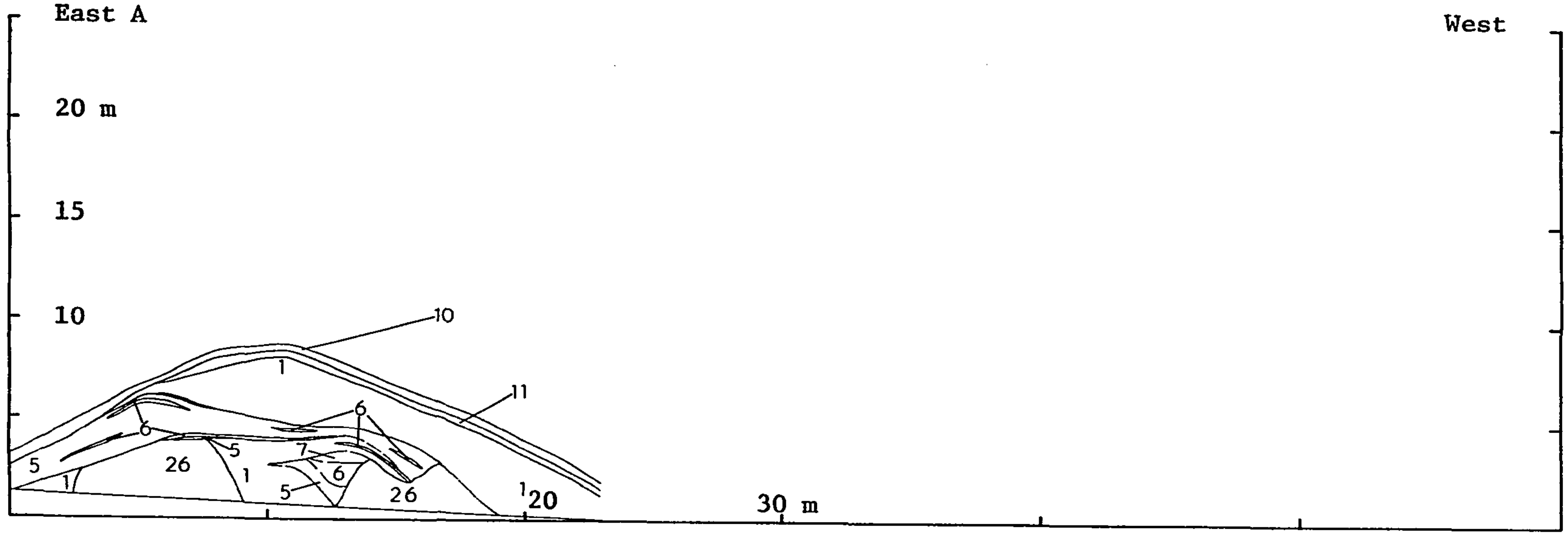

East
20 m
15
10
20
40
West
20 m
15
80 m
Mu
20A
22A
22B
21A
5A
5B

Figure 22. RC7-76 and RC8-76.

A. While creep phenomena are not covered in this dissertation they are exhibited in this roadcut. Clasts of limestone in the A horizon of the modern soil profile are aligned parallel with the modern ground surface. The silt beds at each end of the cut are inclined parallel with the modern ground surface. The upper surfaces of these silt beds would have been horizontal when they accumulated. For location see Figure 51.

B. The ash deposit has been highly contorted in the westernmost ten meters of the roadcut. In the eastern twenty meters the ash and brown silts have been contorted to a lesser degree. There is no apparent bedding the brown colluvium. For location see Figure 51.


East A
West
20 m
15
10
20
30 m
10
11
1
6
5
26
7

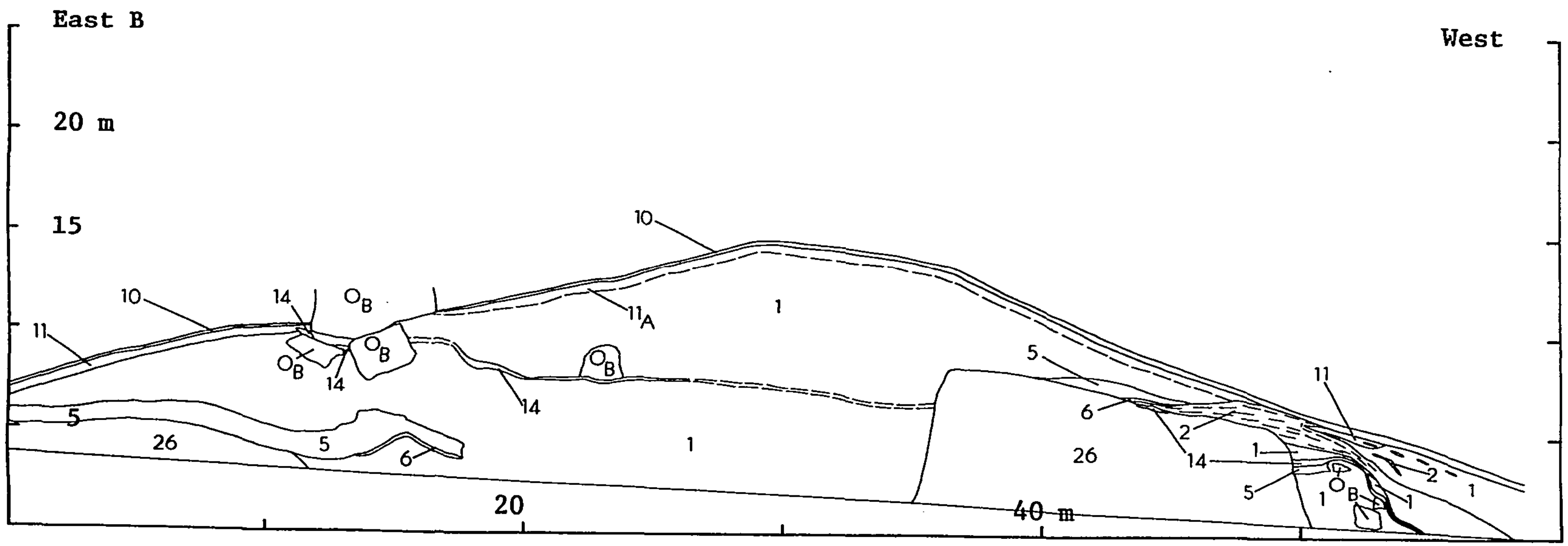

East B
West
20 m
15
20
40 m
10
11
11A
14
OB
1
5
26
6
2

Figure 23. RC10-76. In colluvium, near the head of a slump, no internal deformation takes place. The original crude stratification of the colluvium has been preserved. At least one period of slumping has occurred along the "fault" at 130 meters with no apparent internal deformation of the slump block on the west side of the fault. For location see Figure 51.

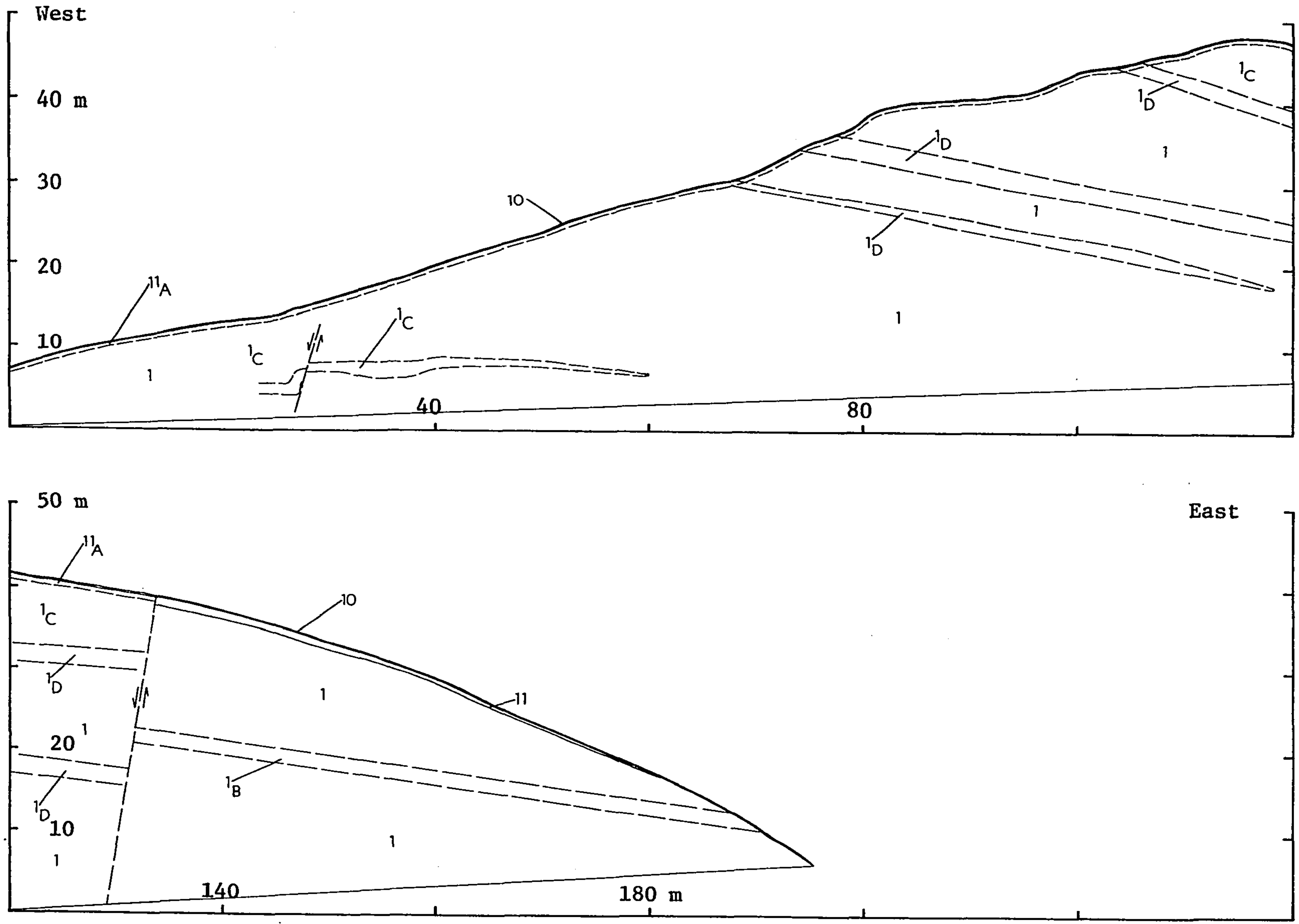
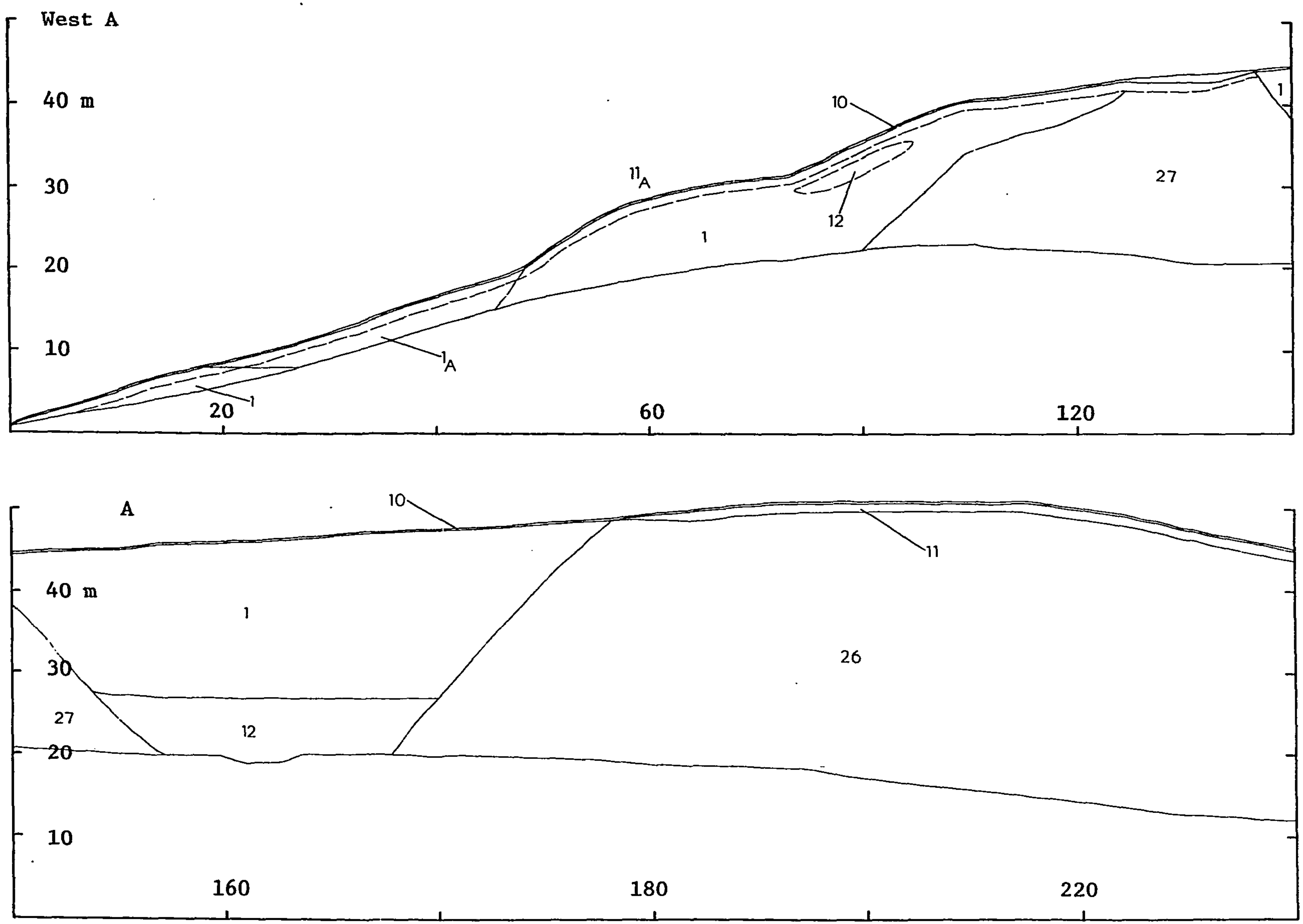

West
40 m
30
20
10
11A
10
1C
1D
1
40
80
50 m
East
11
1B
140
180 m

Figure 24. RC12-76 and RC13-76.

A. Most of this roadcut is covered by modern slump deposit. However, the bedrock exposed from 260 to 320 meters shows the backwards rotation characteristic of slump deposits. For location see Figure 51.

B. The highly contorted nature of the contact between the green and unstratified brown colluvium indicates that the green colluvium was flowing plastically and that the two were in the process of being mixed together. For location see Figure 51.


West A
40 m
30
20
10
10
11A
12
1
27
1
1A
1
20
60
120
A
10
11
40 m
1
26
30
27
12
20
10
160
180
220

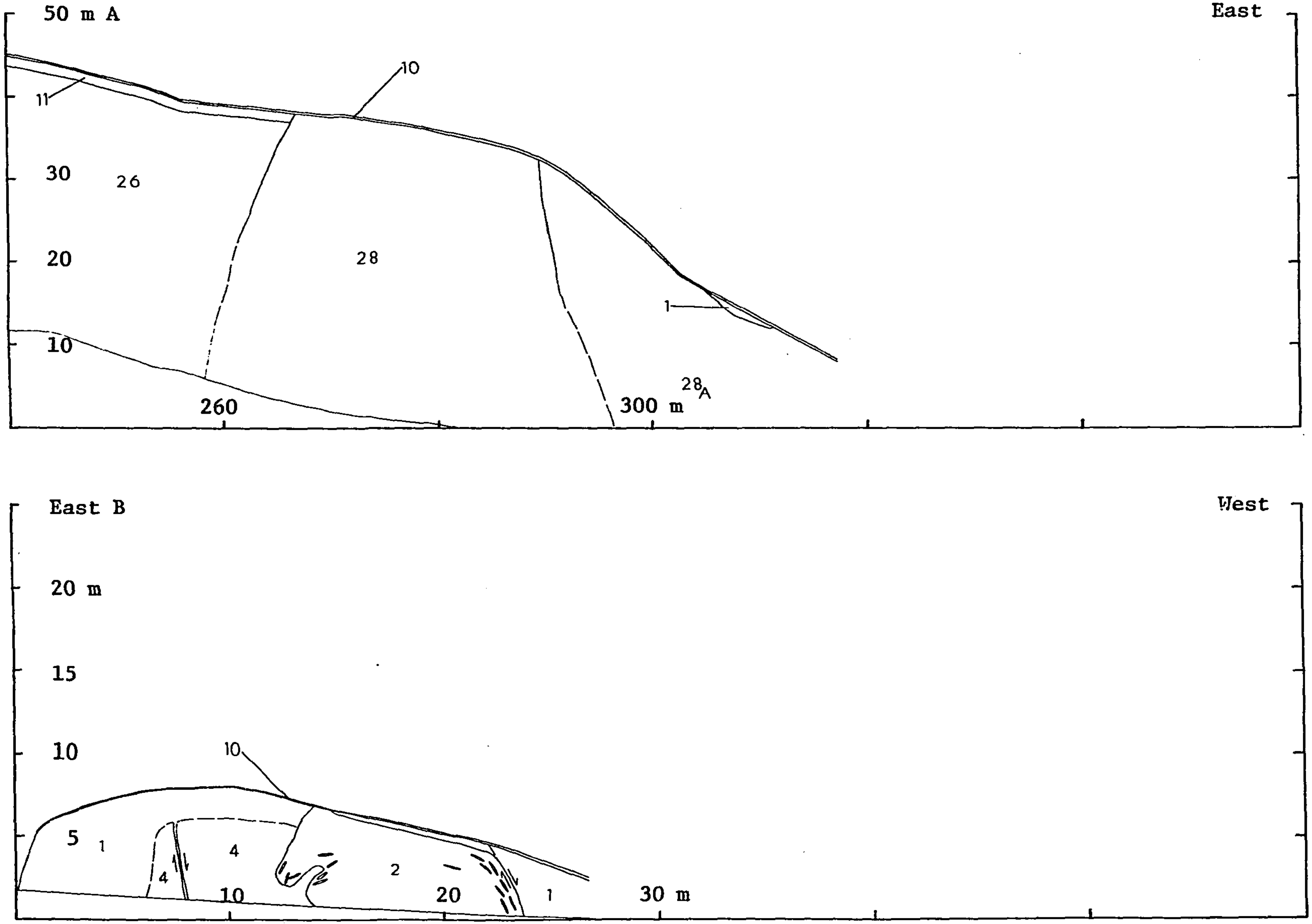
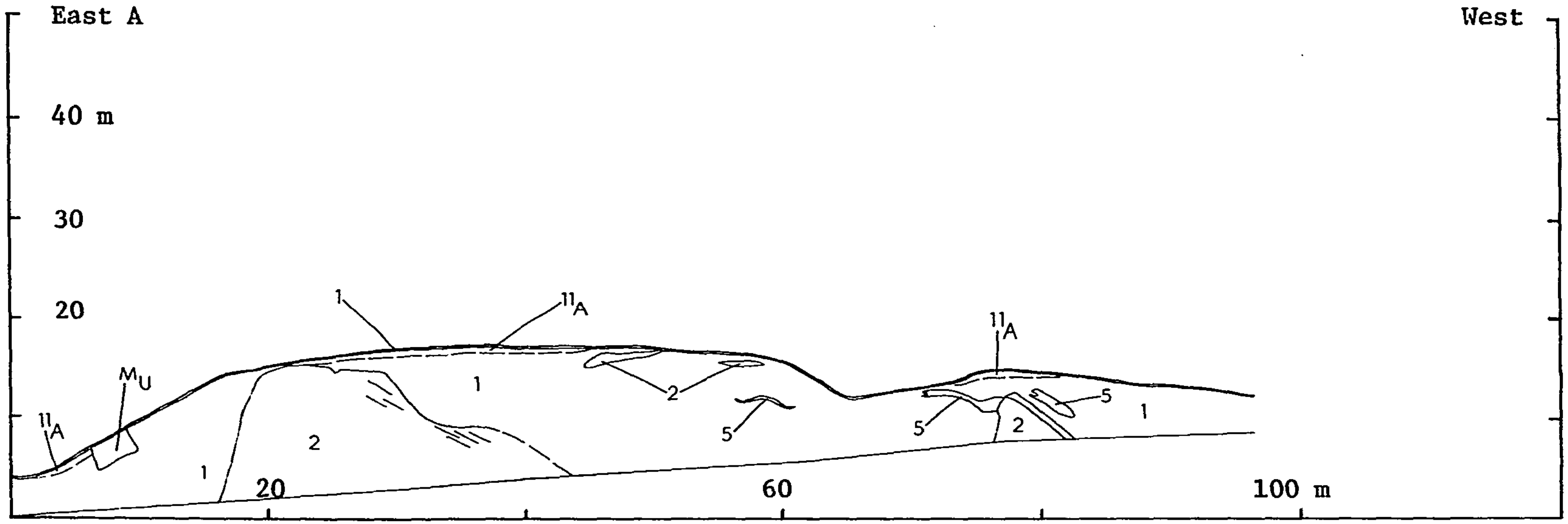


Figure 24. (Continued)

Figure 25. RC15-76 and TC76-1.

A. The highly contorted nature of the contact between the green and unstratified brown colluvium indicates that the green colluvium was flowing plastically and that the two were in the process of being mixed together. For location see Figure 51.

B. Shows cross cutting relationship between crystalline gravels and volcanic ash deposit. For location see Figure 53.


East A
West
40 m
30
20
20
60
100 m
1
11A
11A
11A
MU
1
2
1
2
5
5
5
2
1

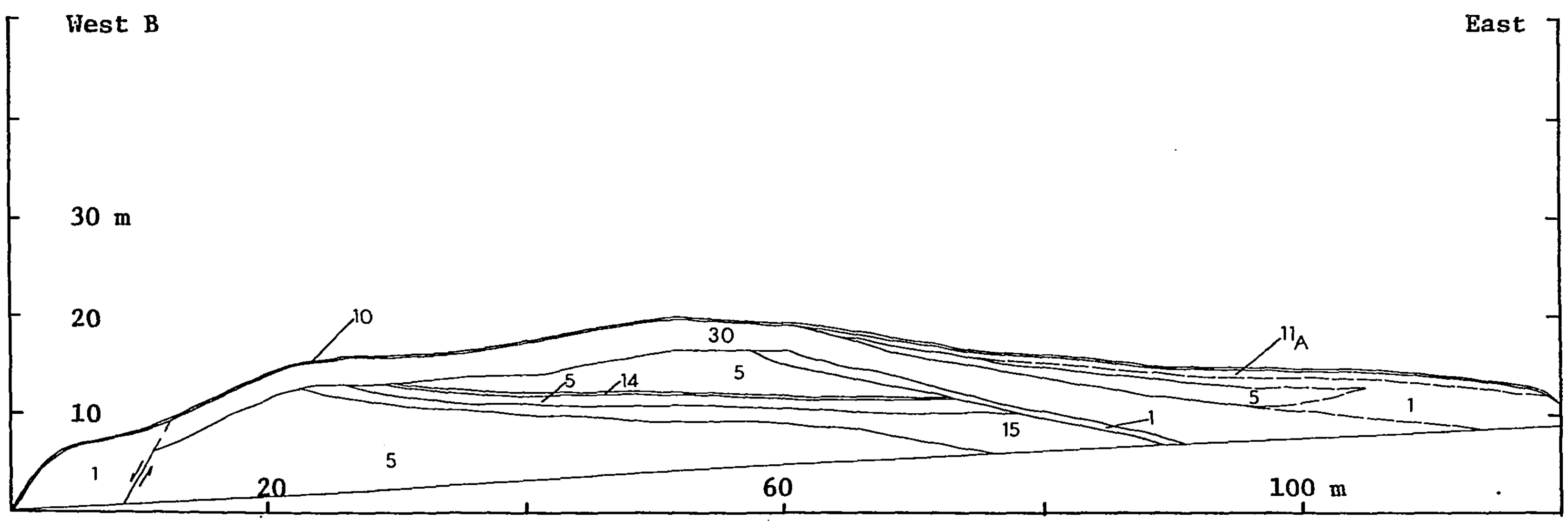
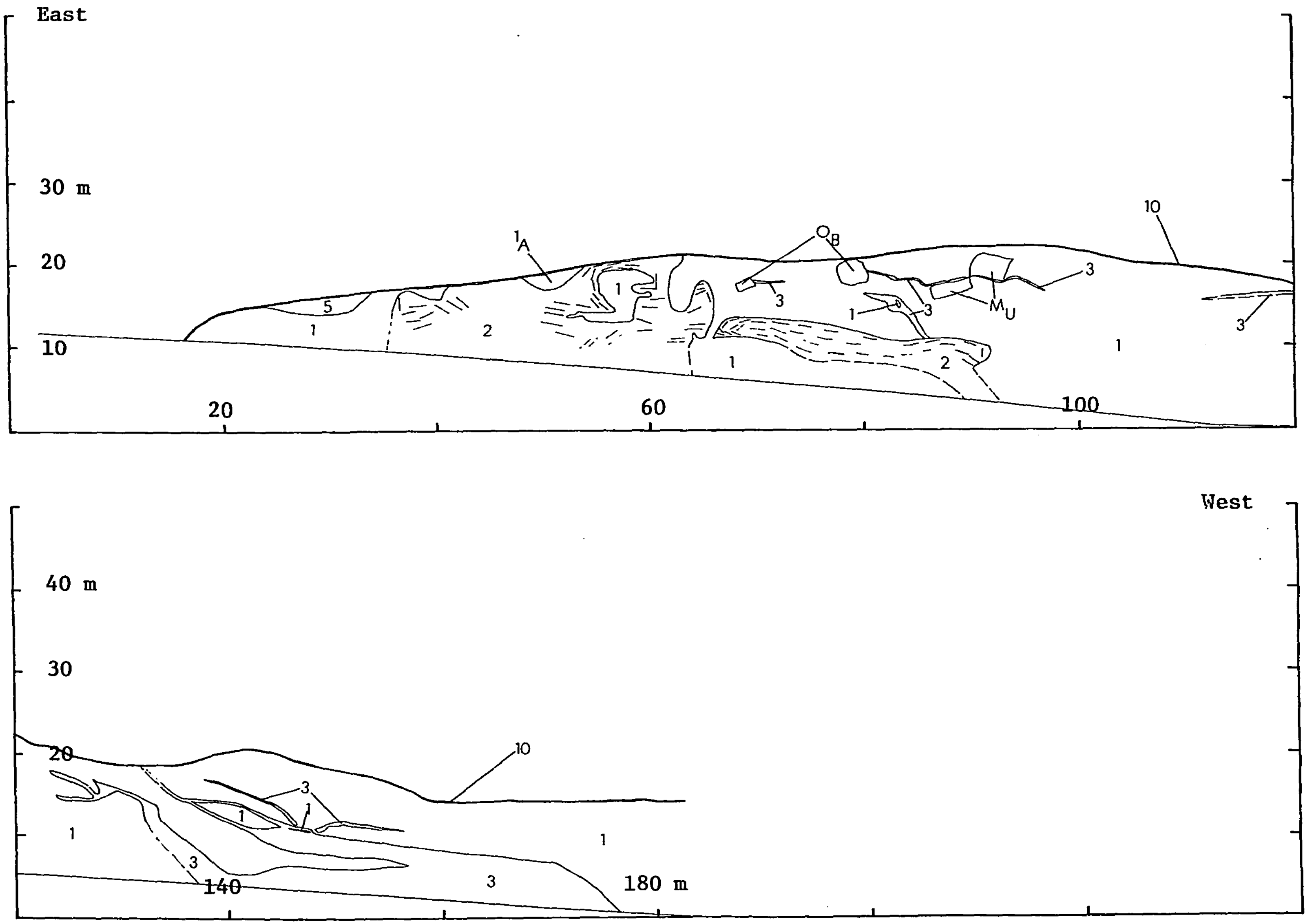

West B
East
30 m
20
10
20
60
100 m
10
30
5
14
5
11A
5
1
1
15
1
5

Figure 26. RC16-76. The highly contorted nature of the contact between the green and unstratified brown colluvium indicates that the green colluvium was flowing plastically and that the two were in the process of being mixed together. For location see Figure 51.


East
30 m
20
10
20
60
100
1A
OB
10
3
5
1
2
MU
West
40 m
30
20
10
3
1
140
180 m

The slumps undergo little internal deformation and original bedding is preserved within the landslide.

When the material is characterized by plastic behavior extreme internal deformation takes place. The word plastic is used here as it is defined in the A.G.I. GLOSSARY OF GEOLOGY (Gary et al., 1974) as:

> Plastic (struc) Said of a body in which strain produces continuous, permanent deformation without rupture.

Where brown colluvium behaves as a plastic substance no stratification is preserved as shown by the roadcuts in Figures 12, 19B, and 22A. The brown colluvium in these exposures has no observable stratification. It is presumed that many of these roadcuts are located near the toes of former landslides; many slumps grade into debris slides at their toes (Varnes, 1958). In this area, plastic behavior rather than brittle would dominate due to an increase in water content of the material.

Where green and unstratified brown colluvium occur together the green colluvium frequently appears to have "intruded" into the brown (Figures 8 - easternmost 90 meters, 20 - 220 meters, 24B, 25A, 26 - easternmost 100 meters). The contacts between the green and brown colluviums are highly irregular. Where clasts of flat pebble conglomerate occur in the green colluvium they are usually aligned parallel with the contacts.

The origin of these "intrusions" is at best speculative. The density of the unstratified brown colluvium averages 1409 kg/m^3 and for the green 1569 kg/m^3. Therefore, the green colluvium did not intrude the brown in a manner similar to a salt dome. During the final stages of a compound slump-debris slide, that is slump at the head and debris slide at the base, movement should cease first near the toe due to decreased slope angle and loss of water. The material behind the toe will still be moving. This causes the area immediately behind the toe to be under compressional stress. Green colluvium has 0 cohesion when saturated and could easily be made to flow. If the landslide consists of brown colluvium overlying green colluvium it is possible that the green colluvium has been forcefully intruded upwards into the brown colluvium in response to this compressional stress.

The relationship between the volcanic ash deposits and the landslide debris exposed in the roadcuts indicates at least two periods of landslide activity prior to the ash deposition, and one post-deposition period. None of the associated landslide deposits have any relationship to the present landslide surface morphology. In Figure 22B the ash at 50 meters lies directly on bedded pond silts. This relationship indicates that a period of landsliding followed by stability occurred prior to the deposition of the ash. Silts of similar texture are accumulating in the closed depressions on modern landslides. The ash deposit in Figure 20 rests directly on brown colluvium. This ash bed is located on the south side of Shell Canyon (Figure 51) where it could only be preserved if it had fallen into a closed depression on the surface of a landslide. Because neither pond silts nor evidence of soil formation exist in the colluvium at the base of the ash, the landslide and the deposition of the ash bed are considered to be essentially contemporaneous. The landslide was probably triggered by the earthquakes which were generated by the same volcanic eruption that produced the ash.

Both ash beds have been contorted by subsequent landslides. This probably did not occur immediately after the deposition of the ash, since the ash in Figure 20 is overlain by pond silts which indicate a period of stability after deposition of the ash.

Activity of Landslides in Shell and Tensleep Canyons

The landslides in Shell and Tensleep Canyons which still have a surface expression have been classified into a series of morphostratigraphic units (Figures 52 and 54). This classification is based only on surface morphology. It does not distinguish landslides on the basis of type of movement or type of material within the landslide. This classification uses three broad subdivisions. In order of increasing relative age, they are active, passive, and inactive. Passive and inactive have in turn been subdivided into a total of six units based primarily on the state of preservation of closed depressions on the surface of the landslides.

Active landslide

An active landslide is moving at the present time. It has both a despositional and an erosional surface morphology. A hummocky surface with numerous closed depressions that commonly contain water characterize the depositional areas. In the source areas fresh scarps are present. Vegetation is poorly established throughout. Large areas of bare earth are common. Springs and seeps are common.

Passive landslide

A passive landslide is no longer moving downslope. The depositional area is still characterized by a hummocky surface. However, closed depressions show at least some evidence of being filled. In the source area the scarp has only been slightly modified by erosion. Vegetation is well established on the landslide but areas of bare earth still exist. Springs and seeps may be present.

Passive-1 landslide A passive-1 landslide has been stable for a short period of time. It has a hummocky surface morphology with greater than 1% of total surface area in closed depressions, some of which contain water. All closed depressions display some evidence of being filled with sediment.

Passive-2 landslide In a passive-2 landslide closed depressions still occupy more than 1% of the surface area. However, they are almost completely filled with sediment and contain water only seasonally.

Passive-3 landslide Here closed depressions occupy less than 1% of the surface area. These are almost completely filled with sediment and contain water only seasonally.

Inactive landslide

An inactive landslide is no longer moving downslope. In the depositional area no closed depressions remain. In the source area the scarp has been severely eroded. Vegetation is well-established on the landslide and areas of bare earth are rare. Springs and seeps are rare.

Inactive-1 landslide No closed surface depressions remain. In the source area the scarp has been severely eroded but is still easily recognizable as such.

Inactive-2 landslide No closed depression remains. The surface morphology consists of a series of benches and/or small hills. In the source area the scarp has been so severely eroded that it is difficult to recognize as such.

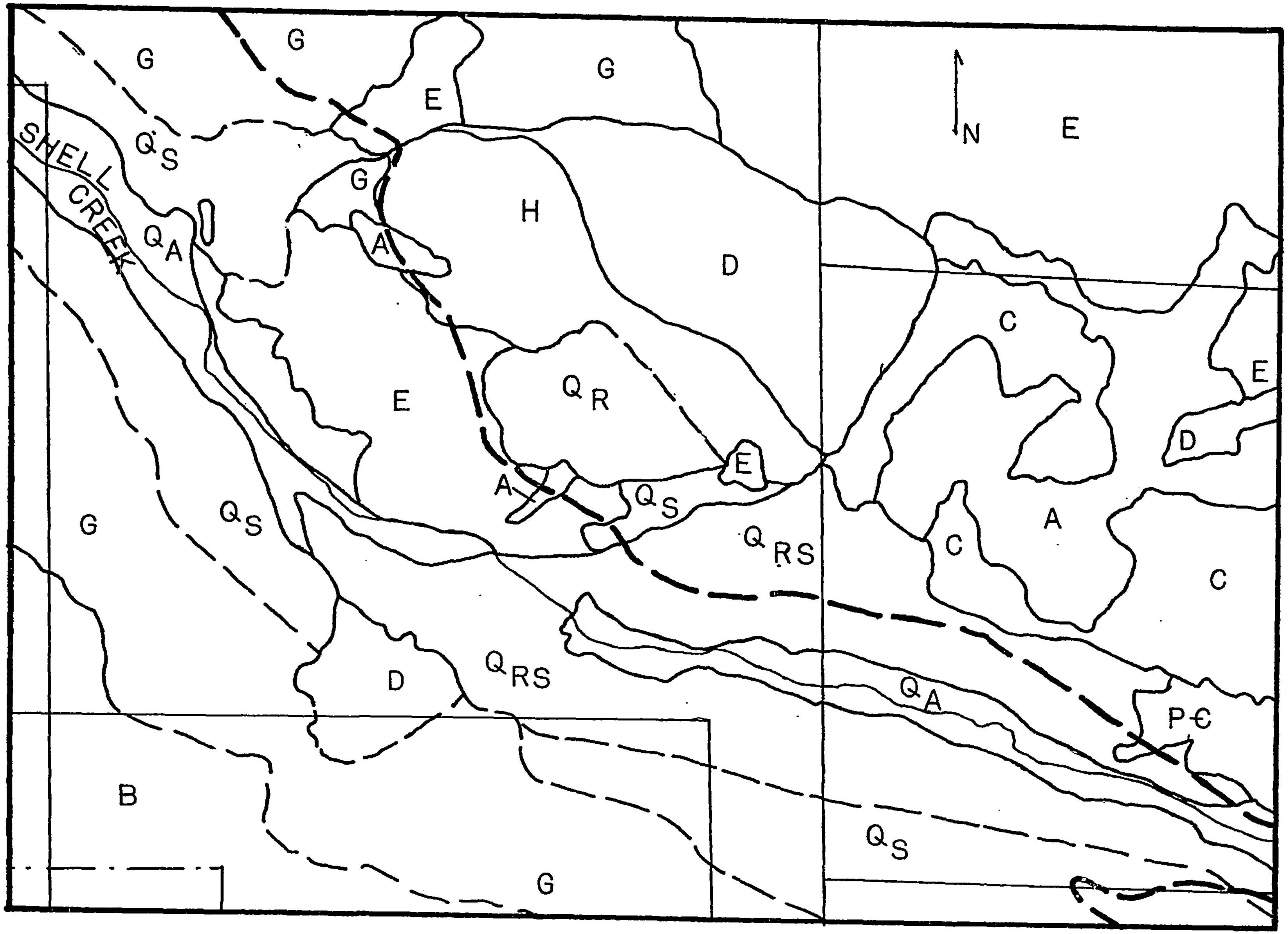
Inactive-3 landslide An inactive-3 landslide has no recognizable landslide morphology remaining.

In Shell Canyon at the eastern margin of the study area (Figure 51), the glacial moraines of the Shell Creek Glacier and the surficial landslides display cross-cutting relationships (Figure 27). These relationships allow the correlation of the landslide morphostratigraphic units with the glacial chronology. Inactive-3 landslides are overlain by the Ruble Creek moraine and are thus at least pre-Bull Lake II in age. The Shell Creek moraine overlies both inactive-2 and inactive-1 landslide deposits indicating they are both pre-Bull Lake I in age. Passive-3 landslides cut out the Shell Creek moraine and are in turn cut out by the Ranger Station moraine. This indicates that passive-3 landslides are post-Bull Lake pre-Pinedale in age. Passive-2 landslides cut out the Ranger Station moraine and are thus post-Pinedale I in age. Farther up the canyon the passive-2 landslides are cut out by the Crooked Creek moraine indicating they are pre-Pinedale II in age. Passive-1 and active landslides must both be post-Pinedale II in age. Passive-1 landslides are tentatively classed as pre-Pinedale III age landslides. The same sequence of landslide deposits and glacial moraines has been observed in Tensleep Canyon. These cross-cutting relationships indicate that there was a period of landslide activity preceding each recognizable advance of the Shell Creek Glacier.

Figure 27. Map showing cross-cutting relationships between moraines and landslide deposits. - - - - Hyattville Road. For location see Figure 51.

A = active landslides
B = talus deposits
C = passive-1 landslides
D = passive-2 landslides
Q_{RS} = Ranger Station Moraine
E = passive-3 landslides
Q_S = Shell Creek Moraine
F = inactive-1 landslide
G = inactive-2 landslide
Q_r = Ruble Creek Moraine

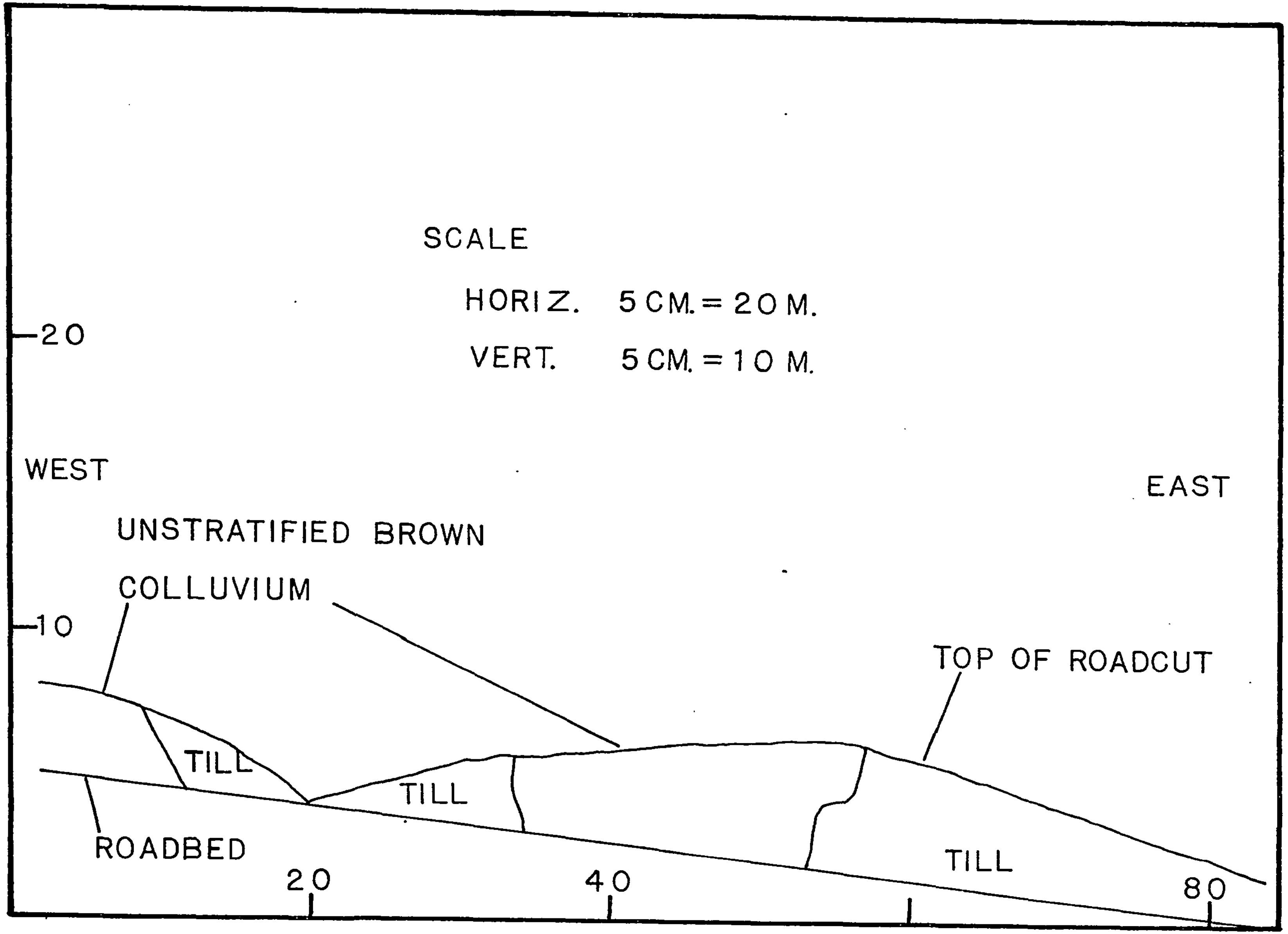
0 Scale 1 KM


SHELL CREEK
N
G
E
H
D
C
A
B
QS
QA
QR
QRS
P-Є

The short duration of time between landslides and the subsequent glacial advance is indicated by the analysis of a roadcut through the Shell Creek moraine and an adjacent landslide deposit (Figures 51 and 28). There are no paleosols between the landslide deposits and the glacial till. The contact between the landslide debris and the till in the westernmost twenty meters of Figure 28 is sharp. The glacial till consists of crystalline cobbles and boulders in a sandy matrix. The sand consists of fragments of quartz and feldspars. The landslide debris consists of the unstratified brown colluvium previously described. There are no carbonate rock fragments from the brown colluvium mixed into the glacial till. Therefore, the glacier was not eroding material at this point. If there had been sufficient time for the formation of a soil profile on the landslide debris evidence of it would be preserved. There is none and it is concluded that landslide activity immediately preceded each glacial advance and is thus early glacial in age. If the landslides are early glacial in age, it can be assumed that the slopes are relatively stable during interglacial time.

It is unlikely that there was any landslide activity triggered by the periodic retreat of the Shell Creek Glacier. The Shell Creek Glacier was relatively feeble and incapable of doing extensive erosion (Darton, 1906). Bull Lake and younger moraines were deposited on or near the Precambrian surface at the bottom of the canyon. Thus, the glaciers did not deepen and oversteepen the valley so that slopes would become unstable upon retreat of the ice as may have happened in many other areas of the western U.S.

Figure 28. RC18-77. Westernmost twenty meters show relationship of Shell Creek moraine overlying landslide deposits (unstratified brown colluvium). Easternmost 60 meters of roadcut indicate unstratified brown colluvium has been intruded into the Shell Creek moraine but there is no evidence here of "mixing" either. The contact between the two materials is sharp. For location see Figure 51.


SCALE
HORIZ. 5 CM. = 20 M.
VERT. 5 CM. = 10 M.
20
10
WEST
EAST
UNSTRATIFIED BROWN
COLLUVIUM
TOP OF ROADCUT
TILL
TILL
TILL
ROADBED
20
40
80

The terminal moraines for each of the last four glacial advances, Bull Lake through Pinedale III, are found at successively higher elevations than the one proceeding it, in both Shell and Tensleep Canyons. This relationship indicates that each of the last four glacial advances has been less extensive than the one proceeding it. If the landslide activity is related to the same climatic changes that triggered the glacial advances then the landslides of each age should have a similar systematic distribution in space.

The activity classes of the landslides in both Shell and Tensleep Canyons are systematically distributed in space. Older landslides, inactive-1 and 2, are found in the lower portions of each canyon (Figures 52 and 54) and the landslides become progressively younger with increasing elevation. Other than the landslides triggered by highway construction, the only active landslides are found in the higher, presently moister areas of each canyon. It is also apparent that even though large areas of the canyons have undergone landsliding in the past only relatively small areas are active at the present time. It thus appears that the area affected by landslide activity has both decreased in area with each glacial advance and has occurred at progressively higher elevations. During the interglacial (post-glacial) interval, landslides are restricted to local areas of greater than average moisture. The distribution of the landslide activity classes is thus compatible with the distribution of glacial deposits. Detailed mapping of the landslide deposits in select areas yields a similar distribution.

The surface morphologies of landslide deposits were mapped in detail in three small drainage basins, Post Creek, Grouse Creek, and Salt Creek (Figure 51). If the landslide history of Shell Canyon is indeed characterized by alternating periods of stability and instability then there should be a systematic distribution of landslide deposits of different ages (surface morphologies). If not, then the ages of the landslide deposits should be randomly distributed.

At Post Creek (Figures 29 and 51) the original widespread pre-Bull Lake slump blocks (G1 and G2) have partially disintegrated and partially been buried by smaller and younger slumps, first by slumps F3 during later pre-Bull Lake time. During post-Bull Lake-pre-Pinedale I time small slumps (E4 and E5) progressively buried the older deposits. The pre-Pinedale I deposits were then partially buried by post-Pinedale II age talus. Post Creek is located downstream from the Precambrian surface (Figure 52), and landslides could have been initiated by base level changes of Shell Creek.

In the Grouse Creek area, older pre-Bull Lake age slump blocks (G2 and G3) have again been partially disintegrated and buried by younger landslides, first by Pre-Bull Lake slumps (F4 and F5) (Figures 30 and 51). The pre-Bull Lake slumps were also partially buried by post-Bull Lake-pre-Pinedale I debris slides (E6). Between post-Pinedale I and pre-Pinedale II time the Grouse Creek debris slides (E6) were partially reactivated (D7) and the pre-Bull Lake slumps continued to disintegrate (D7). During post-Pinedale II time there was only a small area of renewed activity (C8) which in turn has been partially buried by post-Pinedale II

Figure 29. Detailed landslide activity map of Post Creek. For location see Figure 51. Contour interval is 61 meters.

B6 = post-Pinedale II age talus

E5 = landslide deposits

E4 = landslide deposits

F3 = landslide deposits

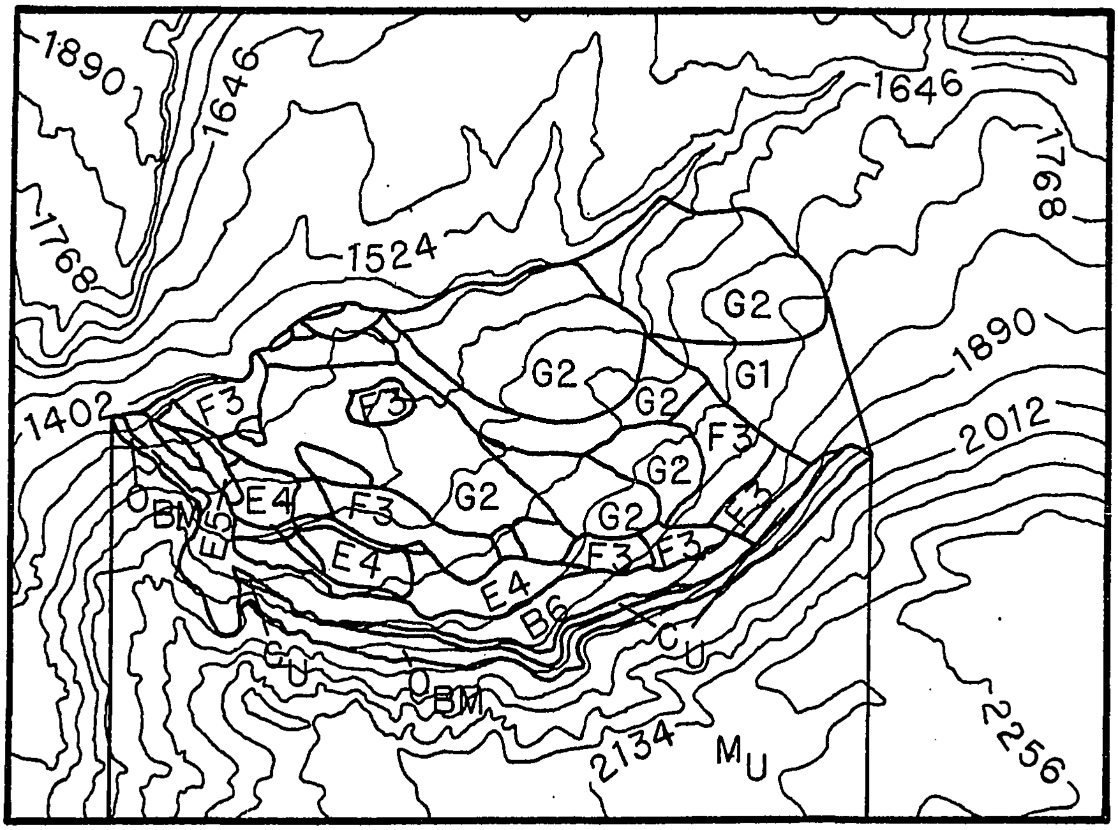
G2 = landslide deposits

G1 = landslide deposits

M_U = Madison Fm., Jefferson Fm., and Leigh and Horseshoe Mtn. Mbrs. of Bighorn Fm.

O_{BM} = Steamboat Point Mbr. of Bighorn Fm.

C_U = Gallatin, Gros Ventre, and Flathead Fms. undif.



POST CREEK

0 KM. 1

N

Figure 30. Detailed landslide activity map of Grouse Creek. For location see Figure 51. Contour interval is 61 meters.

B9 = post-Pinedale II age talus

C8 = landslide deposits

D7 = landslide deposits

E6 = landslide deposits

F5 = landslide deposits

F4 = landslide deposits

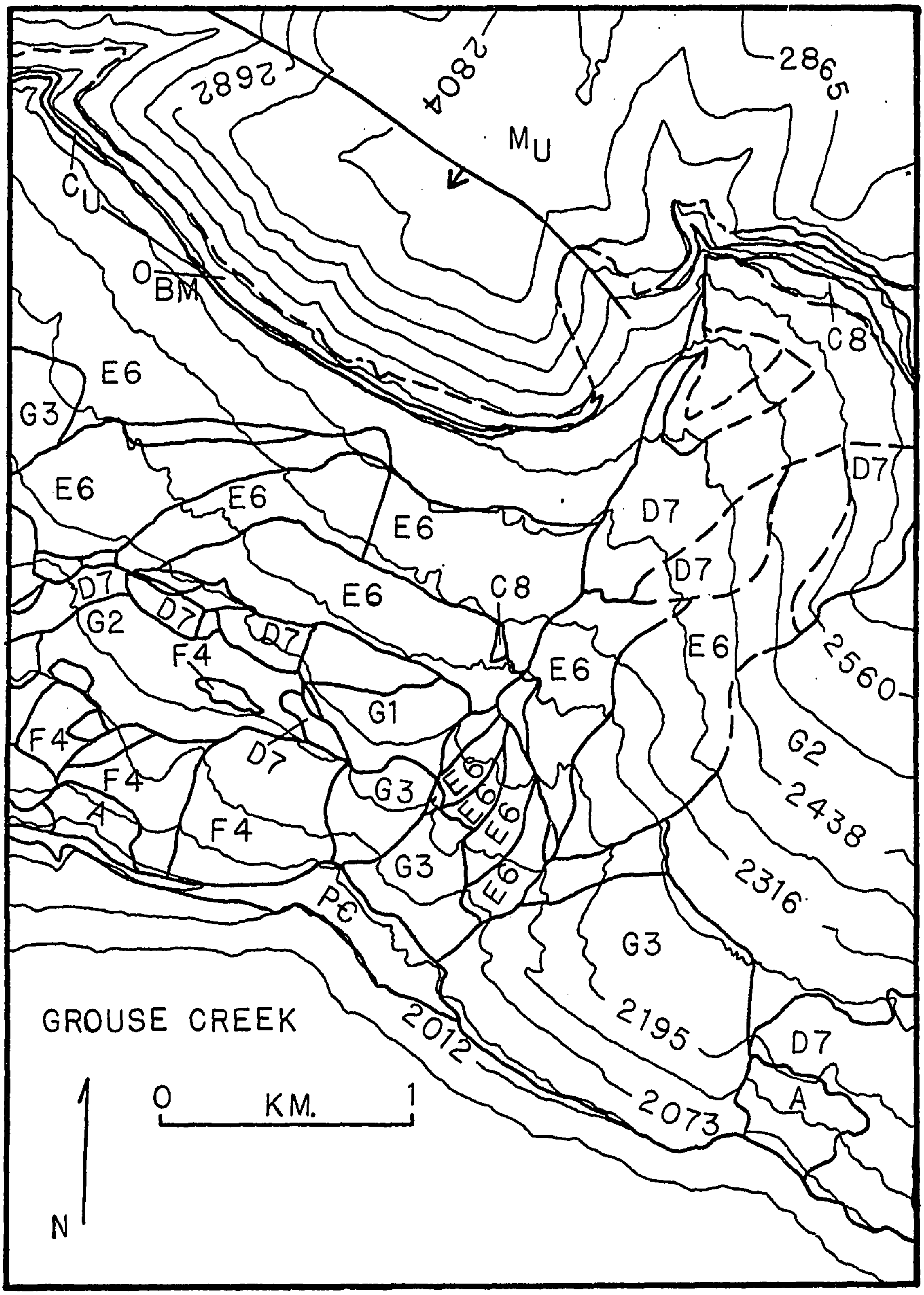
G3 = landslide deposits

G2 = landslide deposits

M_U = Madison Fm., Jefferson-Threeforks Fms., and Leigh and Horseshoe Mtn. Mbrs. of Bighorn Fm.

O_{BM} = Steamboat Point Mbr. of Bighorn Fm.

C_U = Gallatin, Gros Ventre, and Flathead Fms. undif.


2682
2804
2865
MU
CU
OBM
C8
E6
G3
E6
E6
E6
D7
D7
D7
D7
D7
C8
G2
F4
E6
E6
2560
G1
F4
D7
G2
F4
G3
E6
E6
E6
2438
A
F4
G3
E6
2316
PC
G3
GROUSE CREEK
2195
D7
2012
2073
A
0
KM.
1
N

talus. Grouse Creek is located above the inner Precambrian gorge of Shell Creek (Figure 52) and the slope stability could not have been affected by the base level changes of Shell Creek.

At Salt Creek (Figures 31 and 51) the same general sequence is present. However, the oldest landslide deposits present are post-Bull Lake-pre-Pinedale I debris slides (E1). These have been partially disintegrated and buried by post-Pinedale I-pre-Pinedale II deposits (D2). During post-Pinedale II time renewed activity again took place (C3). Post-Bull Lake to post-Pinedale II deposts are presently being disintegrated and buried by active debris slides. Salt Creek is located above the inner Precambrian gorge of Shell Creek (Figure 52) and the slope stability could not have been affected by base level changes of Shell Creek.

Four general trends appear in the geologic histories of the three areas. Most apparent is that as the mean elevation of the sites increases from 1615 meters at Post Creek through 2316 meters at Grouse Creek to 2682 meters at Salt Creek, the age of the oldest landslide in each area becomes younger as does the age of the youngest landslide. Likewise, as the elevation of each site increases towards the cliff, the ages of the landslides become younger. Fourth, within all sites, the older landslides have disintegrated during subsequent episodes of slope instability. The systematic decrease in the ages of the youngest and oldest landslides at each site is compatible with the systematic decrease in the extent of the late Pleistocene glaciations and confirms a climatic control upon the landslide activity. The systematic decrease in the age of landslides toward the cliff which often times spans a major interglacial further

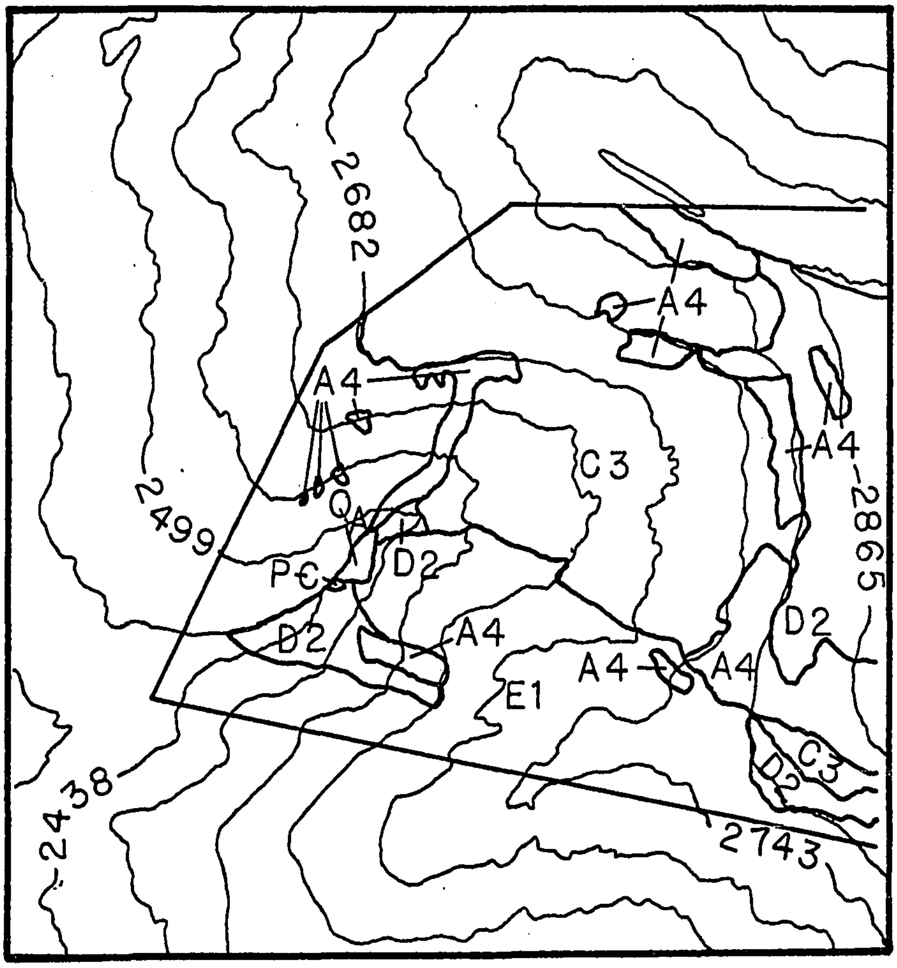
Figure 31. Detailed landslide activity map of Salt Creek. For location see Figure 51. Contour interval is 61 meters.

active landslides

C3 = landslide deposits

D2 = landslide deposits

E1 = landslide deposits



SALT CREEK

N

0 KM. 1

indicates that the slopes are not responding to either base level changes or retrogressive failure but to a stimulus associated with the cliff.

Environmental Controls of Landslides

Landslides in Shell and Tensleep Canyons occur in two types of materials, bedrock and colluvium. The bedrock landslides are slumps, block glides, or debris slides depending on the structural orientation of the bedrock relative to valley sides. The controls on the colluvial landslides are more complex but water, i.e., seepage forces, is of prime importance.

Bedrock landslides

While compiling a photogeologic map of the entire Bighorn National Forest for the U.S. Forest Service, it was noted that widespread landslide activity does not commence until erosion has exposed the upper part of the Gallatin Formation. This formation is the first lithologically incompetent unit encountered by streams eroding into the lower Paleozoic rocks of the Bighorn Mountains. Once this formation is exposed landslides become widespread. For a discussion of the regional concept of landslides see Appendix A. Evidently the shales in the Jefferson Formation in the Bighorn Mountains are not thick enough to trigger widespread landsliding.

The structural orientation of bedrock relative to valley walls controls the type of bedrock landslide that occurs. Where the dip of the bedrock is away from the valley, as along the south side of Shell Canyon, slumps occur (Figures 7 and 52). They range in length from 180 meters to 500 meters and in width from 500 to 900 meters (Table 6). Although the

Table 6. Size data for bedrock landslides; all size measurements are in meters (W = width, L = length)

Maximum size	Slump	Block glide	Debris slide
Length	550	1525	910
Width	910	3050	180
Area	$5x10^5$ m^2	$4.7x10^6$ m^2	$1.6x10^5$ m^2
F = W/L	1.7	2.0	0.2
Minimum thickness	180	300	?
Mean size			
Length	510	71	350
Width	875	85	75
Area	$4.5x10^5$ m^2	$6.0x10^3$ m^2	$2.6x10^4$ m^2
F = W/L	1.7	1.2	0.2
Minimum thickness	100	67	?
Minimum size			
Length	180	60	60
Width	500	60	60
Area	$9x10^4$ m^2	$3.6x10^3$ m^2	$3.6x10^2$ m^2
F = W/L	2.8	1.0	1.0
Minimum thickness	73	67	?

Bighorn and Madison limestones are involved in the slumping, the main part of the failure surface is located in the Gallatin and Gros Ventre shales.

Where the dip of the bedrock is into the valley (less than 20°) either block glides or debris slides occur, depending on what rock types are exposed. Where the Bighorn and Madison limestones are forming the canyon walls block glides occur. Their size varies greatly (Table 6). The very large block glides are composed of both the Bighorn and Madison

Formations. The failure surface is again located in the Gallatin Formation. In this case the failure involves limestone sliding on shale. These large block glides are rare throughout the entire Bighorn Mountains. An example is the Cedar Creek block glide (Figure 52).

The most common block glides are relatively small, minimum size in Table 6. They involve only the Steamboat Point Member of the Bighorn Formation. These glock glides do not begin moving until the overlying limestones have been removed by erosion. Once this overlying material is removed the entire exposure of the Steamboat Rock Member is involved in the block glides. The failure surface is also located in the Gallatin Formation.

Few springs have been observed in the field associated with any of the actively moving block glides. Evidently failure is due to a creep phenomenon rather than to high pore pressures or lubrication of the failure surface.

Bedding plane failures in the Madison Formation, limestone sliding on limestone, have been documented in the Bighorn Mountains by Patton (1966). However, these cover an insignificant area of the Bighorn's when compared to the block glides failing on a limestone-shale contact.

Where the Gallatin Formation makes up the canyon wall, the relatively thin limestone beds, less than 1.5 meters thick, break up rapidly upon initiation of landsliding and debris slides result. Although an entire hillside may be covered by complexes of debris slides, individual slides are relatively small (Table 6). Actively moving debris slides are associated with numerous springs. Jointing in the limestone beds allows ground water to reach the limestone-shale contacts where it acts both as a lubricant and to raise pore pressures.

Colluvial landslides

Two types of landslides occur in the colluvium, slumps and debris slides. The slumps are larger than the debris slides and have a higher form ratio (F = W/L) (Table 7). The slumps are found in the lower, presently drier portions of the canyons whereas the debris slides occur in the higher, presently moister area of each canyon. However, the controls on colluvial landslides are not obvious.

To gain a better understanding of the factors controlling the distribution of the colluvial landslides a statistical analysis was used. Twenty-four landslides in Shell Canyon and ten in Tensleep Canyon were selected at random and eighteen variables measured. The variables are defined in Table 8. Spearman Correlation Coefficients were calculated for all variables to determine those natural interactions. Stepwise multiple regression analysis was used to determine the significant factors controlling the activity of the landslides, their map area, their length, and their width/length ratio (Tables 10, 11, and 12).

Spearman correlation coefficients

The eighteen variables measured may be classified into five subsystems: the moisture, topographic, rock property, location, and landslide (Table 9). The landslide subsystem is composed of dependent variables which are influenced by the independent variables in the other four subsystems.

Table 7. Size data for colluvial landslides; all size measurements are in meters (W = width, L = length)

Maximum size	Slump	Debris slide
Length	2240	778
Width	5824	545
Area	6.1×10^6 m^2	1.9×10^5 m^2
F = W/L	2.5	0.7
Mean size		
Length	769	432
Width	1138	160
Area	1.2×10^6 m^2	7.4×10^4 m^2
F = W/L	1.5	0.4
Minimum size		
Length	174	148
Width	56	31
Area	4.6×10^4 m^2	1.5×10^4 m^2
F = W/L	0.3	0.2

The moisture subsystem contains those variables that are indicators of the moisture regime of the landslide. PER PINE is an indicator of the present moisture conditions on the surface of the landslide. The greater the PER PINE the higher the overall soil moisture is, ASPECT is an indicator of both the present and past moisture conditions. The more southerly the aspect the higher the evaporation rate and the lower the soil moisture. ASPECT can also be considered a topographic variable. DRA AREA is an indicator of the amount of water that is being supplied to the landslide either at the present or during past climatic changes. The

Table 8. Definition of parameters measured for statistical analysis of colluvial landslides

Name	Definition
PER PINE	Percent area on landslide covered by pinetrees.
ASPECT	Aspect of the long axis of the landslide, measured from 0°, north, to 359°.
DRA AREA	Area of the drainage basin above the landslide which is supplying water to it.
ELE BL	Elevation of local base level.
ELE CT	Elevation of the top of the Paleozoic cliff behind the landslide.
ACT	Activity of landslides as defined in the section Activity of Landslides in Shell and Tensleep Canyons. 1 = active, 2 = passive-1, 3 = passive-2, 4 = passive-3, 5 = inactive-1, 6 = inactive-2.
PRESLO	Hillslope prior to landslide movement, measured from the base of the toe of the landslide to the top of the scarp.
POSTSLO	Hillslope after landslide movement, measurement from the base of the toe of the landslide to the base of the scarp.
CLIFFSLO	Slope of the Paleozoic cliff behind the landslide.
SHFAC	Vertical distance of the scarp below the Bighorn-Gallatin contact.
DISFAC	Ratio of the distance of the scarp base of the landslide from base level/distance of the Paleozoic cliff from base level.
OVSLOPE	The average slope measured from the base of the Paleozoic cliff to local base level.
HFAC	Vertical location of the scarp of the landslide relative to local base level.
MAP AREA	The map area of the landslide measured parallel to slope.
LENGTH	The length of the landslide measured parallel to slope.
F	The width/length ratio of the landslide.

Table 9. Landslide subsystems

Subsystem	Moisture	Topographic	Rock	Locational
Independent variables	PER PINE	PRESLO	SHFAC	DISFAC
	ASPECT	OVSLOPE	CLIFFSLO	HFAC
	DRA AREA			
	ELE CT			
	ELE ST			
	ELE BL			
Dependent variables	Landslide			
	ACT			
	POSTSLO			
	MAP AREA			
	LENGTH			
	F			

larger the DRA AREA the greater the potential seepage forces within the slope. ELE CT is an indicator of the amount of precipitation falling in the DRA AREA. As the ELE CT increases the precipitation increases, assuming that precipitation increases with altitude. ELE ST and ELE BL are both indicators of the amount of precipitation which may fall directly on the landslide assuming that precipitation increases with elevation.

The variables in the topographic subsystem are indicators of slope geometry. As PRESLO or OVSLOPE become greater the tendency for landslides to occur should increase.

The rock subsystem contains two variables. SHFAC is a measure of the depth of failure surface below the Bighorn-Gallatin contact. The smaller this number the greater the thickness of shale involved in the landslide. CLIFFSLO is an indicator of the amount of talus which can be contributed to the slide area. The steeper the cliff the more talus it can supply at any one time.

The locational subsystem contains the variables DIS FAC and HFAC. A larger DIS FAC indicates that the slide scarp is closer to the Paleozoic cliff. The greater the HFAC, the higher the scarp is above local base level.

The four dependent variables ACT, MAP AREA, LENGTH, and F plus POSTSLO make up the landslide subsystem. The dependent variables all describe the relative age, size, and shape of the landslide. They are controlled by the independent variables in the other four subsystems. POSTSLO describes the final stable slope angle. POSTSLO can also be considered a topographic variable.

In Shell Canyon only the independent variables DIS FAC and HFAC are strongly intercorrelated, $R^2 = 0.91$ (Figure 32). Two other sets of variables ASPECT and DRA AREA, and ELE BL and CLFFSLO have a moderate degree of intercorrelation, both have R^2s of 0.59. The intercorrelation of ASPECT and DRA AREA is not surprising since all sample sites selected were on the north side of Shell Canyon. All other independent variables measured are truly independent.

Within the landslide subsystem, ACT is influenced directly by the moisture parameters ELE ST, ELE CT, and ELE BL (Figure 32). The moisture

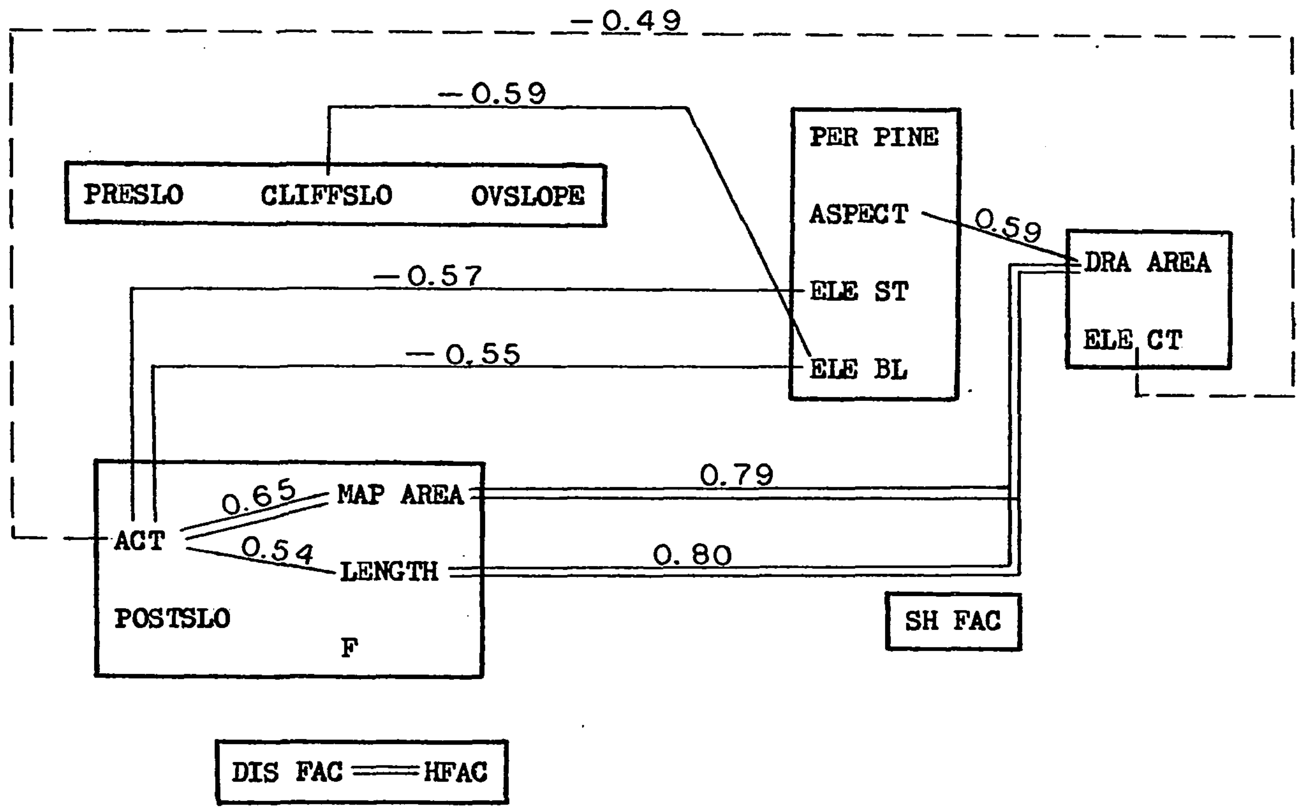


Figure 32. Plot of Spearman Correlation Coefficients for Shell Canyon. ---- $\alpha < 0.05$, —— $0.5 > \alpha > 0.01$, ═══ $\alpha < 0.001$.

control is interpreted to indicate that in the late Quaternary as each successive wet-dry climatic change became less intense, the zone of maximum available moisture occurred at successively higher elevations and the resulting landslides likewise occurred at successively higher elevations.

The size parameters of the landslides, MAP AREA, and LENGTH are controlled primarily by the size of the DRA AREA supplying water to that particular landslide. As the DRA AREA becomes larger the landslides become larger. Since DRA AREA is a measure of the ground water being supplied to a landslide, this relationship indicates that the size of a landslide is primarily controlled by the amount of water in the colluvium. F is only weakly influenced by DIS FAC, while POSTSLO is not controlled by any of the independent variables.

In Tensleep Canyon (Figure 33) DISFAC and HFAC are strongly intercorrelated, $R^2 = 0.90$. ELE BL and OVSLOPE are moderately intercorrelated, $R^2 = 0.68$. MAP AREA and LENGTH are strongly intercorrelated, $R^2 = 0.71$. All other variables are truly independent.

ACT is not significantly correlated with any of the independent variables measured. This indicates that the factors controlling ACT differ between the two canyons.

The size parameter MAP AREA has an even stronger correlation with DRA AREA than in Shell Canyon. Again, size is being controlled by the amount of ground water supplied to the landslide. POSTSLO is also strongly influenced by DRA AREA, the greater the DRA AREA the gentler the POSTSLO.

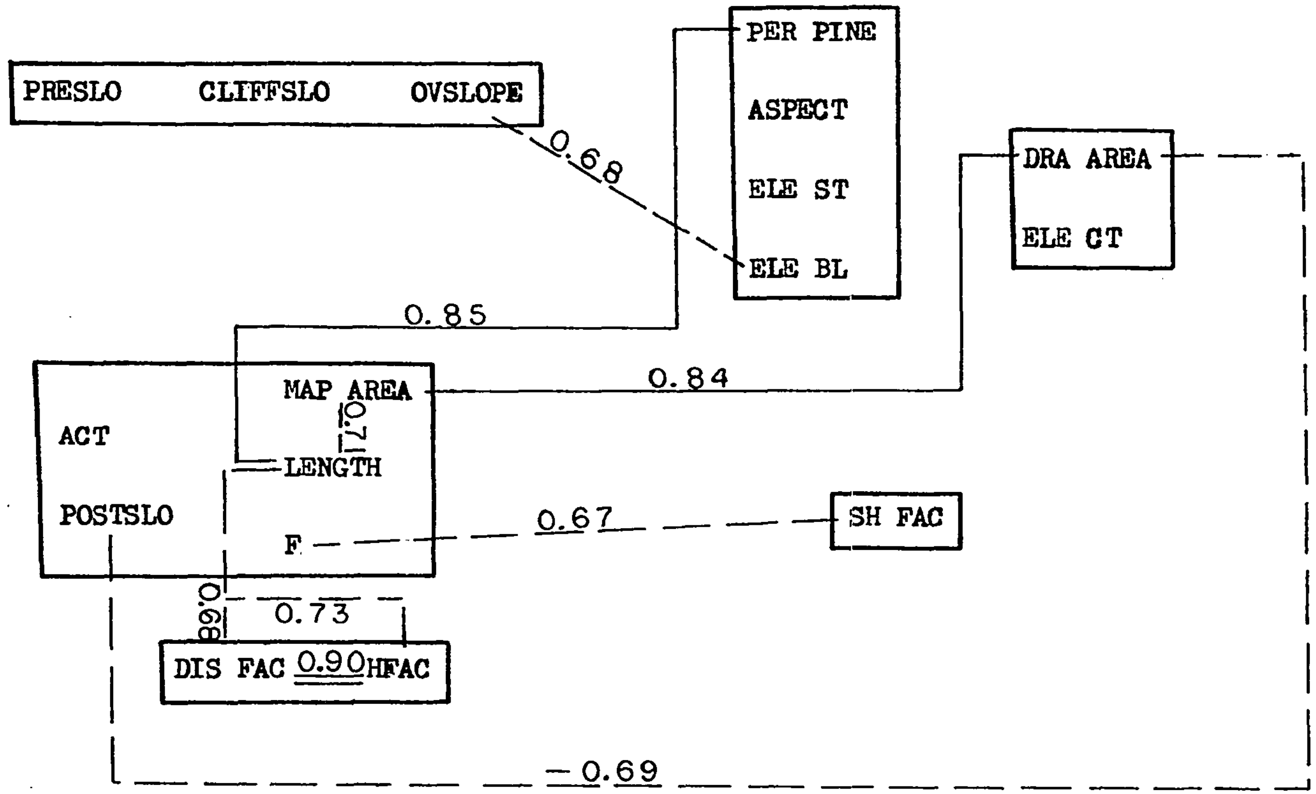


Figure 33. Plot of Spearman Correlation Coefficients for Tensleep Canyon. ---- $\alpha < 0.05$, —— $0.05 > \alpha > 0.01$, ══ $\alpha < 0.001$.

LENGTH is controlled by PER PINE and the intercorrelated parameters DISFAC and HFAC, and MAP AREA. This indicates that at present longer landslides have a greater percent tree cover and their scarps are located nearer the Paleozoic cliffs than shorter landslides. Longer landslides also have larger DRA AREA than short ones.

On the other hand F is being controlled by SHFAC, a variable that bears no relationship to water. Slumps tend to have high F values and debris slides low F values (Table 7). It is apparent that although size is being controlled by water content, the actual type of failure is being controlled by other factors.

Stepwise multiple regression analysis

The same independent variables appear to be controlling the size and shape of the landslides in both Shell, and Tensleep Canyons. The parameters MAP AREA and LENGTH are controlled primarily by DRA AREA (Tables 10, 11, and 12). F on the other hand is controlled mainly by the slope geometry. However, the controls on ACT differ in each canyon.

ACT In Shell Canyon 70 percent of the variation in ACT is explained by ELE ST, DRA AREA, and PER PINE (32, 33, and 4 percent, respectively) (Table 10A). The negative correlation of ACT with ELE ST and PER PINE indicates that younger landslides (ACT decreases) are found in higher, presently moister environments than older ones. During a series of successively less intense climatic changes younger landslides would also be expected to occur at successively higher elevations. The positive correlation of ACT with DRA AREA indicates that older landslides have larger drainage basins than younger ones.

Table 10A. Regression equations for the landslide parameters measured in Shell Canyon

For individual values, N = 24

ACT = 11.647 - 0.0137 PER PINE + 2.584 DRA AREA - 0.003 ELE ST $R^2 = 0.70$

MAP AREA = -201490.051 + 3913369.515 DRA AREA $R^2 = 0.76$

LENGTH = 739.499 + 1412.265 DRA AREA - 1499.541 PRESLO $R^2 = 0.80$

F = 0.003 + 3.113 PRESLO - 4.207 POSTSLO + 0.179 ACT $R^2 = 0.50$

Table 10B. Regression equations for the landslide parameters measured in Shell Canyon

For mean values, N = 6

ACT = 17.679 + 3.201 DRA AREA - 0.006 ELE ST $R^2 = 0.89$

MAP AREA = -175584.099 - 14167.353 PER PINE + 4188131.236 DRA AREA $R^2 = 0.90$

LENGTH = -2495.767 - 6.314 PER PINE - 0.1336 ASPECT - 0.764 ELE CT + 1.680 ELE ST + 8.404 DISFAC + 293.047 ACT $R^2 = 0.99$

F = 0.810 + 3.713 DRA AREA - 0.179 ACT $R^2 = 0.89$

Table 11A. Regression equations for the landslide parameters measured in Tensleep Canyon

For individual values, N = 10

$ACT = 0.031 + 4.690\ HFAC \qquad R^2 = 0.53$

$MAP\ AREA = -847389.763 + 778997.714\ DRA\ AREA + 381.536\ ELE\ ST \qquad R^2 = 0.99$

$LENGTH = -1604.0468 + 153.371\ DRA\ AREA + 0.726\ ELE\ ST + 97.825\ ACT \qquad R^2 = 0.90$

$F = -6.123 + 0.031\ ASPECT + 0.649\ DRA\ AREA - 0.406\ ACT \qquad R^2 = 0.92$

Table 11B. Regression equations for the landslide parameters measured in Tensleep Canyon

$ACT = -1.186 + 5.944\ HFAC \qquad R^2 = 0.77$

$MAP\ AREA = 21986.663 + 782233.697\ DRA\ AREA \qquad R^2 = 0.98$

$LENGTH = 317.692 - 559.260\ DISFAC + 62.947\ HFAC + 146.995\ ACT \qquad R^2 = 0.99$

$F = 3.686 - 8.576\ POSTSLO \qquad R^2 = 0.90$

In Tensleep Canyon 53 percent of the variation in ACT is explained by HFAC (Table 11A). In general, the landslides become younger toward the base of the adjacent cliff.

When the two canyons are analyzed as one population (Table 12A) only 34 percent of the variation in ACT can be explained. This decrease in the coefficient of determination is interpreted to indicate that the controls on ACT are different between the two canyons and that each canyon must be treated separately.

Table 12A. Regression equations for landslide parameters in Tensleep and Shell Canyons combined

For individual values, N = 34

ACT = -4.659 + 0.727 DRA AREA + 0.003 ELE CT - 0.004 ELE ST $R^2 = 0.34$

MAP AREA = -4152422.245 + 957107.164 DRA AREA - 2336.206 ELE BL
3312.513 ELE ST + 379539.164 ACT $R^2 = 0.68$

LENGTH = -443.456 + 205.051 DRA AREA - 1.825 ELE BL - 1.257 ELE CT
3.070 ELE ST - 3309.572 PRESLO + 1742.544 POSTSLO + 1.676
SHFAC + 2163.802 OVSLOPE + 148.153 ACT $R^2 = 0.89$

F = 5.357 + 0.654 DRA AREA - 0.002 ELE CT + 2.990 PRESLO - 4.403
POSTSLO - 0.674 HFAC $R^2 = 0.66$

Table 12B. Regression equations for landslide parameters in Tensleep and Shell Canyons combined

For mean values, N = 6

ACT = 17.528 - 0.006 ELE ST $R^2 = 0.52$

MAP AREA = 20563.763 + 1289539.604 DRA AREA $R^2 = 0.36$

LENGTH = 43.100 + 116.7331 ACT $R^2 = 0.70$

F = -0.197 + 0.010 ASPECT - 4.350 POSTSLO $R^2 = 0.73$

MAP AREA In Shell Canyon 76 percent of the variation in MAP AREA is explained by one variable, DRA AREA (Table 10A). This relationship indicates that larger landslides are associated with large drainage basins which supply more water to them. In other words, the size of the landslides in Shell Canyon are controlled by the amount of water that is supplied to them.

Regression analysis of MAP AREA in Tensleep Canyon (Table 11A) produces an equation similar to the one for Shell Canyon. DRA AREA explains 98 percent of the variation, ELE ST only one percent.

When the data are analyzed as one population (Table 12A) only 68 percent of the variation in MAP AREA can be explained. A plot of MAP AREA vs. DRA AREA for each canyon (Figure 34) clearly shows that the slopes and intercepts of the two lines are different. This indicates that while the control on MAP AREA is the same in both canyons the manner in which it affects MAP AREA varies slightly between canyons.

Figure 34 indicates that a larger DRA AREA is required in Tensleep Canyon than in Shell Canyon to trigger a landslide of the same size. OVSLOPE, PRESLO, and POSTSLO are all steeper in Tensleep Canyon than in Shell (2, 4, and 1 degree respectively). For eqivalent size landslides, if slope angle is the primary factor controlling slope stability then DRA AREA should be smaller rather than larger in Tensleep Canyon. However, the bulk of the precipitation in the Bighorn Mountains comes in the form of snow. The water equivalency for the May first snowpack in the uplands around Shell Canyon averages 300 mm while in Tensleep Canyon only 100 mm (Despain, 1973). If the precipitation patterns were similar during glacial periods then larger DRA AREAs would be needed in Tensleep Canyon to supply the same amount of water to the slopes below and trigger landslides of the same size as those in Shell Canyon. This again indicates that climate is the primary factor in controlling slope stability in the Bighorn Mountains.

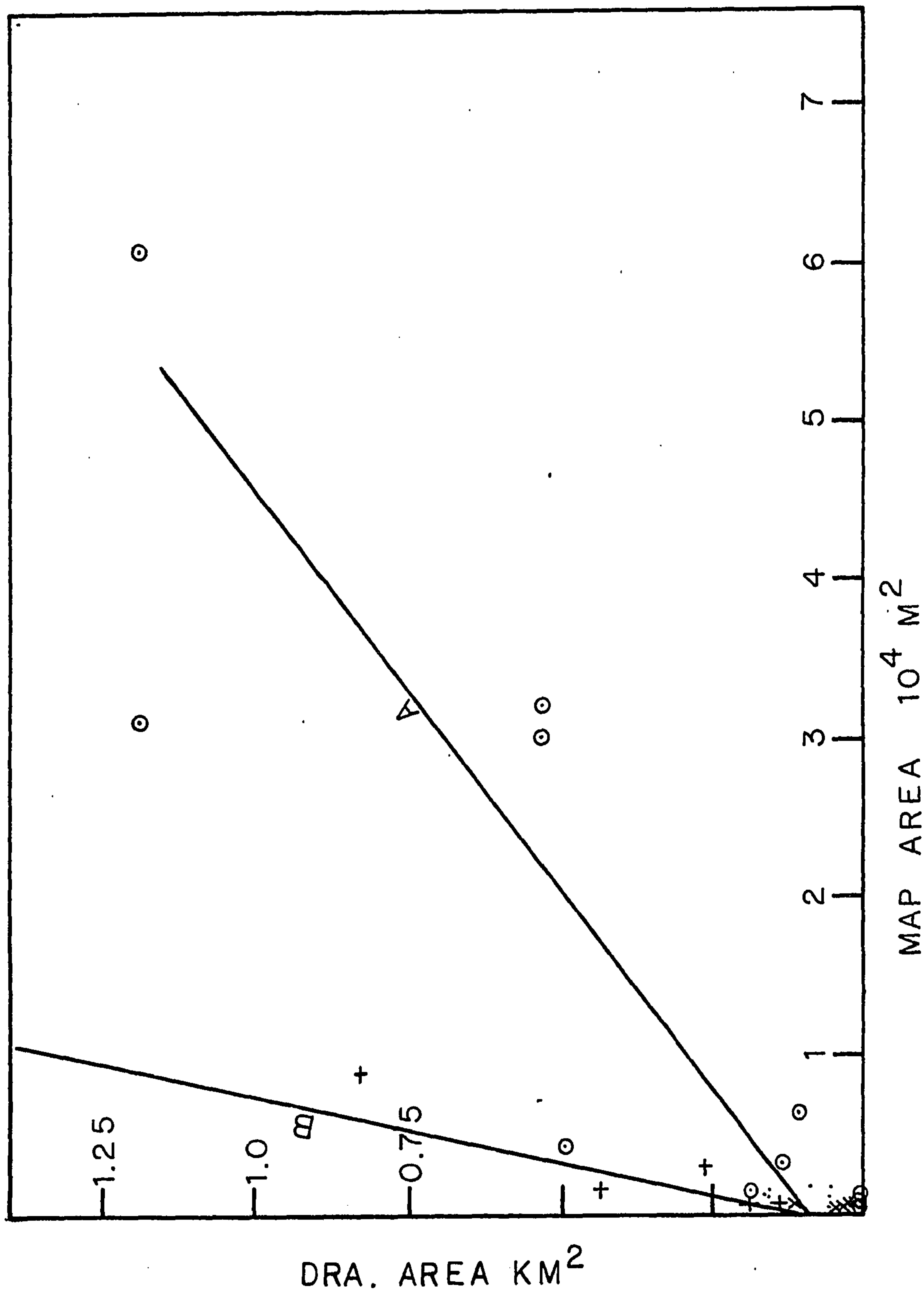
Figure 34. Drainage area vs. map area (DRA AREA vs. MAP AREA) for landslides in Shell Canyon (A) and Tensleep Canyon (B).

⊙ = slumps in Shell Canyon

• = debris slides in Shell Canyon

+ = slumps in Tensleep Canyon

X = debris slides in Tensleep Canyon


MAP AREA 10^4 M^2
DRA. AREA KM^2
1
2
3
4
5
6
7
1.25
1.0
0.75
A
B

LENGTH DRA AREA explains 76 percent of the variation in LENGTH in Shell Canyon (Table 10A). The remaining four percent of the variation is explained by PRESLO. In Tensleep Canyon 62 percent of the variation in LENGTH is explained by DRA AREA (Table 11A). The remaining 28 percent is explained by ELE ST and ACT. This again indicates that ground water is the primary factor controlling the size of a landslide.

When the data are combined (Table 12A), a complicated equation results with DRA AREA explaining only 30 percent of the variation. The two canyons must be treated separately.

F The controls on the width/length ratio (F) of a landslide are less obvious than those on either MAP AREA or LENGTH. In general slumps have high F values and debris slides have low F values. No sharp division can be drawn between the two however.

In Shell Canyon, when individual landslides are analyzed (Table 10A) only 50 percent of the variation in F is explained, 30 percent by PRESLO and POSTSLO, 20 percent by ACT. The regression equation indicates that high F values (slumps) are favored by steeper PRESLO and gentler POSTSLO. However, when mean values are regressed, DRA AREA explains 69 percent of the variation of F (Table 10B) indicating that landslides with higher F values (slumps) have larger drainage basins supplying water to them. However, it must be remembered that the mean values were generated by ACT. Since DRA AREA appears in the mean ACT equation (Table 10B) and ACT and DRA AREA both appear in the mean F equation the fact that DRA AREA explains 69 percent of the variation in F may in part be due to covariation. In reality older landslides have larger DRA AREA than younger ones

(Table 10B) which explains the correlation between F and DRA AREA. Therefore, the main control on F is considered to be slope geometry.

In Tensleep Canyon, when individual landslides are analyzed (Table 11A), ASPECT, DRA AREA, and ACT control the variation in F (45, 29, and 18 percent respectively). ASPECT can be considered in part a geometric parameter and it explains the bulk of the variation. Tensleep Canyon trends NE-SW in the study area. As ASPECT becomes more northerly, more nearly at a right angle to the canyon, F becomes greater. DRA AREA again indicates that slumps are favored by larger drainage basins. The mean regression equation for F (Table 11B) indicates that as POSTSLO becomes less landslides with higher F values (slumps) have tended to occur.

The combined population (Table 12A and B) indicates that both slope geometry and ground water influence the type of failure, but in a more complex way. This again indicates that both Canyons should be analyzed separately.

Summary The variation of ACT reflects the influence of both the environmental setting and the climatic history. The positive correlation of DRA AREA and ACT indicates that the oldest landslides have the largest drainage basins. The most severe climatic changes are also thought to have occurred earliest. The positive correlation of ACT with ELE ST and HFAC indicates that younger landslides are found higher and nearer the modern Paleozoic cliff. This may reflect the accumulation of talus below the cliff which would increase the driving force on a landslide immediately below the cliff. ELE ST and ELE CT are positively correlated when both canyons are analyzed as one population.

The stepwise regression analyses clearly indicate that the size, MAP AREA and LENGTH of the landslides in the two canyons are controlled primarily by the seepage forces within the hillslopes. As the DRA AREA increases the amount of ground water supplied to the colluvium from the upland increases. The seepage forces within the colluvial slopes increase and larger landslides result. The regression analyses also indicate that the precipitation falling directly on the landslides is not responsible for their size but that the seepage forces have an external source of water.

Although the R^2 values for F are not as high as those of MAP AREA and LENGTH, they do indicate that the type of landslide occurring is controlled mainly by slope geometry rather than seepage forces. This observation tends to contradict the work of Komamura and Huang (1974) that water content controls the type of landslide. However, their conclusions are based on laboratory studies while the ones in this work are based on field studies.

Contrasting Behavior of Slopes in Tensleep Canyon

The importance of water in the form of seepage forces is conclusively demonstrated by the behavior contrast between the slopes on the northwest and southeast side of Tensleep Canyon. The north side of the canyon is composed of colluvial deposits with no landslide surface morphology (Figure 11), whereas the southeast side is entirely landslide deposit (Figure 54). There are three deposits of volcanic ash in the talus deposits on the northwest side of the canyon (Figures 15C, 15D, and 25B).

The oldest, Figure 15C, is type 0 Pearlette in age. All three ashes are undeformed which indicates that the northwest slope of the canyon has been stable since the deposition of the ash beds. There are also numerous buried C_{Ca} horizons exposed in roadcuts along the north side of the canyon which are undeformed. It thus appears that one side of the canyon has remained stable for over 0.6 million years while the other side has undergone repeated failure even though both sides of the canyon are composed of the same brown colluvium.

The obvious difference between the two sides of the canyon is in the size of the drainage basins above the canyon rim (Table 13). The drainage divide on the southeast side of Tensleep Canyon is over 3.3 kilometers from the canyon rim whereas it coincides with the canyon rim on the northwest side (Figure 35). The mean drainage basin area on the north side is significantly smaller than that on the south side at a 99 percent confidence level (Table 13). The overall slope angle (OVSLOPE), however, is significantly steeper on the northwest stable side than on the southeast side (Table 13 and Figure 35).

The contrasting behavior of the slopes is interpreted to indicate a dominant control by ground water supplied from the surrounding uplands and the resulting seepage forces. If base level fluctuations had been the dominant control, both slopes should have failed, or at least the steeper northwest slope should have. As pointed out, however, the northwest slope has remained stable. If precipitation falling directly upon the slides is the control both slopes might have failed. The stability of the north slope in this case could be explained by its steeper slopes which promote

Table 13. Comparison of slope parameters for north and south side of Tensleep Canyon

	DRA AREA km^2	ELE CT m	ELE BL m	OVSLOPE rise/run
		North side		
$\bar{X}$	2.586×10^{-2}	2379	2070	0.332
σ	2.497	115.217	125.154	0.042
		South side		
$\bar{X}$	0.529×10^{-1}	2513	2087	0.310
σ	0.971	199.663	179.601	0.098

more overland flow and by its exposure which promotes drier soils. However, the significant difference in mean drainage basin area between the two slopes favors the conclusion that seepage forces are the dominant control. This conclusion is compatible with the regression and correlation analyses.

Engineering Factors Controlling the Distribution of Landslides

Because of a lack of bore hole data it was not possible to perform a rigorous slope stability analysis utilizing back calculations. However, an analysis of landslides consisting of brown colluvium using Taylor's stability numbers (Taylor, 1937) and of the green colluvium using a modification of the infinite slope concept (Skempton and Hutchinson, 1969) is possible. The analysis should indicate those factors promoting slope failure. If the conclusion, based on the activity distribution in space and the statistical analysis is correct, water, i.e., seepage forces, should again prove to be the critical factor.

Figure 35. Cross section across Tensleep Canyon. See Figure 8 for location of traverse line E-W.

M_U = Ordovician, Bighorn Fm., Leigh and Horseshoe Mtn. Members, Devonian, Jefferson Formation, and Mississippian, Madison Formation

O_{BM} = Ordovician, Bighorn Fm., Steamboat Point Fm.

C_U = Cambrian rocks undifferentiated

PC = Precambrian rocks undifferentiated

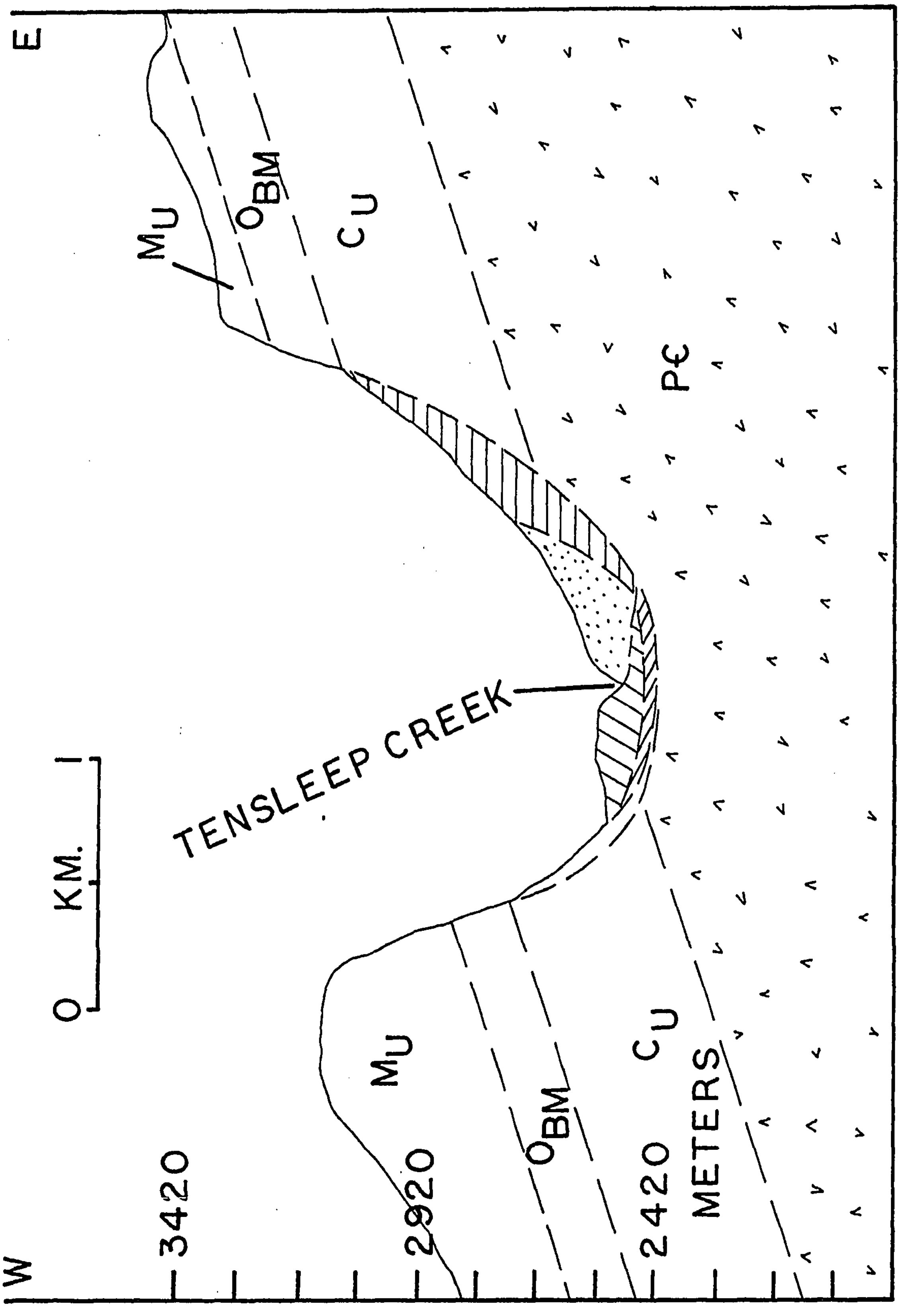
= slump

= debris slide

= talus

= Tyrrell Moraine

= Squaw Creek Moraine



W
E
0 KM. 1
TENSLEEP CREEK
M_U
O_{BM}
C_U
P€
3420
2920
2420
METERS

Where brown colluvium is involved in landsliding, slumping is the dominant type of movement and seepage forces are critical in triggering the failures. Based upon test data provided by the Federal Highway Commission for the section of highway above Shell Falls, the curves of critical slope height vs. slope angle in Figure 36 were constructed using Taylor's stability numbers (Taylor, 1937). The critical slope height is calculated by the following equation:

$$H_{cr} = (c/\gamma)\cdot(1/SN)$$

where

H_{cr} = critical slope height

c = unit cohesion

γ = bulk density

SN = Taylor's stability number

Where steady seepage is involved a weighted friction angle, ϕ_w, is used to find the correct stability number (Taylor, 1937). ϕ_w is approximated by the equation:

$$\phi_w = (\gamma_b/\gamma_t)\phi_d \text{ (approx.)}$$

where

ϕ_w = weighted friction angle

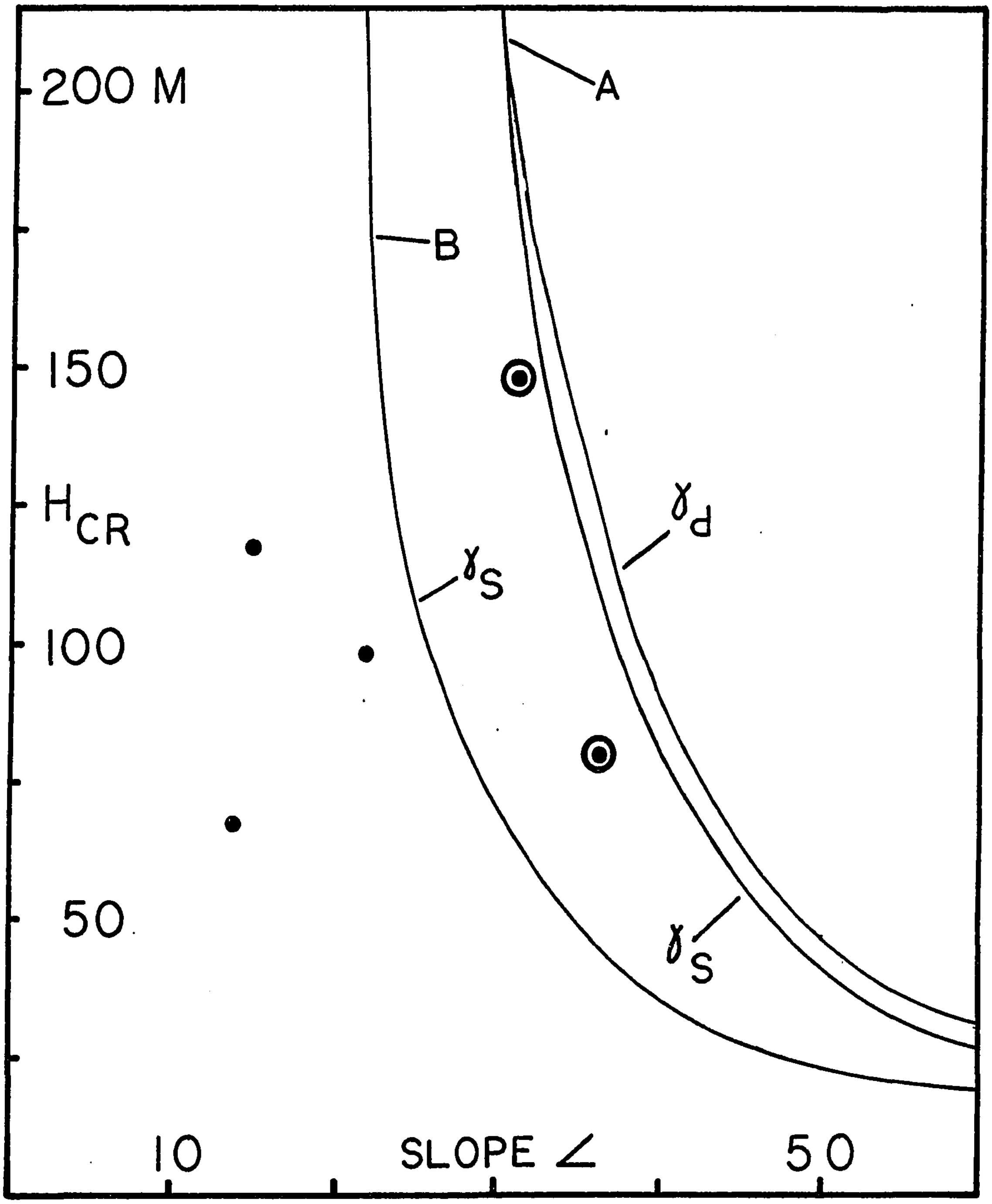
γ_b = buoyant unit weight

γ_t = total unit weight

ϕ_d = developed friction angle

This is the same ϕ_w as is used in the case of sudden drawdown. However, Taylor (1948) states, "It may be shown that the case of steady seepage is in general slightly more stable than the sudden drawdown case, and thus

Figure 36. Critical slope height (H_{cr}) vs. slope angle in degrees for brown colluvium in Shell Canyon. Curve based on Taylor's stability numbers, and cohesion of 3792 kg/m^2, ϕ_d of 30°. γ_d curve based on dry bulk density of 58 kg/m^2, γ_s curve based on saturated bulk density of 64 kg/m^2. ◉ slopes above Shell Falls that failed, ● slopes above Shell Falls that were stable. A - no seepage forces, B - seepage parallel to slope.



200 M
150
H_{CR}
100
50
10
SLOPE ∠
50
A
B
γ_s
γ_d
γ_s

the stability number for the sudden drawdown case may often be used as a conservative approximation of the stability number under steady seepage."

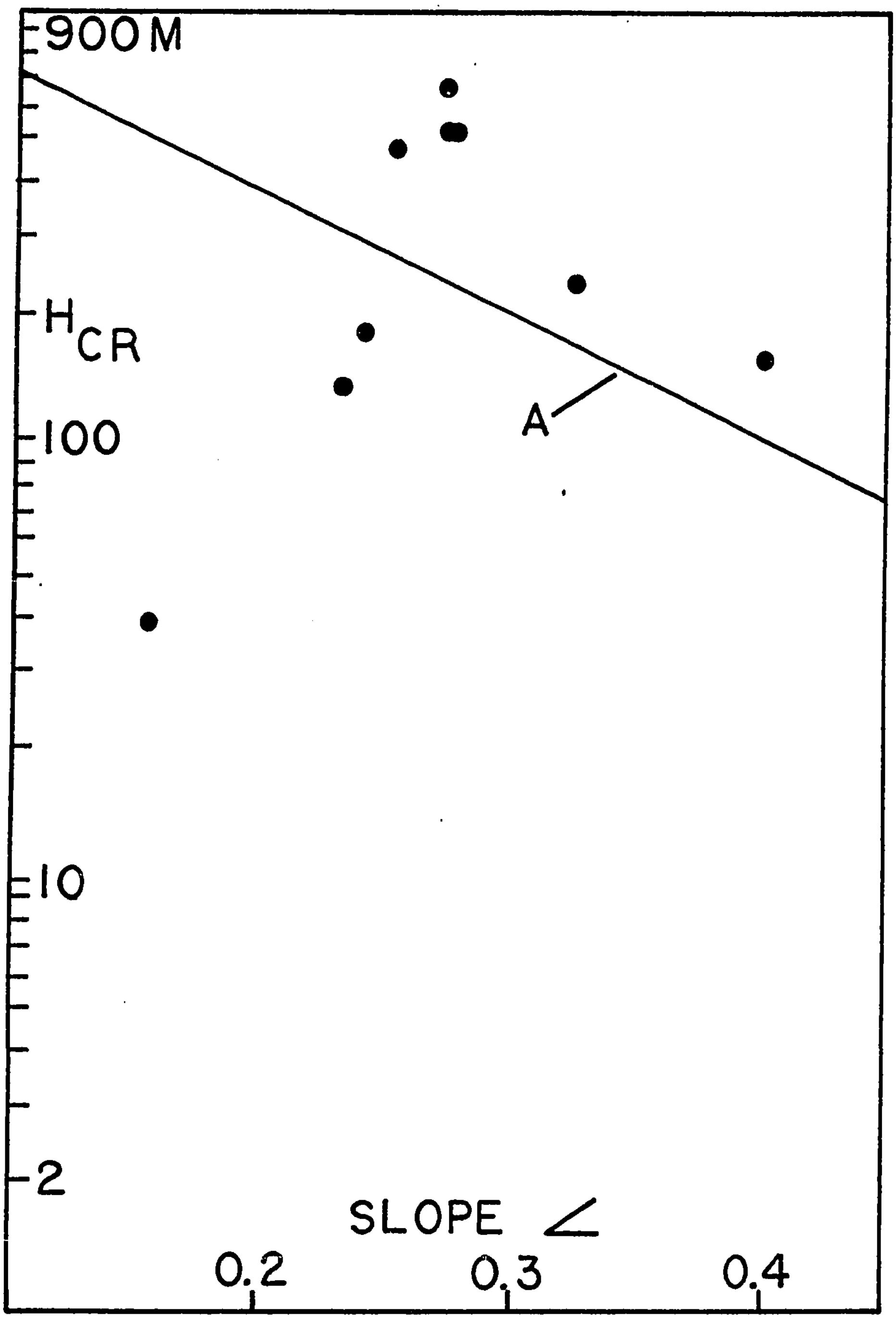
The calculations for the roadcuts above Shell Falls are based on a single triaxial determination of c = 3792 kg/m^2, and ϕ_d = 30° for the brown colluvium. When no seepage forces are involved (Figure 36, curve A) the stability calculations indicate that all roadcuts above Shell Falls should be stable as all roadcuts plot below curve A. However, two of these roadcuts have failed in the recent past.

When seepage forces are taken into account (Figure 36, curve B), the critical slope height is reduced. The two roadcuts that failed plot above the critical slope height curve. Those that are presently stable plot below the curve. It is clear then that seepage forces were responsible for the failure of the two roadcuts.

Seepage forces also appear to be important in triggering naturally occurring landslides in Shell Canyon. Of the twenty-four landslides statistically analyzed, nine were slumps. When H_{cr} vs. slope angle is plotted for these slumps (Figure 37) six of the nine plot above the critical slope height line for steady seepage. Seepage forces would be expected to increase during a climatic change when there was more available moisture. The three slumps that plot below the H_{cr} line may be composed of some material other than brown colluvium or they may have been seismically triggered.

Although the debris slides cannot be analyzed directly, it can be demonstrated that as the moisture content of the green colluvium of which they are composed increases the slope stability decreases. Data supplied

Figure 37. Critical slope height (H_{cr}) vs. slope angle for naturally occurring slumps in Shell Canyon. H_{cr} is in meters. Slope angle is in the form of rise/run. Line A is the H_{cr} line for F = 1.



900 M
H_{CR}
100
10
2
A
SLOPE ∠
0.2
0.3
0.4

by the Federal Highway Commission (Table 14) indicate that the green colluvium has a friction angle (ϕ) of 0° and that cohesion decreases with increasing moisture content (Figure 38).

Landslides on a planar surface of failure in an infinite slope (debris slides) may be analyzed using the following equation (Skempton and Hutchinson, 1969):

$$F = \frac{c + z\cos^2\beta(\gamma - m\gamma_w)\tan\phi}{\gamma z \sin\beta\cos\beta}$$

where

F = safety factor

z = depth to failure surface

γ = bulk density of soil

γ_w = bulk density of water

m = ratio of height of water table above failure surface to total depth of failure surface

ϕ = angle of internal friction

β = slope angle

Assuming $F = 1$ and $\phi = 0$, for the green colluvium, this equation reduces to:

$$\frac{c}{\gamma z} = \sin\beta\cos\beta$$

Two unknowns still remain, z and β, so the equation cannot be solved directly. However, based on the c and γ data supplied by the Federal Highway Commission (Table 14) for the green colluvium it is possible to drawn a set of curves of z vs. β (Figure 39).

Table 14. Triaxial test data for green colluvium supplied by the Federal Highway Commission

% moisture	Density kg/m^3	ϕ	c kg/m^2
10.3	1653	0	18,000
15.1	1778	0	18,000
20.3	1760	0	10,546
24.7	1603	0	2,602
30.4	1486	0	636

For the landslides that were statistically analyzed in Shell Canyon, the depth to z for the debris slides in the green colluvium is unknown, however, elevation of top of scarp-elevation of base of scarp will give an indication of the maximum depth of z. PRESLO is assumed to be equal to β. When the values of maximum z vs. β for the debris slides are plotted on Figure 25, all points plot below curve C. This indicates that the green colluvium has a relatively high moisture content (20.38) when it failed. The moisture content of slope forming materials will increase in a region when the climate is changing towards one of greater available moisture.

The analysis of both the slumps and debris slides indicate that seepage forces are the critical factor in triggering the landslides in Shell and Tensleep Canyons. However, it must be kept in mind that in another geologic setting some other factor such as slope geometry could prove to be more important.

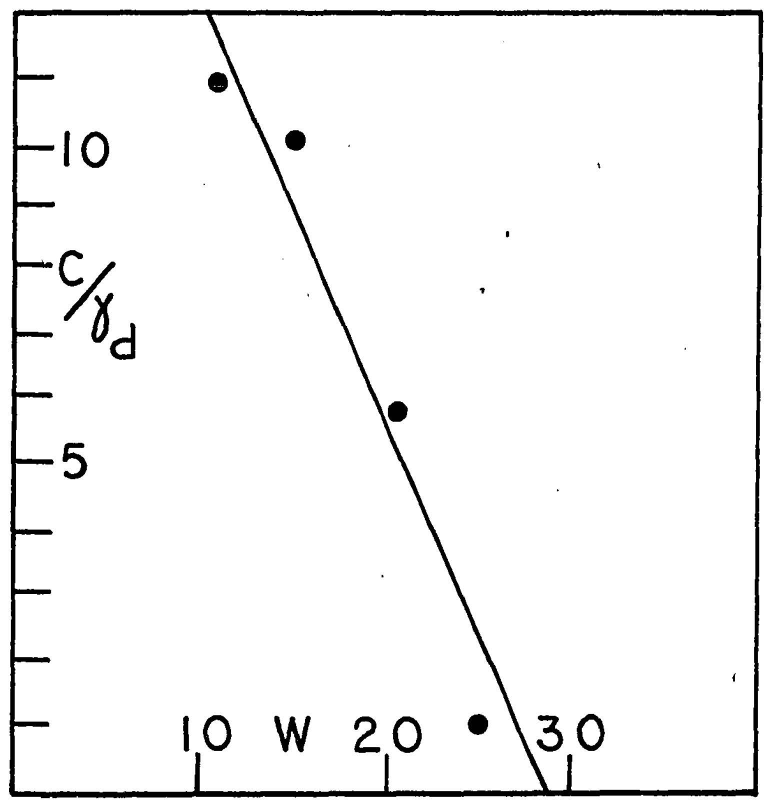


Figure 38. C/γ_d vs. w, moisture content. C/γ_d is in kg/m, moisture content is in percent. R^2 of c/γ_d vs. w line is 0.89. Based on the raw data in Table 14.

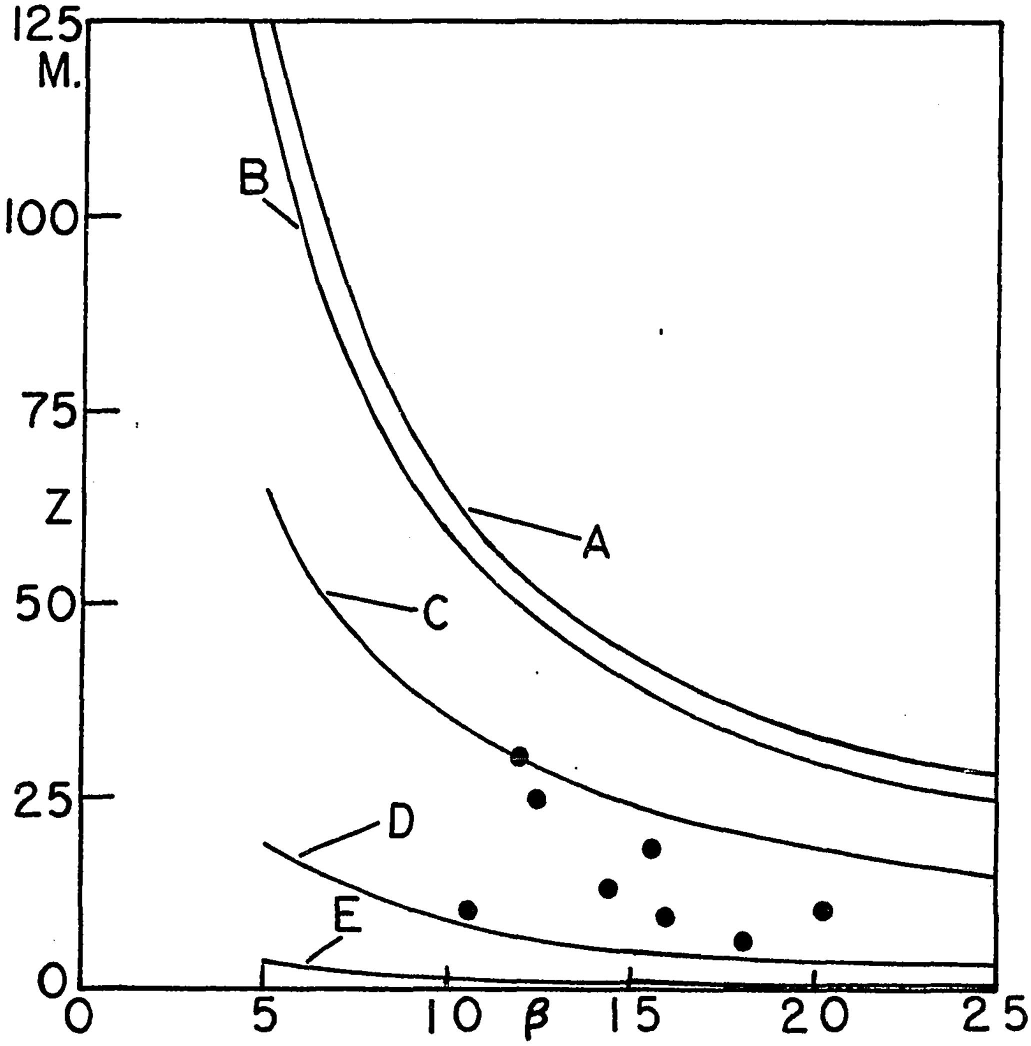


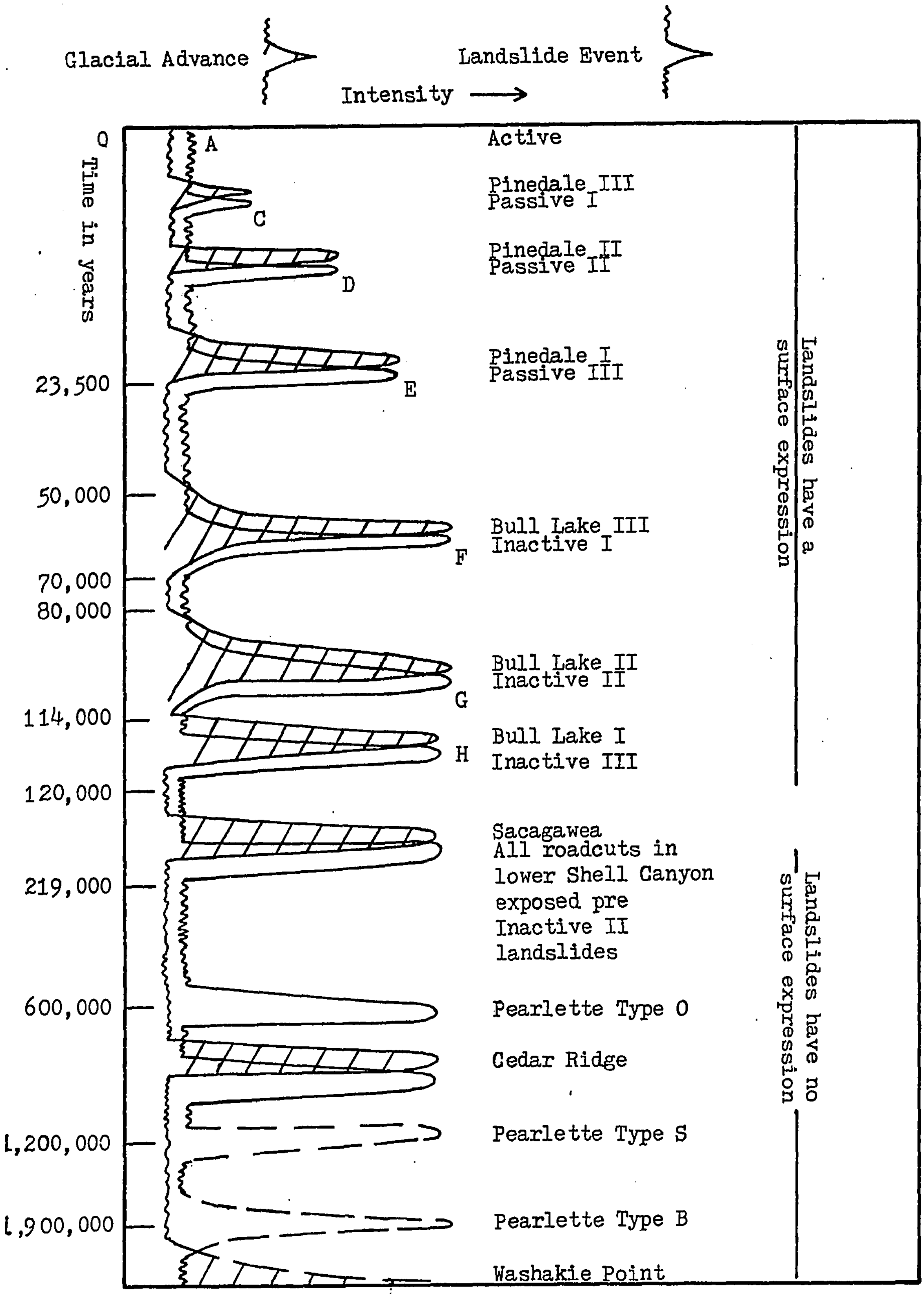
Figure 39. Z vs. β for debris slides in green colluvium. Z is in meters, β is in degrees. Curve A based on c of 18,000 kg/m^2 and % moist. of 10.3. Curve B based on c of 18,000 kg/m^2 and % moist. of 15.1. Curve C based on c of 10,546 kg/m^2 and % moist. of 20.3. Curve D based on c of 2,602 kg/m^2 and % moist. of 24.7. Curve E based on c of 636 kg/m^2 and % moist. of 30.4. For raw data see Table 14.

Quaternary History of Shell Canyon

The Quaternary history of Shell Canyon consists primarily of periodic episodes of landslide activity and advances of alpine glaciers. It is based on the morphology of surficial deposits, cross-cutting relationships between landslide deposits and glacial moraines, the relationship between landslide deposits and volcanic ash deposits, and the stratigraphy of buried landslide deposits. The history is summarized in Figure 40.

What occurred in Shell Canyon prior to the time when Shell Creek cut down to the Precambrian surface can only be speculated upon. Shell Canyon is asymmetric, the northern side being much farther from the modern Shell Creek than the southern (Figure 9). There are three possible causes of this asymmetry. First, it could be due to the lateral migration of Shell Creek to the southwest. The dip of the Paleozoic rocks is to the southwest and the creek could have migrated downdip by the process of undercutting. However, Shell Creek exits the canyon through a narrow gorge; thus this portion of the creek has been fixed in the same position throughout its history. Also, if lateral migration were the cause of the asymmetry there should be abundant crystalline boulders mixed into the brown colluvium on the north side of the canyon. There is only one small isolated location, directly south of Copeman's Tomb, where crystalline boulders were found on the north side of the canyon, so it is unlikely that Shell Creek has migrated laterally any extensive distance. Second, the asymmetry could be due to block gliding along the northern, updip side of the canyon. But, the cliffs on the north side of the canyon are composed of both the Bighorn and Madison Formations. As discussed in the

Figure 40. Quaternary geologic history of Shell Canyon.


Glacial Advance
Landslide Event
Intensity
Time in years
0
23,500
50,000
70,000
80,000
114,000
120,000
219,000
600,000
1,200,000
1,900,000
A
C
D
E
F
G
H
Active
Pinedale III
Passive I
Pinedale II
Passive II
Pinedale I
Passive III
Bull Lake III
Inactive I
Bull Lake II
Inactive II
Bull Lake I
Inactive III
Sacagawea
All roadcuts in lower Shell Canyon exposed pre Inactive II landslides
Pearlette Type O
Cedar Ridge
Pearlette Type S
Pearlette Type B
Washakie Point
Landslides have a surface expression
Landslides have no surface expression

section on Environmental Controls of Landslides block glides in this situation are rare. The third and most likely explanation is that the north side of Shell Canyon has retreated due to the production of talus by the Bighorn-Madison cliff and the subsequent removal of the talus by colluvial landslides.

Shell Creek cut down to the Precambrian surface sometime prior to the deposition of Dirty Sally's ash. It is inferred that at this time the large bedrock slumps, located on the south side of Shell Canyon, were formed because their toes are testing directly upon the Precambrian surface. With the exposure of the Precambrian surface, the base level above the first 2.4 kilometers of Shell Canyon was stabilized for the adjacent landslides.

Shell Creek itself then entered a long period of relative stability once it had reached the Precambrian surface within the study area. The superposition of the Bluejacket and Kane ashes (Figure 15A) indicates that Shell Creek aggraded its channel slightly during an interval of approximately 1.3 million years.

Sometime after the deposition of the Kane ash, Shell Creek again began downcutting and the inner gorge of Shell Canyon was eroded. By the time the Field Camp ash was deposited, Shell Creek had downcut to a level only seven meters above its present floodplain. The creek continued to erode its channel to a point twelve meters below its present level. Twelve meters of Pinedale age alluvium fills the valley at the Wagon Wheel Cafe (Figure 51) (R. C. Palmquist, Iowa State University, Ames, personal communication, 1978). Since Pinedale time, Shell Creek has been gradually degrading its channel.

Within Shell Canyon, the first episode of colluvial landsliding of record occurred prior to the deposition of the Kane ash in Figure 22B. This is indicated by the underlying pond silts. The age of this episode of landsliding can only be speculated upon but it may be related to the same climatic changes that caused the Cedar Ridge glaciation.

The second episode of landslide activity was probably seismically triggered. This episode is represented by the landslide that trapped the Kane ash in Figure 20. A period of stability followed during which the pond silts on top of the ash were deposited.

The third episode of landsliding is indicated by the rotation of the ash bed in Figure 20. The age of this movement is unknown. It could be related to the climatic changes that occurred during the Sacagawea glaciation. Or if Richmond (1976) is correct and there were three advances of the Bull Lake glaciers then it might be related to the Bull Lake I glaciation. Here it has been tentatively correlated with the Sacagawea glaciation simply because that is the next younger glaciation.

The evidence for landslide activity related to the Cedar Ridge glaciation, the seismic event, and the Sacagawea glaciation is found only in roadcuts. None of these periods of landslide activity has any relationship to the present landslide surface morphology.

The inactive-3 landslide deposit which underlies the Ruble Creek Moraine may be related to the climatic changes associated with the Bull

Lake I glaciation of Richmond (1976). Part of this landslide deposit is exposed at the surface but its age cannot be conclusively determined.

The first episode of landslide activity which has a surface expression is the inactive-2. This has been tentatively correlated with the Bull Lake II glaciation of Richmond (1976). The remainder of the Quaternary history is characterized by a series of cycles which consist of episodes of landslide activity prior to each of the four remaining glacial advances. Each interglacial time was characterized by relative slope stability as is demonstrated by the present small scale landslide activity.

Quaternary History of Tensleep Canyon

The later Quaternary history that is post inactive-2 landslides of Tensleep Canyon is similar to that of Shell Canyon. The major difference is the stability of the north side of Tensleep Canyon since the deposition of the Kane ash (Figure 15D). The history of the canyon prior to the deposition of the Kane ash is largely unknown. The canyon was cur prior to the deposition of the Kane ash and a period of colluviation occurred to provide the stratified brown colluvium on which it rests.

MODELS OF SLOPE STABILITY

Four factors may affect the regional stability of slopes in any given physiographic province. These are base level changes of streams, climatic changes, periods of glaciation, and seismic events. Four models are developed to explain the effect of these factors (Figures 41, 42, 43, and 44). The climatic, seismic, and composite glacial models are based on observations presented in this dissertation. The base level model is based on theory. In any particular area, one model may dominate over the others depending on the local geologic setting, or two or more models may interact simultaneously to modify the slope stability.

The models are not designed to explain the stability of a slope at a specific site. The models are designed to explain the regional response of slopes to changes in their environment. The word region is herein used for an area ranging in size from a first order drainage basin to a physiographic province. The level of detail with which a model may be applied to any one region will vary depending on the physical size of that region.

The base level, climatic change, and composite-glacial models are long term models. The time scale of the base level model is on the order of 100s to 1000s of years. The time scale of the climatic change and composite-glacial models is on the order of glacial-interglacial, i.e., thousands of years. The seismic model is the only short term model. The time scale is on the order of minutes or days. Therefore, landslides triggered by random precipitation events, which can and do occur (Nilsen et al., 1976), are not included in the time frame of these models.

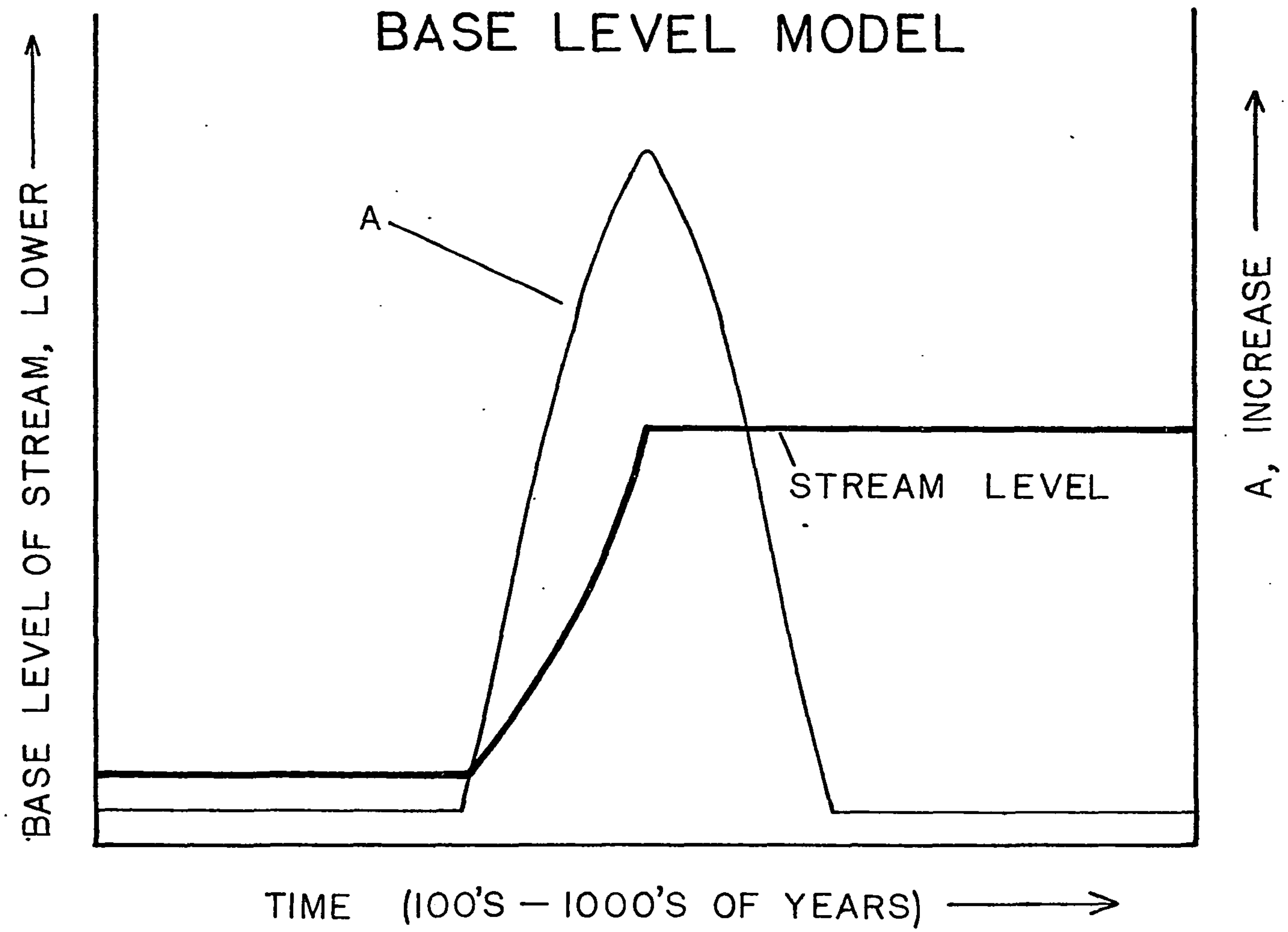
Base Level Model

In the long term, the basic premise for this model is that the stability of the slopes in a region is controlled by the base level of streams at their base. With the initiation of downcutting by the streams the valley slopes are oversteepened and become unstable (Figure 41). The area of unstable slopes will be related to the length of the reach wherein the streams are downcutting. After the streams cease downcutting, the slopes will continue to fail until they reach a slope angle adjusted to the new lower base level.

The age relationships of the landslides in a region will be determined by the manner in which the streams lower their base level. When the base level lowering is due to knickpoint migration upstream, the age of the landslides will decrease toward the headwaters of the valley. The area where the knickpoint originated is the site of the earliest downcutting and is likewise the first area where the streams reach their new base level and the landslides stabilize. The landslides are actively moving in the area of the knickpoint. When the base level lowering is caused by regional tilting, the streams in a region will simultaneously downcut throughout their length. In this case, the landslides will occur simultaneously throughout the valley and all will be roughly the same age.

Provided the overall slope angle is not reduced by overland flow, etc., slopes affected by the base level model will remain in a state of quasi-equilibrium because the landslides will have moved just enough to reestablish the minimum stable slope angle. Therefore, older landslides need be no more "stable" than young ones.

Figure 41. Base level model of slope stability. A stands for relative area of slope failure.



BASE LEVEL MODEL
A
STREAM LEVEL
BASE LEVEL OF STREAM, LOWER
A, INCREASE
TIME (100'S — 1000'S OF YEARS)

All slopes remain sensitive to either natural or man made environmental changes around them. A period of renewed downcutting will trigger a new period of landsliding. On the other hand, if the streams go through a period of aggradation the slopes will become more stable due to the buttressing effect of material deposited at the toes of the slopes.

This model would apply to areas underlain by unconsolidated sediments, areas of relatively weak sedimentary and metamorphic rocks, or volcanic rocks. Areas underlain by high grade metamorphic, or intrusive igneous rocks will be stable under any circumstances, provided they are not severely jointed.

In the short term, landslides triggered by random precipitation events such as those described by Nilson et al. (1976) will be superimposed upon the slope failure curve (Figure 41). Specific slopes near failure due to base level changes could fail from the decreased strength resulting from increased pore pressure generated by a short period of heavy precipitation. However, these failures would not change the overall shape of the curve.

Climatic Change Model

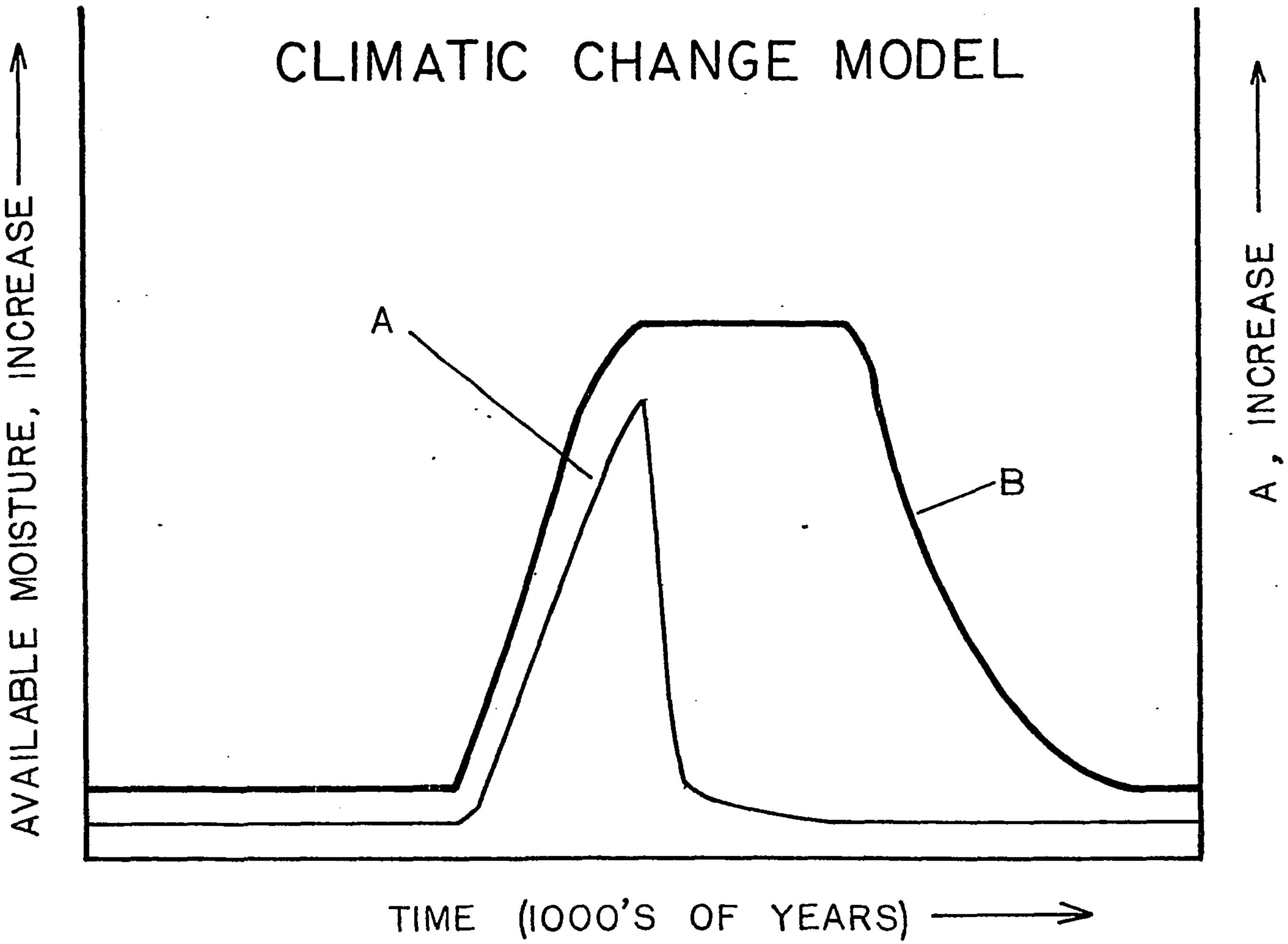
In this model base level does not change but the slopes in a region become unstable due to an increase in available moisture. This increase in available moisture may result from either a decrease in temperature and/or an increase in precipitation. The effect of either will be to increase the seepage forces within a slope. The model assumes that seepage forces are capable of affecting the stability of the slopes.

In the long term, if slopes are adjusted to a prevailing "dry" climate, then landsliding begins at or soon after the time when the climate becomes more "moist" (Figure 42). Provided the slopes fail at the same rate as the increase in available moisture, landsliding will cease soon after the available moisture curve has reached its peak (Figure 42). This quick response gives rise to large areas of the region being covered by landslides of the same age.

Through geologic time a region may be affected by numerous periods of "wet" and "dry" climate. If a second period of "wet" climate supplies more available moisture than the preceding one, then it should reactivate the landslides initiated by the the first period of "wet" climate, provided that these slopes have not been stabilized by some other factor. If the second period of "wet" climate provides less available moisture than the first, then no new landslides should be initiated. On a regional basis, there would be no increase in the relative area of slope failure with the onset of this second period of "wet" climate.

In mountainous regions, however, a special situation exists. Mountain valleys are frequently bounded by steep slopes or cliffs made up of resistant rocks. This situation allows colluvium to accumulate at the base of the cliff during a period of "dry" climate when the slopes below the cliff are stable. The talus accumulation has the effect of increasing the slope angle and driving force on the slopes below the cliffs. Colluvium may be formed during the "wet" periods of climate. There may indeed be more formed. It simply never accumulates on the slopes below the cliffs because these slopes are failing by landslides.

Figure 42. Climatic change model of slope stability. A stands for relative area of slope failure. B stands for available moisture.


CLIMATIC CHANGE MODEL
AVAILABLE MOISTURE, INCREASE
A, INCREASE
A
B
TIME (1000'S OF YEARS)

The increase in slope angle and driving force on the slopes below the cliffs means that a period of active slope failure may occur with each period of "wet" climate. During a period of "wet" climate the overall slope angle below the cliffs is reduced due to landsliding. During a "dry" period of climate the overall slope angle increases due to the accumulation of colluvium. The next period of "wet" climate need not provide as much available moisture as the one preceding it to cause the slopes to fail again, provided enough colluvium accumulated at the base of the cliff.

The shape of the decay portion of the relative area of slope failure curve in Figure 42 may vary according to the rate at which talus is supplied. A high rate of talus production will cause the curve to be "stretched" out over a longer period of time. A low rate of talus production will cause landsliding to cease soon after the peak in the available moisture curve is reached.

If the available moisture is related to altitude, more at high altitude and less at low, each successive period of less intense "wet" climate will only reactivate landslides at successively higher altitudes. The oldest preserved landslides will be found at the lowest elevation because the most intense period of "wet" climate will affect the greatest overall area. This particular sequence would apply to mountainous areas that have undergone successively less intense "wet-dry" climatic changes during the late Pleistocene. Depending upon the length of the intervening "dry" periods landslides of distinctly different ages could occur in the same valley.

The relative stability of the modern slopes will be determined by what part of a "wet-dry" climatic cycle exists in a region at the present time. If the region is in the beginning phase of a "wet" period of climate the slopes will be relatively unstable and will remain so until the available moisture curve peaks. During a "dry" period they will be relatively stable.

This model applies primarily to two situations. First, valleys with stable base levels such as those floored by an inner gorge of high strength rocks that prevent base level changes by the valley's stream from affecting the valley slopes above the gorge. Or second, to areas underlain by moisture sensitive materials.

In the short term, landslides triggered by random precipitation events such as those described by Nilson et al. (1976) can be superimposed on the relative area of slope failure curve (Figure 42). Specific slopes near failure due to seepage forces could be made to fail due to a sudden and temporary increase in those seepage forces. However, this would not change the overall shape of the curve.

Composite-Glacial Model

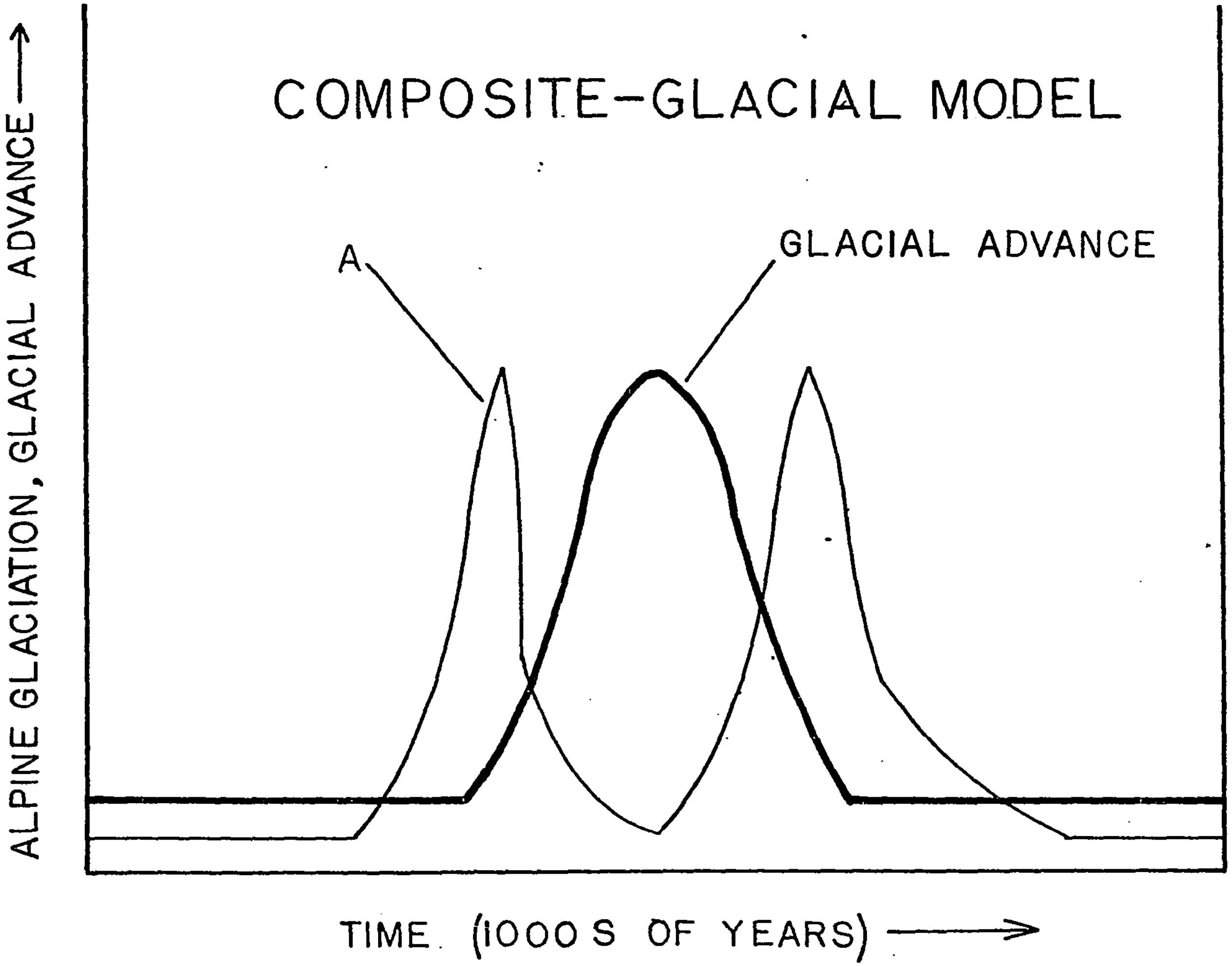
This model is a combination of the base level model and the climatic change model. It applies to mountainous areas that have undergone alpine glaciation. The model is based on three assumptions: one, that the glacier itself advanced into the part of the valley undergoing landslides; two, that the glacier was capable of active erosion in that area and that the height of the slopes glacially oversteepened exceeds the height of any morainal deposits; third, the glacial advance is contemporaneous with a period of increased available moisture. The increased available moisture is due to a decrease in temperature and/or increased precipitation.

Over the long term, the landslides occur in two distinct pulses (Figure 43). The first pulse of slope failure occurs prior to the advance of the glacier into that section of the valley and is explained by the climatic change model. The landslides are initiated by the same climatic change that caused the glacial advance. The second pulse of landslide activity occurs after the retreat of the ice and is explained by the base level model in that the valley has been deepened and slopes oversteepened due to erosion by the glacier. Landsliding will continue to occur until the slopes attain a stable angle consistent with the new base level and interglacial climate. During the actual ice advance the slopes are relatively stable due to the buttressing effect of the ice mass on the surrounding valley sides.

The relative stability of the slopes in a glaciated region is determined by what phase of the composite-glacial model the region is in. "Just prior to" and "just after" the glacial advance the region is characterized by unstable slopes. During the remainder of the interglacial and during the glacial advance itself the slopes should be relatively stable.

Under this model there will be two ages of landslides in a region for each glacial advance. The minimum difference in ages of the two periods of landslide activity in any one valley will be determined by the time the glacier actually occupied that valley. However, only the second pulse of landslide activity will be preserved for any particular glacial advance.

Figure 43. Composite-glacial model of slope stability. A stands for relative area of slope failure.


COMPOSITE-GLACIAL MODEL
A
GLACIAL ADVANCE
ALPINE GLACIATION, GLACIAL ADVANCE
A, INCREASE
TIME (1000 S OF YEARS)

This model will apply to areas underlain by surficial materials or where the bedrock is of insufficient strength (shales, schists, phyllites, etc.) to form stable, steep slopes. The model does not apply to regions underlain by high grade metamorphic or intrusive igneous rocks, unless heavily jointed. When not heavily jointed these rocks will form steep slopes that are relatively stable.

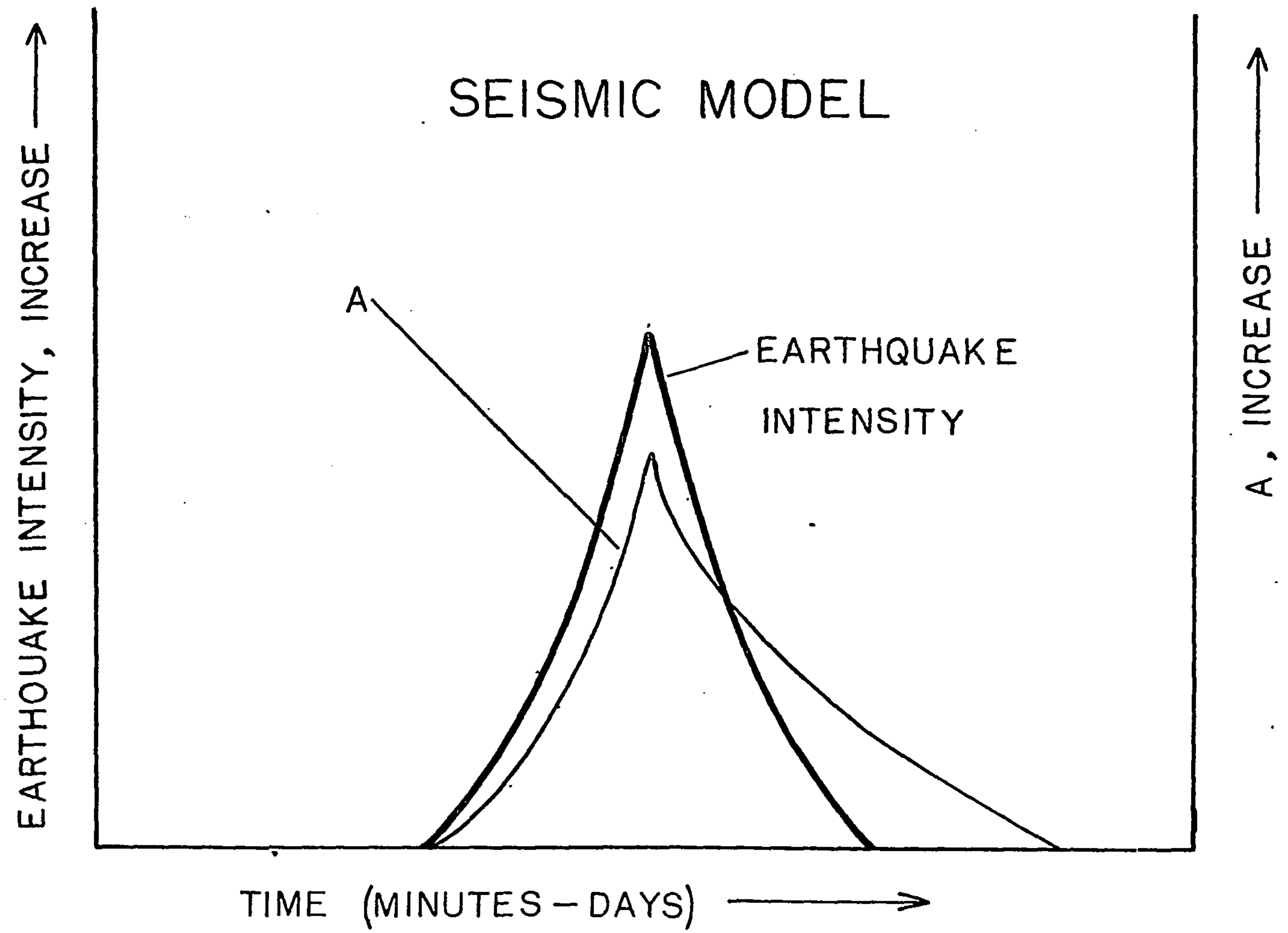
In the short term, landslides triggered by random precipitation events such as those described by Nilson et al. (1976) can be superimposed on the relative area of slope failure curve (Figure 43). Specific slopes near the point of failure could be made to fail due to a short term rise in the water table. However, this would not change the overall shape of the curve.

Seismic Model

This is the only one of the four models that deals with a relatively short term event (Figure 44). Assuming that landslides are not taking place due to other causes, during an earthquake landslides will occur on slopes that are otherwise stable. The more intense the earthquake is the larger the relative area of slope failure. Slopes already near failure within a region will fail first, then the more "stable" areas will fail. Landslides will continue for a period of time after the earthquake ceases as the slopes adjust themselves to stresses imposed on them by the earthquake.

The age distribution of the landslides in a region will depend on the timing of the earthquakes. For any one earthquake, landslides will occur

Figure 44. Seismic model of slope stability. A stands for relative area of slope failure.


SEISMIC MODEL
A
EARTHQUAKE
INTENSITY
EARTHOUAKE INTENSITY, INCREASE
A, INCREASE
TIME (MINUTES - DAYS)

over a relatively short period of time (minutes, hours, days, or weeks, rather than hundreds or thousands of years). If the earthquakes are scattered randomly through time then the resulting landslide deposits will have no systematic age distribution. If the earthquakes are systematically distributed through time then the landslides will also be.

Application to Shell and Tensleep Canyons

In Shell Canyon the base level, climatic change model and the seismic models apply to different parts of the canyon. The composite-glacial model does not apply because the Bull Lake and younger glaciers advanced no more than three kilometers into the part of the canyon where landslides occurred, and the Bull Lake and younger glaciers did not deepen and oversteepen this part of Shell Canyon.

On the south side of Shell Canyon, above the inner Precambrian gorge (Figure 52) the base level model applies to the bedrock slumps which were initiated by the erosion of the Cambrian-age shales above the Precambrian nonconformity. When Shell Creek eroded a gorge below the Precambrian surface, base level changes for the slumps ceased.

Only one of the landslides exposed in the roadcuts in Shell Canyon can be definitely assigned to a model. The proximity of Shell Canyon to Yellowstone Park should make the area subject to earthquakes during the eruption of the Pearlette ashes. The ash bed in Figure 20 in Shell Canyon proper was deposited in a closed depression formed by a landslide. Geologic evidence indicates this landslide took place immediately prior to the deposition of the ash. Therefore, it seems likely that the seismic model applies to this landslide.

The colluvial landslides in the areas which have a landslide surface morphology are younger than the erosion of the inner Precambrian gorge (Figure 40). The climatic model must apply to these landslides since base level changes are precluded.

To the west of the Precambrian gorge, base level changes have taken place throughout the history of Shell Canyon. Since the available engineering data indicate the material making up these slopes is sensitive to seepage forces it appears that both the climatic change and the base level models are superimposed on this area.

The largest continuous area of landslides is located on the north side of Shell Canyon above the Precambrian inner gorge. The deposits retain a landslide surface morphology and are younger than the erosion of the inner gorge (Figure 40). The landslides are also younger than the landslide containing a volcanic ash deposit which was seismically triggered. Since neither base level change nor glaciation could have initiated these landslides, climatic changes appear to be the triggering factor. The age distribution of the landslides supports this. Large areas are covered by landslides of the same age (Figure 52). The position of the Bull Lake and Pinedale moraines indicates that each period of "wet" climate was less intense than the one that preceded it. In general, successively younger landslides are found at successively higher lelvations (Figures 29, 30, and 31).

In Tensleep Canyon the situation is less obvious but the climatic change model appears to dominate over the others. In Tensleep Canyon no inner Precambrian gorge exists to form the base level of the landslides. However, the base of the Pinedale I moraine is at the level of the modern Tensleep Creek. For the area upstream there have been no base level changes to initiate landslides since the deposition of the Pinedale I moraine. Neither has the Pinedale I glacier deepened or oversteepened the valley. Because landslides are found both upstream and downstream from the moraine, it is assumed that climatic changes have caused both of them. The most convincing evidence in support of the climatic change model, however, is in the different behavior of the northwest and southeast side of Tensleep Canyon previously discussed.

In other areas of the Western U.S., particularly areas underlain by thick sequences of shales that have been recently uplifted, the base level model may dominate over the others. Bailey (1970) implies that base level changes are responsible for triggering most of the landslides in the Teton National Forest, particularly in the area of Moran Junction.

CONCLUSIONS

1. Landslides have been a major agent of erosion in Shell and Tensleep Canyons throughout the Quaternary. Periods of increased available moisture (glacial climates) were characterized by unstable slopes and intense landslide activity, whereas periods of decreased available moisture (interglacial climates) were characterized by relative slope stability.

2. Two types of landslides are found in the canyons, bedrock and colluvial. Bedrock landslides consist of slumps, block glides, and debris slides. The type of landslide that occurs is controlled by the geometric setting of the bedrock. Colluvial landslides are composed of slumps and debris slides. The type of landslide that occurs appears to be controlled by slope geometry. However, the initiation and the size of the colluvial landslides are controlled by seepage forces. Base level changes are relatively unimportant in this geologic setting.

3. Landslides which still retain a surface morphology may be classified on the basis of their activity. When these units are mapped it is possible to determine regional trends in slope stability.

4. Volcanic ash deposits of four different ages are found in the study area. They can be differentiated locally on the basis of weight loss and fusion temperature. The relationship of landslide deposits to these ashes, plus the relationship of landslides to glacial deposits, permits a detailed Quaternary history of the study area to be determined.

5. There are four models that may be used to explain the stability of slopes. The climatic change model applies to the bulk of the slopes in

both Shell and Tensleep Canyons. The relative stability of the slopes in any given area is determined by the applicable model and what point in time the area is in.

6. There is no single model that will explain the behavior of all slopes in all regions. In any given region one of the four models may apply or a combination of two or more. Each new area will have its own set of unpleasant surprises depending on the climatic history and geological setting and must be treated accordingly.

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APPENDIX A: CLASSIFICATION AND REGIONAL CONCEPT OF LANDSLIDES

Introduction

A complete review of the literature on landslides is not physically possible. At this point over 700 papers have been found on the subject. The last comprehensive review of landslides was by Sharpe (1938). The purpose of Appendix A is to discuss the classification of landslides, the recognition of landslides, the regional concept of landslides, and landslides in the Rocky Mountains.

Classification

Many workers on the subject of landslides have recognized the need for the systematic classification of such phenomena. Ward (1945) stated:

> A classification of the types of failure is necessary to the engineer to enable him to recognize the different phenomena for purposes of design and also enable him to take the appropriate remedial or safety measures necessary. The geographer and geologist need a classification so that they may interpret the past and predict the present trends of topography as revealed by their observations.

The different schemes of classification are many and varied. Terzaghi (1950) said, "A phenomenon involving such a multitude of combinations between materials and disturbing agents opens unlimited vistas for the classification enthusiast."

Molitor (1894) presents one of the earliest comprehensive classifications of landslides (Table 15). He stated, "A landslide, especially if of any great extent, may be classed among the worst of difficulties which the engineer is called upon to overcome." He based his classification on the

Table 15. Molitor's (1894) classification of landslides

Type	Criteria
1	Those occurring where the slope is too steep to maintain equilibrium of the mass.
2	Those caused by inclination of the natural strate, combined with the lubrication action of water.
3	Slides caused by the action of water alone.
4	Slides where the underground is not capable of supporting the weight of the overlying material.

conditions causing landslides. In type 1 and 2 landslides Molitar (1894) placed mass-movements with a clearly defined sliding surface. In type 3 landslides the material becomes water saturated and behaves as a fluid, i.e., mudflow. Type 4 landslides are caused by the collapse of the roofs of caves or mine tunnels. Both natural and man-made landslides fit into this simple classification. Molitar's (1894) paper appears to be considerably "ahead of its time" and is recommended as excellent reading on the subject of landslides.

Russel's (1900) classification recognized only two types of landslides. One is the downhill movement of a single block of either rock or unconsolidated sediment, with a backward rotation. This would be a slump in Varnes's (1958) classification. Two is displaced blocks with open fissures. This appears to be a block glide. More importantly Russel recognized that a continuous gradation from snow avalanches to landslides to soil creep exists rather than distinct breaks between the different types of movement.

Howe (1909) conducted one of the earliest regional studies of landslides in the United States. He recognized that the Mancos Shale was involved in most of the landslides in the San Juan Mountains of Colorado. He classified the landslides there on the basis of component material and type of movement (Table 16). His classification is broader than previous works since it includes both soil creep and mudflows. However, he puts all landslides caused by construction into the same group.

MacDonald (1915) derived a partial classification of landslides (Table 17), based on his work in the Panama Canal Zone. This classification is oriented toward engineering practices. Mass-movemenst resulting from structural breaks and deformation can be up to several hundred yards in length. They consist of a block of material that settles vertically and is accompanied by bulging of the ground surface at the toe of the slope. Later the block tilts outward and disintegrates. This type of landslide is due to weak rock units and an oversteepened slope. The normal or gravity slides form where porous and permeable material slides over impermeable material into the cut. This type of landslide is aggravated by jointing of the rocks. The fault zone slides occur in the sheared zones along faults. When an excavation cuts into the sheared zone a landslide usually results. Slides due to erosion and slides due to wash of streams appear to be simply slope wash on bare ground and wave erosion respectively.

Newland (1916) recognized five different types of landslides that occurred along the Hudson River Valley (Table 18). Although not specifi-

Table 16. Howe's (1909) classification of San Juan landslides

Type	Material
Soil (or earth) creep	Detritus
Earth slides or soil slips	
Mud flows	
Talus slumps	
Submarine slides at edge of continental shelf, or from ends of deltas	
Rock slides: large masses of rock rotating backward on axes parallel to strike of slope down which movement takes place	Solid rock
Rock falls: rock shattered; if of sufficient magnitude shattered rock moves with great velocity outward from base of cliff as a flow of newly made detritus	
Rock slides or slides on detritus, resulting in the movement of both	Detritus & solid rock
Slides from artificial cuts	Misc.
Sinking of ground over mines or caverns	

Table 17. MacDonald's (1915) classification of landslides

Type	Criteria
1	Structural breaks and deformations in the rock material
2	Normal or gravity slides
3	Fault zone slides
4	Slides due to erosion
5	Slides due to wash of streams

Table 18. Newland's (1916) classification of landslides

Type	Criteria
Surface creep	Involve soil, sand, and gravel, little active in plastic clays
Slumps and flows	Peculiar to clays and silts
Subsidence	Due to squeezing out of a wet clay substratum on the plane of its bed
Subsidence	Due to unbalanced pressure on confined liquid sub-stratum, leads to an upward movement at a distance

cally stated his classification appears to be based on type of movement and material.

Ladd (1935) was concerned primarily with railroad engineering and divided landslides into five main classes (Table 19). His seventeen subdivisions are based on the kind of material involved and the type of movement. His classification is rather restricted since naturally occurring ground subsidence and rockfalls have no place in this classification.

Ladd did notice that natural materials are rarely homogeneous, which makes the mathematical treatment of landslides extremely difficult. Also, the second half of his paper is an excellent review of the methods used in the prevention and control of landslides.

Sharpe (1938) attempted a continent wide classification of landslides. His classification is based on the kind of movement and their relative rates. He felt that a classification system should be based on either observation of the movement or of its resulting deposits.

Table 19. Ladd's (1935) classification of landslides

Type	Flows:	Criteria
1		
a		Mud flows consisting of clay material
b		Mud flows consisting of volcanic ash or its decomposition products
2	Slope readjustments; in materials as follows:	
a		Soil accumulations, originating in situ
b		Talus accumulations, originating through gravity, and frost and weathering processes working on cliff faces of rock formations, or on steeply sloped surfaces
c		Beds of clay
d		Sand accumulations
e		Heterogeneous glacial debris
f		Unconsolidated volcanic products
g		Aggregates of shattered serpentine, or of any of the clay-like group of serpentine materials
h		Artificial fills and half-fills made of earth-materials other than boulders and gravel
3	Undermined strata (cases not included in subsidences and rock falls because of horizontal element in movement):	
a		Collapse with slide characteristics, resulting from squeezing-out of underlying wet clayey beds, or the escape of underlying rounded sand beds (unconsolidated)
b		Collapse with slide characteristics, due to breaking down of underlying weak, poorly consolidated strata; or such areas in igneous rock masses (volcanic)
c		Collapse with slide characteristics, due to burning of underlying lignite beds
4	Structural slides. Movement on and because of:	
a		Bedding planes
b		Joint planes
c		Fault planes
d		Schistose planes
5	Clay ejection from ancient clay-filled caves opened by cuts (rare)	

The types of landslides are subdivided primarily according to their predominant type of movement. He defines flowage as a viscous or plastic movement. No shear plane is present and the movement takes place by a continuous deformation. A slide movement takes place on a slip surface. Within each type of movement, a great range in the rate of movement exists.

Sharpe's second major criteria for subdivision is the water or ice content of the material involved. The kind of material is third in importance. His classification (Figure 45) has ten major types and eight subtypes. In Figure 45 a wedging out or the use of dashed lines indicates a gradation rather than a sharp boundary between types of movement. Sharpe suggests that forms intermediate in nature be described as transitional or compound. Submarine landslides are not included in the classification. The chief advantage of Sharpe's classification over many earlier ones is that natural and artificial landslides are not separated. Sharpe recognized that the same general processes are involved in both.

Ward (1945) offers another comprehensive classification of landslides. It encompasses mass movement from solifluction and creep to rotational slumps. Ward's classification (Table 20) is based on (1) the geological strata and structure of the slope, and (2) the climate, intensity and frequency of rain, temperature changes, and wind. The depth of the movement increases towards the bottom of the table. He defines the terms used in Table 20 as follows:

a. Solifluction--the movement may be classed as a modified form of soil creep with the freezing and thawing process predominating, and may only affect the top few inches of soil.

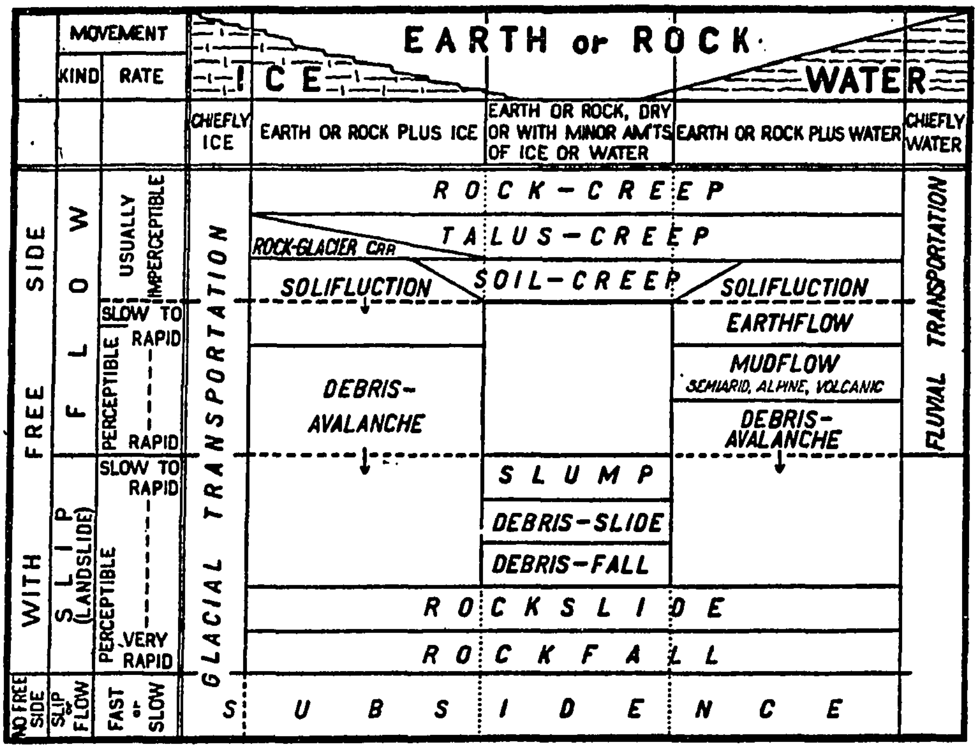


Figure 45. Sharpe's (1938) classification of landslides.

Table 20. Ward's (1945) classification of landslides

Type		Climate
Surface erosion creep	Solifluction (frost heaving and thawing)	Temperature, rain
	Soil erosion, involving rapid transport of surface materials by wind and rain	Wind and rain
Fragmental slides		
(1) Dry	Rolling down of surface layers of scree, sand, and gravel slopes	Wind, vibrations
(2) Partially sat.	Fine material behaves as if slight cohesive, shallow mass slide. Shale screes develop cohesion and become detritus slides.	Rain, wind
(3) Sat.	Saturated fine loose sands may pack closer on slight disturbance, and behave as a heavy liquid. Submerged dense sands behave as in (1).	Rain, vibrations
(4)	Collapse of overlying strata undermined by washing out of sand	Rain, tides
Rockfalls and slides	Falls resulting from frost action and deeper slides along joints and faults	Temperature, rain
Detritus slides	Shallow mass slides in predominantly cohesive materials, considerable relative distortion within the moving mass, mud run	Rain
Rotational	Deeper seated rotational slips, minor initial distortion of moving mass	
Shear slips	Typical of clays	Rain

b. Soil erosion--it involves surface transport and pickup of friable soils under frictional drag of water and wind.

c. Soil creep--this phenomena is one of slow progressive downhill movement of the upper few feet of soil.

d. Fragmental slides--fragmental refers to cohesionless materials such as sand, gravel, and scree.

e. Rotational shear slips--movement is a rotational one with minor distortion of the moving mass.

f. Rockfalls and slides--these are movements associated with steep rock exposures when not underlain by weaker materials.

g. Detritus slides--shallow movements in cohesive materials.

Ward (1945) recognized the occurrence of compound landslides. However, the classification (Table 20) does not include mass movement in bedrock other than rockfalls and slides.

In 1958, Varnes presented a classification of landslides (Figure 46) which utilizes features that might be observed in the field with a minimum of investigation. It does not refer to the causes of the landslides but is based upon two criteria: (1) the type of material involved in the landslide (based on the condition of the material prior to movement), and (2) the type of movement. Varnes (1958) states that this classification, "resembles more than any other that proposed by Sharpe (1938)." He recognized that:

> More often than not, any one landslide shows several types of movement within its various parts or at different times in its development. Most slides are therefore complex.

For a detailed discussion of the terminology used in Figure 46 see Varnes (1958). Varne's classification is used in this paper.

Jones et al. (1961) used two different methods of classifying landslides in the Columbia River Valley. In 1942 they classed the lands along the shore of Franklin D. Roosevelt Lake into five general groups for land use appraisal. The classes are: (1) landslides likely, (2) landslides unlikely, (3) slide areas, (4) bedrock, and (5) indeterminate.

TYPE OF MOVEMENT	TYPE OF MATERIAL			
	BEDROCK		SOILS	
FALLS	ROCKFALL		SOILFALL	
SLIDES — FEW UNITS	ROTATIONAL SLUMP	PLANAR BLOCK GLIDE	PLANAR BLOCK GLIDE	ROTATIONAL BLOCK SLUMP
SLIDES — MANY UNITS		ROCKSLIDE	DEBRIS SLIDE	FAILURE BY LATERAL SPREADING
FLOWS	ALL UNCONSOLIDATED			
	ROCK FRAGMENTS	SAND OR SILT	MIXED	MOSTLY PLASTIC
DRY	ROCK FRAGMENT FLOW	SAND RUN LOESS FLOW		
		RAPID EARTHFLOW	DEBRIS AVALANCHE	SLOW EARTHFLOW
WET		SAND OR SILT FLOW	DEBRIS FLOW	MUDFLOW
COMPLEX	COMBINATIONS OF MATERIALS OR TYPE OF MOVEMENT			

Figure 46. Varne's (1958) classification of landslides.

Although this appears to be a simple, useful system for land use mapping it is mentioned only briefly by the authors and their terminology is not defined. They also classified landslides (Table 21) by age, relation to bedrock, and process of movement. The authors define recent as a landslide that is recorded or can be recalled by a local resident, and ancient as a landslide that is not recorded or cannot be recalled by a local resident.

Table 21. Jones et al. (1961) classification of landslides

Type	Criteria
1	Recent slump earthflow
2	Recent slump earthflow limited by bedrock
3	Ancient slump earthflow
4	Slip-off slopes
5	Multiple alcoves
6	Landslides off bedrock
7	Talus slumps
8	Landslides in artificial slopes, including some natural material
9	Mudflows
10	Dry earthflows

Hutchinson (1968) classified landslides on the basis of the mechanism of movement and the morphology of the resulting deposit (Table 22). The rate and type of material involved in the landslide are secondary criteria. This classification system is similar to Sharpe's (1938) system, but does take into account mass movement by creep and solifluction.

Table 22. Hutchinson's (1968) classification of mass movement

Type	Criteria
(1) Shallow, predominantly seasonal creep	Creep
a. Soil creep	
b. Talus creep	
(2) Deep-seated creep; mass creep	
(3) Progressive creep	
(4) Freeze-thaw movements	Frozen ground phenomena
a. Solifluction	
b. Cambering and valley bulging	
c. Stone streams	
d. Rock glaciers	
(5) Translational slides	Landslides
a. Rock slides; block glides	
b. Slab, or flake slides	
c. Detritus, or debris slides	
d. Mudflows	
(i) Loess flows	
(ii) Flow slides	
(6) Rotational slips	
a. Single rotational slips	
b. Multiple rotational slips	
(i) In stiff, fissured clays	
(ii) In soft, extra-sensitive clays; clay flows	
c. Successive, or stepped rotational	
(7) Falls	
a. Stone and boulder falls	
b. Rock and soil falls	
(8) Sub-aqueous slides	
a. Flow slides	
b. Under-consolidated clay slides	

Carson (1976) classified landslides on the basis of mode of deformation and character of the material. His classification system includes creep phenomena and is most similar to that previously proposed by Hutchinson (1968).

Finally, Blong (1973) tried to devise a numerical classification of the debris slide, debris avalanche, and debris flow series of Varne's (1958) classification. His attempt was based on "19 numerical (erosional, slope length, etc.) and 43 disordered multistate (shear plane shape, etc.) attributes." However, he found no single form or attribute that distinguished between the types of landslides. He concluded that until some more distinctive criteria could be found that we were better off using simple descriptive classifications. Carrara et al. (1977) have also reached the same conclusion.

Recognition of Landslides

The three basic methods by which landslides may be recognized are a ground survey, the study of topographic, geologic and soils maps, and the study of aerial photographs. One of the most obvious characteristics of landslides is the presence of a hummocky ground surface (Ritchie, 1958). Also a knowledge of the general setting in which a landslide may take place is best obtained through personal acquaintance and long term observation of the area (Ritchie, 1958). The criteria for recognizing active or recently active landslides has been summarized by Ritchie (1958), and is presented in the following paragraphs.

Ritchie places special emphasis on the observation of cracks in the ground surface. He believes these can give important information as to the cause and the character of a landslide. En echelon cracks are particularly important because they generally develop before other signs of failure. A map of en echelon cracks can generally outline the slide area. Where a slump type of failure is developing (Figure 47), the cracks at the head of the slump will be slightly curved in the vertical plane and concave towards the direction of movement. If appreciable vertical offset has occurred, the cracks will wedge shut at depth. On the other hand, in a block glide type of movement (Figure 48), most of the cracks will be parallel to the slope or the cliff face. And the cracks will not wedge shut at depth. Block glides can be distinguished from lateral spreading. In a block glide only a few major cracks appear in the upper part of the slide, whereas a maze of intersecting cracks exist where failure has taken place by lateral spreading. It is important to be able to recognize the different types of failure since for engineering purposes different types of failure will require different corrective procedures (Ritchie, 1958).

Topographic, geologic, and soils maps have proven useful in the study of landslides. Even though they generally neither show landslides nor yield detailed information to solve specific landslide problems, they do provide useful background information which Ritchie (1958) has summarized as:

a. Rock and soil units and their characteristics.

b. Areal distribution of rock and soil units.

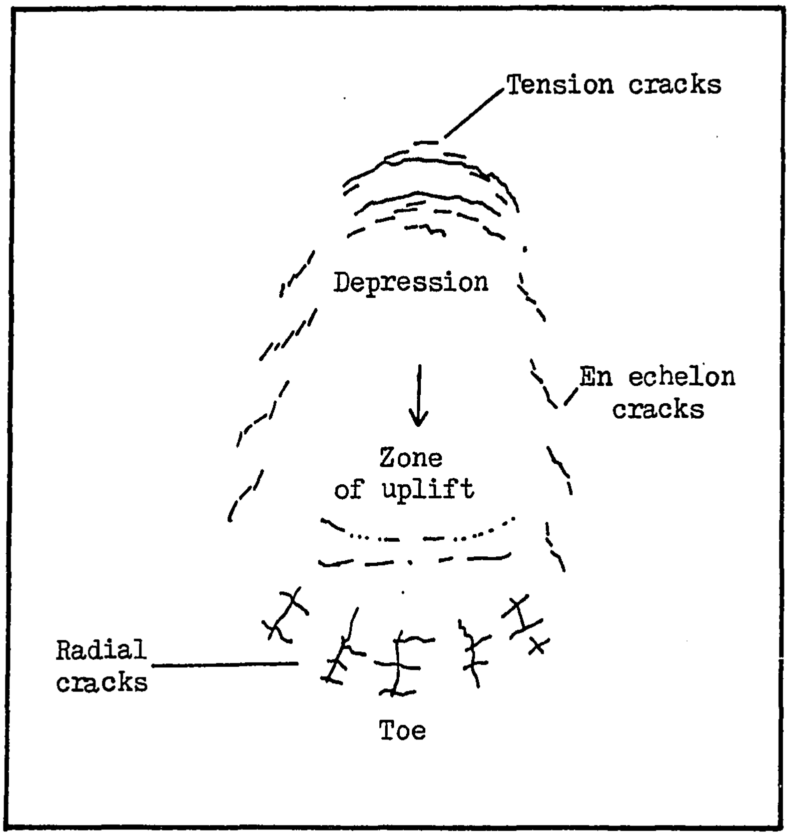
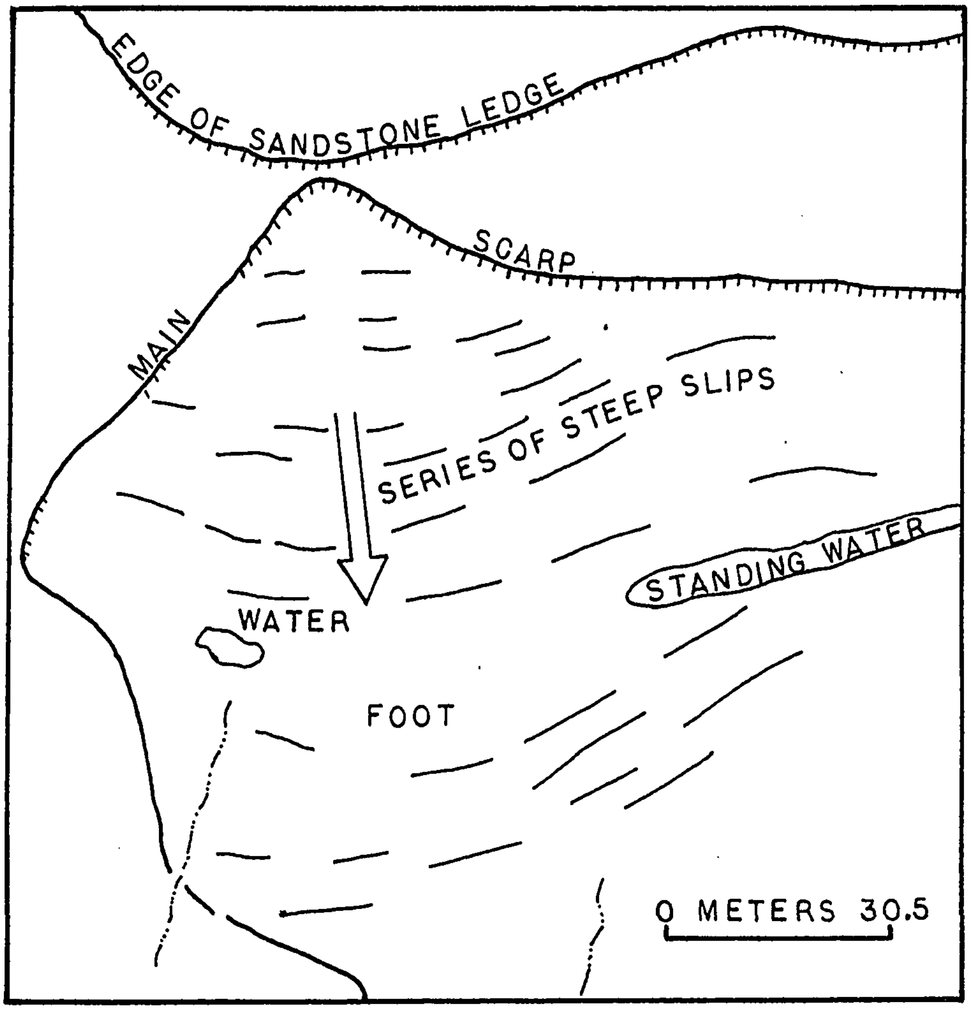


Figure 47. Tension cracks as typically developed in a slump slide in cohesive materials. (Based on Terzaghi and Peck, Figure 151, 1947).

Figure 48. Crack pattern in slump (block glide??) that indicates flowage in depth beneath harder material at surface. Broken pipes from reservoir at top of hill dumps a large amount of water into an old slide and reactivated it. Horseshoe-shaped scarp in imperfect, differentiating it from that of a true slump. The greatest movement is near the center of the slide, as indicated by arrangement of cracks and of standing water. The fact that cracks are convex outward is indicative of flow movement in depth. South side of Reservoir Hill, Dunbar, W. Va. (From drawings supplied by Robert C. Lafferty, Consulting Geologist) (Ritchie, 1958.)


EDGE OF SANDSTONE LEDGE
MAIN
SCARP
SERIES OF STEEP SLIPS
STANDING WATER
WATER
FOOT
0 METERS 30.5

c. Sequence of rock and soil units. For example, a weak unit that could cause failure may not be exposed at the surface but may be plainly shown on a geologic cross-section or on a soil profile.

d. Character and distribution of folds, faults, and joints in bedrock, all of which may seriously affect its susceptibility to sliding.

e. Location of volcanic cinder cones and similar features that offer special problems.

f. Drainage pattern, streams, lakes, and swamps, all of which give indication of relative permeability of underlying materials.

g. Bowl shaped headwater regions of creeks, which suggest landslide origins.

h. Terraces, slopes, and depressions.

i. Abnormally steep slopes, with mounds of possible landslide origin at their bases.

j. Scalloped escarpments that suggest landslide origins.

k. Anomalous constrictions in canyons, quite possibly caused by landslides.

The use of air photos has numerous advantages over conventional maps, and in some cases over ground surveys. These advantages are summarized by Liang and Belcher (1958) as:

a. Air photos present an overall perspective of a large area. When examined with a pocket or mirror stereoscope, overlapping photos give a three-dimensional view.

b. Boundaries of existing slides can be readily delineated on airphotos.

c. Surface and near surface drainage channels can be traced.

d. Important relationships in drainage, topography, and other natural and manmade elements that seldom are correlated properly on the ground become obvious on air photos.

e. A moderate vegetative cover seldom blankets details to the photo-interpreter as it does to the ground observer.

f. Soil and rock formations can be seen and evaluated in their "undisturbed" state.

g. Continuity and repetitions of features are emphasized.

h. Routes for field investigations and programs for surface and subsurface exploration can be effectively planned.

i. Recent photographs can be compared with old ones to examine the progressive development of slides.

k. Air photos can be studied at any time, in any place, and by any person.

l. Through air photos, information about slides can be transmitted to others with a minimum of ambiguous description.

However, there are certain limitations on the use of air photos in investigating landslides. Liang and Belcher (1958) state that these are:

a. Personal Experience - The usefulness of air photos increases with the individual's experience in interpretation and with his knowledge concerning the area under study. An inexperienced interpreter should be particularly careful in a new, complex area in which he has little background knowledge.

b. Scale - The scale of ordinary existing photography (1:15,000 to 1:30,000) is adequate for the study of most terrain and slide problems. However, in geologically complex areas or in areas where landslides are rather small, a scale of 1:5,000 to 1:10,000 would be desirable. Pictures within this range of scale are commonly available when the route has been photographed for photogrammetric mapping purposes. Photography of scales even larger than this is good for detailed examination, but the area covered in each photograph is limited and, therefore, the over-all perspective is more difficult to grasp.

c. City Development - In well built-up areas, natural conditions are altered or concealed by human activities. There, air photography may have special merits in city planning and related purposes, but its usefulness in landslide investigation is greatly handicapped, especially when the landslides are small.

d. Ground Investigation - It should be emphasized that the use of air photos cannot and should not replace ground investigation entirely. Through careful planning with air photos, however, the surface and subsurface exploration necessary for a landslide study can be profitably reduced to a minimum.

The choice of the proper scale is particularly important in the study of landslides. Salgeiro (1965) using aerial photos at a scale of 1:6,000 was able to map the crack and joint pattern of a potential landslide directly from the photographs. However, if the scale is too large then "massive" landslides, greater than one square mile, are almost impossible to detect (Dishaw, 1967). Dishaw (1967) found scales of 1:12,000 and 1:10,000 to be of little use and he was best able to detect these landslides at 1:63,000 scale photographs. To locate these massive landslides one must look for anomalies in the valley cross-section and Dishaw's (1967) criteria for recognizing them are:

a. The u-shaped cross-section of a glaciated valley is absent (in a glaciated area).

b. The valley is usually narrower at the slide site, which is sometimes a canyon.

c. The presence of a large block of material in the bottom of an otherwise unbroken valley section.

d. The presence of bedrock islands in a river or lake occupying a former glaciated valley.

e. The irregular shoreline of either a lake or a river.

f. The presence of deep and extensive areas of broken bedrock.

g. The slide material has a jagged or at least hummocky appearance.

h. Rapids in a stream.

i. Bulging at the toe of a slide.

j. The presence of a scarp face on the valley side, usually with associated talus banks.

k. The presence of ponds and undrained depressions on the valley slopes.

Liang (1959) feels that when photographs of the proper scale have been obtained the most obvious morphologic features of landslides that can be observed on the photographs are:

a. The scarp at the head of the slide.

b. Hummocky topography and the haphazard drainage pattern of the mass.

c. The strikingly different tones and vegetative characteristics between the slide area and adjacent stable land.

These features become less prominent as the landslide gets older (Liang, 1959). Also, it is possible to determine the slope angle directly from the aerial photographs. Danial (1966) outlines one of the simpler of the graphical methods for determining slope angle from air photos.

Finally, Liang and Belcher (1958) outline a simple format for the investigation of landslides through the use of air photos which is:

a. Lay out locations of road or other planned structures on photos.

b. Take a quick survey, on the photographs, of all cliffs or banks adjacent to river bends, and of all steep slopes in the photo area, to see if landslide movements are evident.

c. Outline areas along the right-of-way that show consistent characteristics of topography, drainage, and other natural elements within the same unit.

d. Evaluate the general landslide potential of the areas with the help of Table 12.

e. Make a detailed study of all cliffs or banks adjacent to river bends and all steep slopes above and below the center line of the road. It is important to compare slopes within the same unit area rather than of different areas. For instance, slopes in bedrock would be more stable, even though steeper, than slopes in adjacent soil areas. Realize that slides usually appear small in photos, and so look carefully, inspecting slopes in minute detail. Look especially for:

a. Existing slides. Relatively new slides appear in white tones (on black and white photographs); vegetation and drainage are not well established on them. The reverse conditions are true for old slides.

   (1) Hillside scars and hummocky topography.

   (2) Parallel moon-shaped dark patches on hillside, likely to reflect vegetation in minor depressions. Draw a line through the axis of scars or crescents in the slides. This line often points to drainageways on higher ground that contribute to the landslide movement.

   (3) Irregular outline of highways and random cracks or patches on existing pavement.

b. Potential slides.

   (1) Ponded depressions and diverted drainageways.

   (2) Seepage areas suggested by faintly dark lines, which may mean near-surface channels and fan shaped dark patches, probably reflecting wet vegetation.

f. Ground check some of the landslides that are recognized in the air photos.

g. Ground check all suspected spots.

The Regional Concept of the Occurrence of Landslides

The frequency and type of landslides vary geographically and if landslides are restricted to only naturally occurring failures, the indication of an "area problem" becomes readily apparent (Baker and Chieruzzi, 1959). Krynine and Judd (1957) define the regional concept of landslide occurrence in a general way as:

> Serious consideration should be given to the regional concept of landslide classification. According to this concept the slides within a geomorphic (or physiographic) province may be defined as an area within which the method of deposition of rocks and soils is approximately identical. This regional concept is accepted by some of the workers interested in landslides, but evidence is still needed.

Baker and Chieruzzi (1959) rated the United States on the basis of landslide severity (Figure 49). They based their measurements on the frequency of occurrence of landslides, on the size of the moving mass, and on the dollars per year spent on correction of landslides. Based on these criteria large parts of the United States do behave similarly with respect to landslides (Figure 49). In relation to the geomorphology of an area Sharpe (1938) feels that landslides are most likely to occur where the valley walls are steepest. This will occur when the area in question is in the transition between youth and maturity.

However, there is some disagreement as to the importance of the influence of a particular rock type on the distribution of landslides. Bruce (1968) for landslides in South Dakota states, "landslides are not controlled by the geologic boundaries in the Pierre Shale, but are controlled by the topographic environment of the slope and the concentration of discontinuities in the slopes." However, the predominant opinion is that rock type does play an important part. Bailey (1970) stated that in the Teton National Forest the primary regional cause of landsliding is the occurrence over wide areas of shales.

Landslides in the Rocky Mountains

This last section consists of a brief review of previous work in the Rocky Mountains. It consists mainly of descriptions of specific sites. Table 23 is a compilation of the geologic formations which have been found to be highly susceptible to landslides.

Figure 49. Landslide severity in the United States (Baker and Chieruzzi (1959).

Legend = landslide frequency

high

medium

low

none

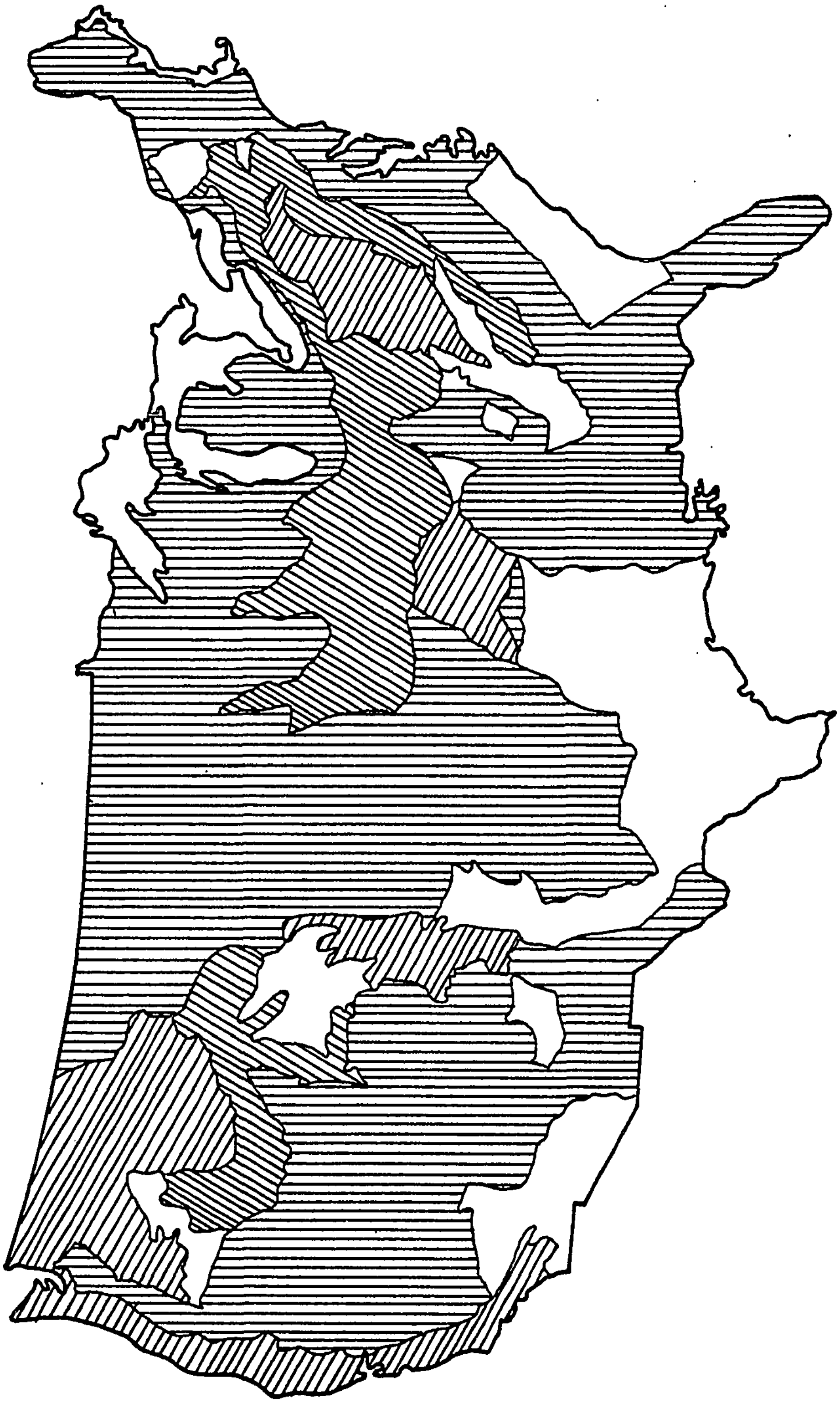


Table 23. Formations in Western U.S. with "high" susceptibility of landsliding[a]

Geologic formation	Age	Area examined
(4) Unnamed formation	Pliocene?	Battlement Mesa, Col.
(1) Wind River	Eocene	Purdy Basin
(1) Indian Meadows	Eocene	Purdy Basin
(3) Willwood	Eocene	Utah
(4) Wasatch	Eocene	Battlement Mesa, Col.
(1) Pinyon Cong.	Paleocene	Mt. Leidy Highlands
(1) Hoback	Paleocene	Hoback Basin
(1) Tertiary Volcanics	Tertiary	Pinyon Peak Highlands
(6) Potosi Volcanics	Tertiary	NW Ariz., SW Col.
(2) North Horn	Cretaceous-Tertiary	Utah
(1) Harebell	Cretaceous	Buffalo Fork River, Wy.
(1) Cody Shale	Cretaceous	Gros Ventre Valley
(1) Frontier	Cretaceous	Gros Ventre Valley
(1) Aspen	Cretaceous	Fall Creek Wy.
(1) Mowry Shale	Cretaceous	Gros Ventre Valley
(1) Thermopolis Shale	Cretaceous	Gros Ventre Valley
(1) Bear River	Cretaceous	Fall Creek, Wy.
(2) Tropic	Cretaceous	Utah
(5) Judith River	Cretaceous	Gardiner, Mont.
(6) Mancos Shale	Cretaceous	NW Ariz., SW Col.
(6) Pictured Cliffs	Cretaceous	NW Ariz., SW Col.
(6) Fruitland Shale	Cretaceous	NW Ariz., SW Col.
(6) Kirtland Shale	Cretaceous	NW Ariz., SW Col.
(7) South Platte	Cretaceous	Front Range Foothills
(10) Tohatchi	Cretaceous	NW New Mexico

[a]Compiled from (1) Bailey (1970), (2) Shroder (1967), (3) Pierce (1968), (4) Yeend (1969), (5) Waldrop and Hyden (1963), (6) Dickinson (1965), (7) Braddock and Eigher (1962), (8) Strahler (1940), (9) Gregory (1917), and (10) Watson and Wright (1963).

Table 23. (Continued)

Geologic formation	Age	Area examined
(10) Menefee	Cretaceous	NW New Mexico
(1) Cloverly	Cretaceous-Jurassic	Gros Ventre Valley
(1) Morrison	Cretaceous-Jurassic	Gros Ventre Valley
(1) Sandance	Jurassic	Gross Ventre Valley
(2) Chinle	Triassic	Utah
(8) Moenkopi	Triassic	Northern Ariz.
(8) Chinle	Triassic	Northern Ariz.
(1) Amsden	Pennsylvanian	Gros Ventre Valley

Bailey (1970) found that in the Teton National Forest the primary regional cause of landsliding is the presence, over wide areas, of shales. The primary diagenetic process affecting these shales has been the removal of overburden pressure which leaves them weak and easily susceptible to landsliding. These shales are mainly of Jurassic and Cretaceous age Bailey (1970).

Shroder (1967) from his work in Utah believes that landslides are most common where strong beds overlie weak ones. Also, the south and southwest facing slopes in Utah were found to have the fewest landslides, evidently because they are driest. Where the landslides occur today, they are confined mainly to the Db, Dc, and BSk climatic zones.

In the Carter Mountain area of Wyoming, landslides are occurring where Tertiary volcanics overlie the Willwood formation (Pierce, 1968). Evidently landslides in this area have occurred intermittently over a considerable period of time. There are at least two major periods of landslide activity and the older landslides are overlain by a moraine which the author feels is Bull Lake in age.

In the Grand and Battlement Mesa areas of Colorado, Yeend (1969) finds that the effect of landslides on the topography of the area is greater than that of glaciation during the Pleistocene. Battlement Mesa has been almost completely destroyed and over one-half of Grand Mesa has been destroyed by landslides in a period of nine million years. Yeend (1969) thinks that the landsliding has been active throughout the Pleistocene and it is still actively going on today, but the rates of movement have been rather variable.

Yeend (1969) found that there is a difference in the fabric between landslide deposits and glacial tills. In landslide deposits the long axis of cobbles dips downslope. In glacial tills (derived from valley glaciers) the long axis of cobbles dip upslope. This is important in areas where moraines and landslide deposits interfinger and might easily be confused with each other.

Work by Waldrop and Hyden (1963) near Gardiner, Montana indicated that an area originally mapped as a glacial moraine was mainly a landslide deposit. The landslides start out as blockglides and slumps, then they become fragmented and move as debris slides. The authors feel that the landslides range in age from interglacial (??) to postglacial. Also, in the San Juan Mountains, Dickinson (1965) examined the type area for the Cerro till and concluded that the deposits were actually landslide debris.

Soon after the earthquake at Hebgen Lake, Montana in 1959, Witkind examined the area and found that the highways in the epicentral area were extensively damaged. In one instance an "ancient earthflow" was reactivated by the earthquake and bowed the centerline of a highway (Witkind, 1959). This earthflow continued to move for at least four weeks after the earthquake.

The earthquake also triggered a large rock fragment flow, the Madison landslide, which was examined by Hadley (1959). He states, "The shocks administered to the ground by every major earthquake result in gravitative adjustment of the surficial material, probably over large areas." Numerous landslides occurred during the earthquake of which the Madison landslide was the most disastrous because of its size; 37 million cubic yards of material fell covering a section of highway and the adjoining Madison River to a depth of 100 to 200 feet (Hadley, 1959). Thirty people were killed.

The valley wall where the Madison landslide took place consisted mainly of gneiss and schist which was strongly sheared and deeply weathered, in some places to a depth of 100 feet or more. The foliation dips into the river valley. There is also some dolomitic marble present at the base of the slope. This gneiss and schist made up the bulk of the slide material and the surface of the slide movement cut obliquely across the schist, gneiss, and marble (Hadley, 1959). The velocities of the landslide could have been as high as 100 miles per hour and Hadley (1959) stated that the slide was due to a "fundamental slope instability." The earthquake merely acted as the trigger mechanism.

Braddock and Eigher (1962) noted that landslides had occurred on the Dakota hogbacks in Colorado. Sandstone units sliding on shale moved down the hogbacks on slopes as gentle as 10 degrees. The block glides were also folded into a series of anticlines and synclines, which seem to conform to the original sliding surface (Braddock and Eigher, 1962). The authors indicated that the landslides are pre-Wisconsin in age.

While studying the Columbia River Valley, Jones et al. (1961) noted that most of the landslides there were located around Franklin D. Roosevelt Lake which has 90 percent of its shoreline composed of Pleistocene and recent age sediments. Most of the landsliding started when the lake was filled and Jones et al. (1961) attributed the landslides to fluctuations in the lake level. There are two major types of landslides present. One is a compound slump-earthflow type movement. This is the most common and covers the greatest area. The other type is the alcove landslide. These are large basinlike features that form by a combination of sliding, flow, and fall. They probably develop rapidly and generally occur where fine-grained sediments fill deep channels cut in the bedrock surface. The bedrock channels control the groundwater flow (Jones et al., 1961).

Mudge (1965) studied rockfall avalanches and rockslide avalanches (rock-fragment flows under Varnes's (1958) classification) in the southeastern part of the Sawtooth Range in Montana. Mudge states that they are characterized by the following geomorphic features:

a. Hummocky surface.

b. Relatively low relief from head to toe.

c. Arcuate ridges and furrows, at least where confined.

d. Lobate form (where not confined).

e. Local pressure ridges where the flowage was impeded by barriers.

f. A trough between the head of the deposit and the base of the cliff or scar.

g. Movement up or over topographically high ground.

h. A volume measurable in the millions of cubic yards or rock.

The rock fragment flows are important mainly because of their size. Varnes (1958) states, "Such flows probably cannot be produced by a few thousand or a few hundred cubic yards of material. Many millions of tons are required . . . ." They can occur suddenly and move with great speed (Mudge, 1965). They appear to be pre-Pinedale I to Recent in age. The controlling factors are the steep slopes and the presence of joints in the rock. On Sawtooth Ridge, Mudge (1965) calculates that these flows have removed roughly 720 million cubic meters of material and caused the cliffs to retreat a maximum of 1010 meters.

The large volumes of the individual flows in the Sawtooth Range indicate that large sections of the cliff dropped simultaneously, possibly triggered by earthquakes (Mudge, 1965). Prostka (1967) found that similar rock-fragment flows had occurred in the valley of Whitetail Creek, a major tributary to the Jefferson River. They were of sufficient volume to permanently alter the course of the creek.

Strahler (1940) while studying the Vermillion Cliffs of New Mexico noted that as the slumps occurring there got older their backward rotation tends to increase. He also proposes an ideal cycle of erosion of a slump block which is:

> Youth: A freshly fallen block consists of an elongate ridge whose strata dip cliffward. The former cliff edge forms a sharp divide on the slumped block paralleling the cliff line and plunging downward at each end of the block. At the base of the block is debris, perhaps arranged in longitudinal ridges, which consists

of disturbed bedrock and of the forward edge of the block which has been overthrust upon the pediment.

> Initial drainage is entirely consequent upon the newly formed slopes. Streams which flow cliffward down the back slope of the block join longitudinal streams which occupy the initial consequent valley between the block and the cliff. This drainage is impeded by rapid addition of material falling from the cliff behind. Streams which flow down the front slope of the block establish courses through the mass of debris at the base of the block and emerge upon the pediment surface. It is reasonable to suppose that the streams would at first be overloaded with the great amount of loose material formed as a result of slumping and would cover the pediment with alluvial fans. As the load diminished, these streams would remove the alluvium and extension of the pediment surface by lateral corrasion would be resumed.
>
> Maturity: In maturity the original surface of the block is gone, and longitudinal subsequent streams are well established between sharp hogbacks of resistant strata. Resequent and obsequent streams drain the sides of these longitudinal valleys. Transverse streams have cut deep canyons into the block tending to divide it into two or more segments. The debris at the base of the block has been removed, and the dipping strata of the block are being beveled by streams extending the area of the pediment by lateral planation. The cliff behind the block has been retreating, and slumping will again take place if the factors are favorable.
>
> Old Age: In old age the block is a low, rounded mass usually lying from one to three miles out from the cliff and completely surrounded by the pediment. Such blocks represent but small remnants of the original masses and are ultimately beveled by streams which flow across the pediment from the cliff.

Since Strahler (1940) derived the "cycle" from work in only one area the details may be wrong but the overall idea would seem to be correct. The formation of a new slump block in close proximity to an older one, a rock-slide burying part of a block, or the formation of a new pediment surface at a lower level can alter this ideal cycle (Strahler, 1940).

Witkind (1959) notes that along Tepee Creek, Montana-Wyoming, mass wasting is one of the most effective erosive agents at work. This is due to high local relief, steep valley walls, and the weak nature of the rock units exposed. Debris slides are common and their shape is controlled by that of the preexisting valleys in which they occur. Where they reach out onto the surrounding plains they tend to have a low hummocky toe (Witkind, 1959). The single most important factor controlling the location of these debris slides is water, both ground and surface (Witkind, 1959).

Reiche (1937) after working in northwestern Arizona defines Toreva-block as a landslide which consists of a single large mass of unjostled material that during descent has undergone a backward rotation toward the parent cliff about a horizontal axis which it roughly parallels. It is apparent that this is a slump. What is interesting is that they have occurred in bedrock and not in unconsolidated material. They can be quite large. Reiche (1937) found they often reached lengths of over 300 meters along strike. They are widely distributed over the southern Colorado Plateau.

Along the Miekle River Valley in Alberta, Naismith (1964) found that valley walls are covered by old landslide deposits. Where the river is eroding into the toe of the valley wall active landslides occur (Naismith, 1964). The inactive areas are located where the slides terminate either on the present floodplain, some distance back from the river, or on terraces overlooking the river. The slides do not encroach out onto the terraces and when stream bank erosion ceases the landslides soon come to a halt. This indicates that renewed erosion at the toe of an inactive landslide could easily reactivate it (Naismith, 1964).

Croft and Adams' (1950) work on the North Fork of the Ogden River demonstrated that landslides may also be significant sources of sediment load in a stream. On May 17 and 18, 1949, unusually heavy rainstorms occurred and the resulting landslides were a major source of sediment in the Pineview Reservoir during the high stream discharge after the storm (Croft and Adams, 1950). There was about 7 hectare meters of sediment deposited in the reservoir which in the average year gets roughly 0.3 hectare meters of sediment. The largest landslides occurred on north facing tree covered slopes while the smallest were on brush covered south facing slopes.

Finally, Watson and Wright (1963) in the Chaska Mountains of New Mexico mapped landslide debris extending as far as eight miles away from the present mountain escarpment. They dated the oldest landslides as older than the oldest Wisconsin moraine in the nearby San Juan Mountains.

In summary, it appears that the most useful classification is that proposed by Varnes (1958). There are numerous factors controlling the distribution of landslides. Landslides can be recognized by systematic study and occur over wide areas of similar geologic setting. In the western United States landslides are important in the erosion process.

APPENDIX B: OBSERVATION ON THE STRUCTURE OF THE BIGHORN MOUNTAINS

During the academic year 1975-76 a photogeologic map of the entire Bighorn National Forest was prepared using color aerial photographs of a scale of approximately 1/16,000. The following is an observation based on that work, which is unrelated to the subject of landslides.

The shape of the central and northern Bighorn Mountains is controlled by major faults paralleling the mountain front (Figure 50). The faults are located in the Precambrian crystalline basement rocks and frequently appear as monoclines or other folds where the overlying Paleozoic rocks are present. They are referred to as the Hunt Mtn. Lineament, the Trapper Creek Fault, and the Dry Fork Fault.

Demorest (1941) divided the Bighorn Mountains into three segments, based on the asymmetry of the adjacent segments. The northern segment is more steeply dipping to the west. It extends from the Pryor Mountains of Montana, southward to approximately the point where Shell Creek and the Tongue River transect the Bighorn Mountains. The central segment is more steeply dipping to the east, and runs from the Shell Creek-Tongue River junction south to the Tensleep fault. The southern segment is located south of the Tensleep fault and is more steeply dipping to the west.

The Bighorn Mountains make an abrupt change in trend along a line stretching from Shell Creek on the west to Goose Creek on the east. South of this line the mountain range trends north-south. North of this line the range trends northwest-southeast (Figure 50). The change in trend on the west side of the mountains occurs where the Hunt Mountain Lineament and the Trapper Creek Fault in Figure 50 intersect. On the east side of

Figure 50. Map of major faults in Bighorn Mountains.

9 = Little Goose Creek

8 = Tongue River

7 = Shell Creek

6 = Tensleep Creek

5 = Approximate area underlain by Mesozoic age rocks

4 = Area underlain by Paleozoic age rocks

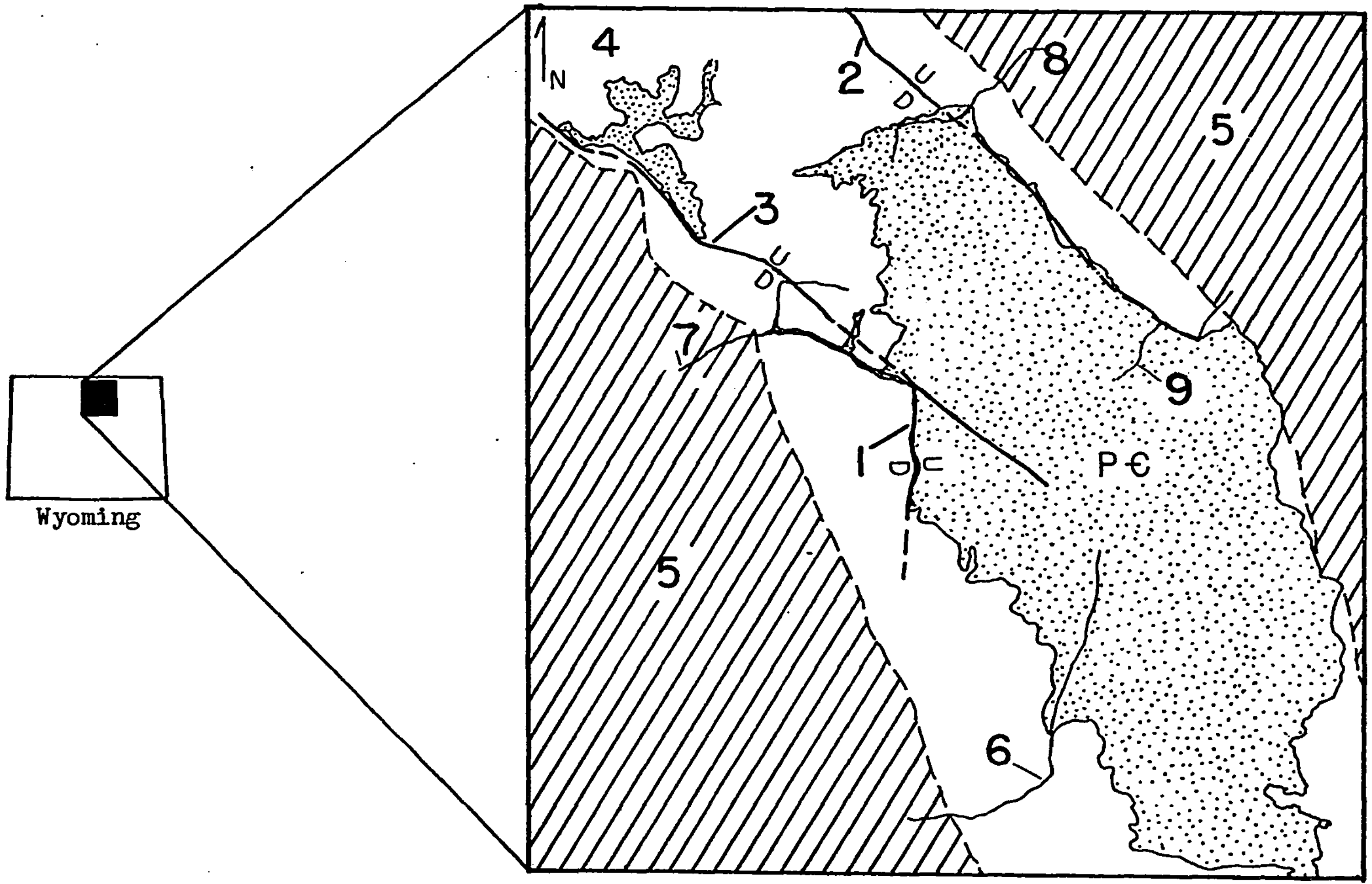
PC = Area underlain by Precambrian age rocks

3 = Hunt Mountain Lineament

2 = Dry Fork Fault

1 = Trapper Creek Fault

0 Scale 20 km



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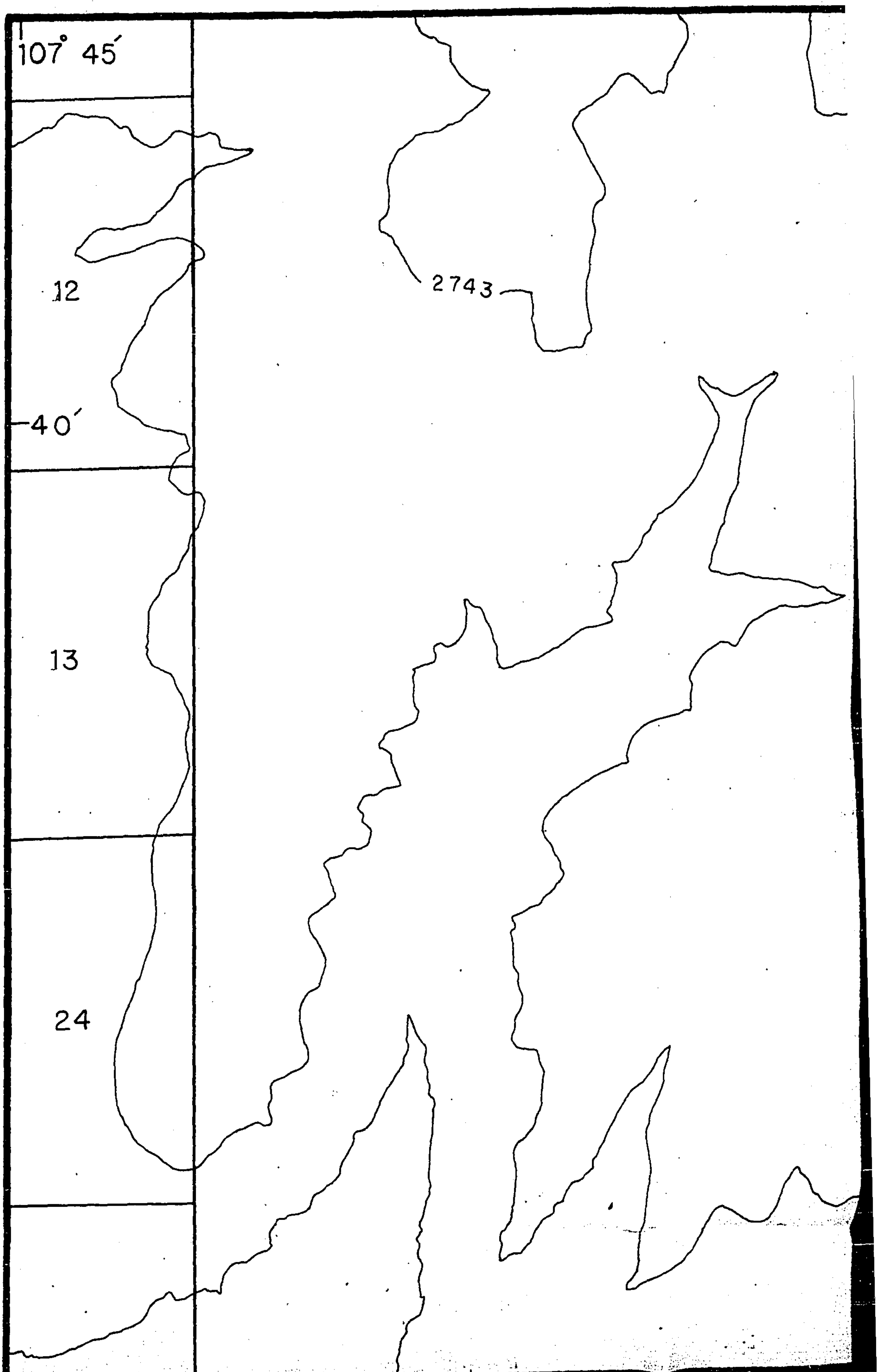
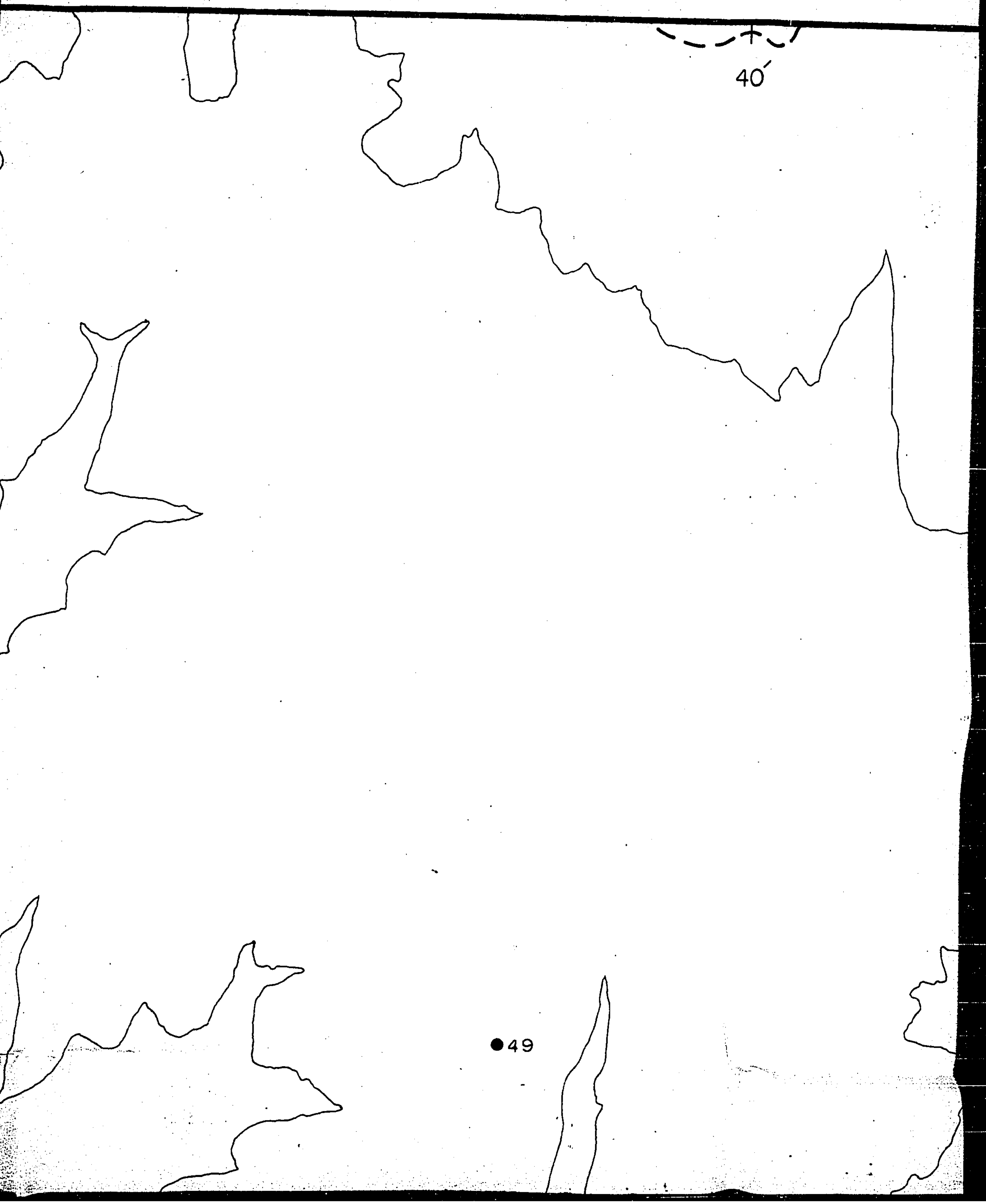
the mountains the change in trend occurs where the Dry Fork Fault intersects the Goose Creek area. The east side of the Dry Fork Fault is upthrown relative to the west side. It is apparent that either there must be an additional fault to the east of the Dry Fork Fault with the west side upthrown, or the direction of movement on the Dry Fork Fault has reversed. Otherwise, the Precambrian surface could not have attained its present elevation. South of the Goose Creek area the presence of a major fault paralleling the mountain front could not be observed due to heavy tree cover, but it would be reasonable to assume that such a fault exists.

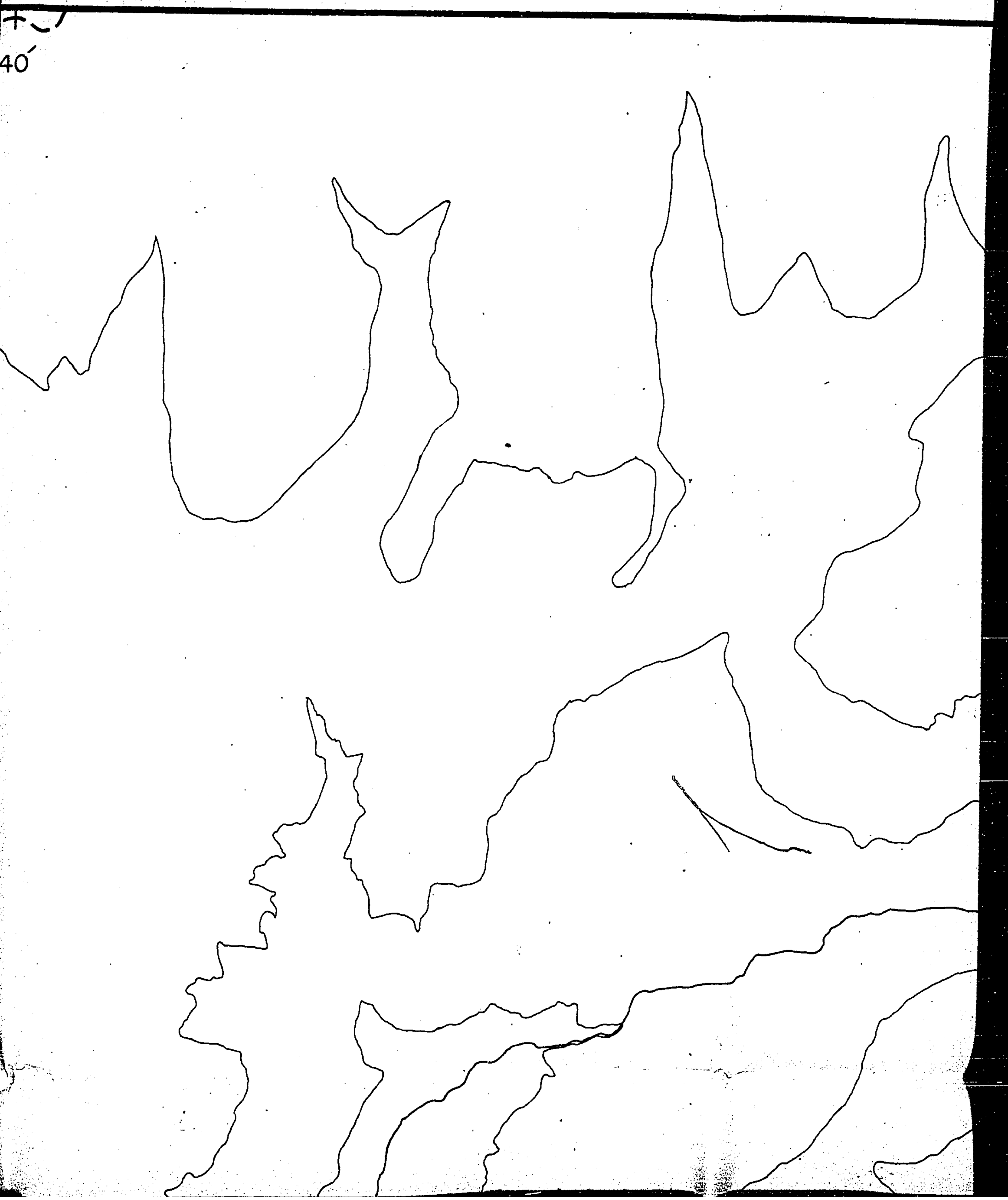
It is proposed that the boundary between the northern and central segments of the Bighorn Mountains be moved southward to a line from Shell Creek to Grouse Creek. This boundary conforms to the change in trend of the mountain front and the intersection of the basement faults.

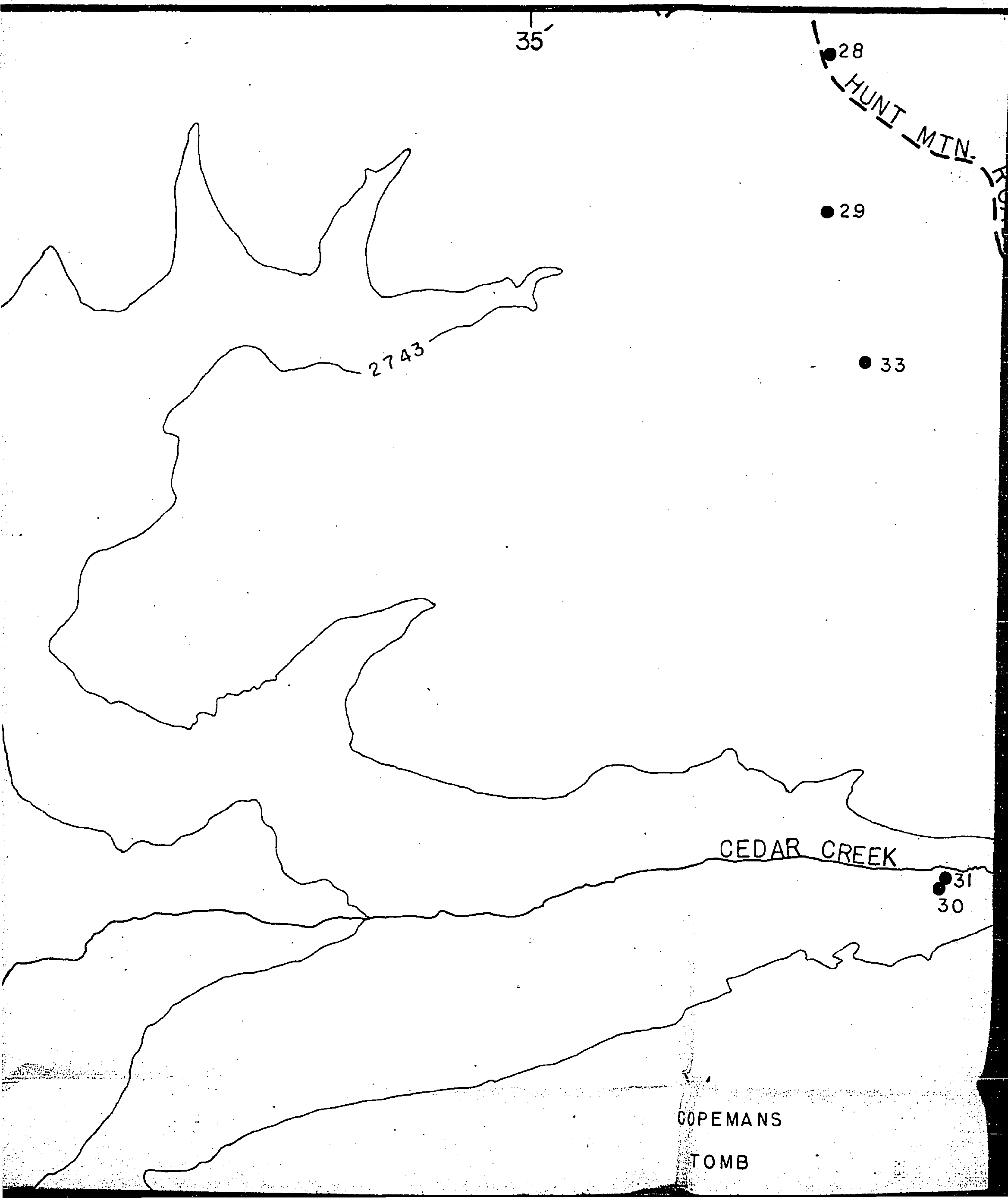
It has been proposed by Hoppin and Palmquist (1965) that Laramide structural features in the Bighorn Mountains are controlled by Precambrian age zone of weakness in the crystalline basement rocks of the mountains. Field evidence in the Shell Canyon area supports this. Where the Hunt Mountain Lineament crosses Cedar Creek there is approximately 240 meters of offset between adjacent sides of the monoclinal flexure on the north side of Cedar Creek Canyon (Figure 7). On the south side of Cedar Creek Canyon the offset has decreased to 180 meters. In the vicinity of Grouse Creek there is only 60 meters of offset. However, the lineament itself continues to the southeast up Shell Creek. This is inferred to mean that only the part of the lineament near the present mountain front was reactivated during the Laramide orogeny.

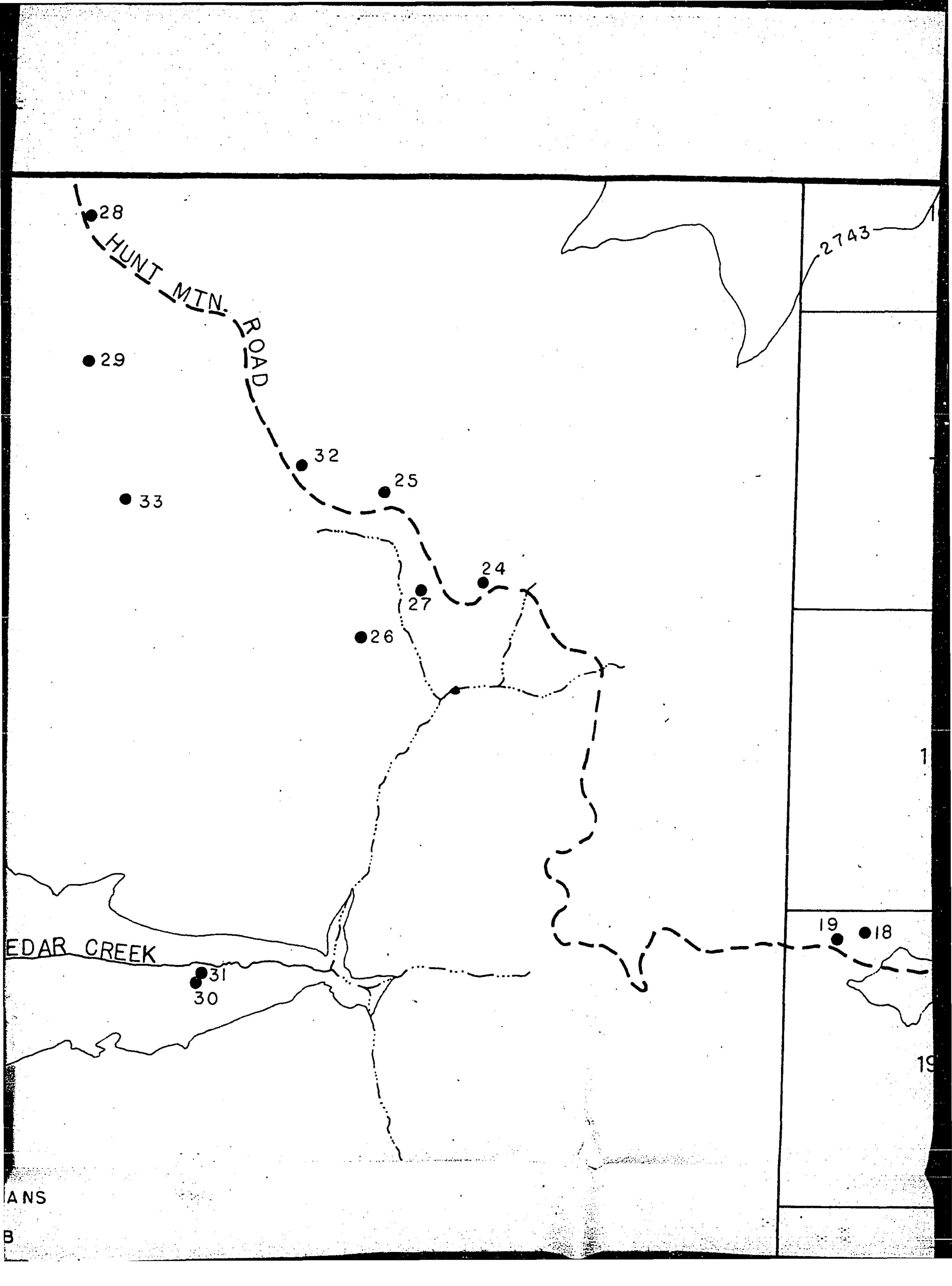
Hoppin and Jennings (1971) suggest that east-west structural lineaments in the central Bighorn Mountains may be the most significant structural elements in the Wyoming Province. They propose that these lineaments are the surface expression of transcurrent faulting (transform faults) originating in the lower part of the lithosphere due to the North American plate overriding the East Pacific Rise. These lineaments are located on the Precambrian crystalline core of the range. Their striking nature on either topographic maps or Landsat photos is due to the fact that they have been preferentially eroded by Pleistocene glaciers. However, where these lineaments intersect Paleozoic bedrock, no movement was observed. It therefore appears that these lineaments are unrelated to vertical uplift of the mountains during the Laramide Orogeny.


107° 45′
12
40′
13
24
25
2743


40′
49


40´


35'
28
HUNT MTN. RD.
29
2743
33
CEDAR CREEK
31
30
COPEMANS
TOMB



28
HUNT MTN. ROAD
29
32
25
33
24
27
26
2743
EDAR CREEK
31
30
19
18
ANS
B

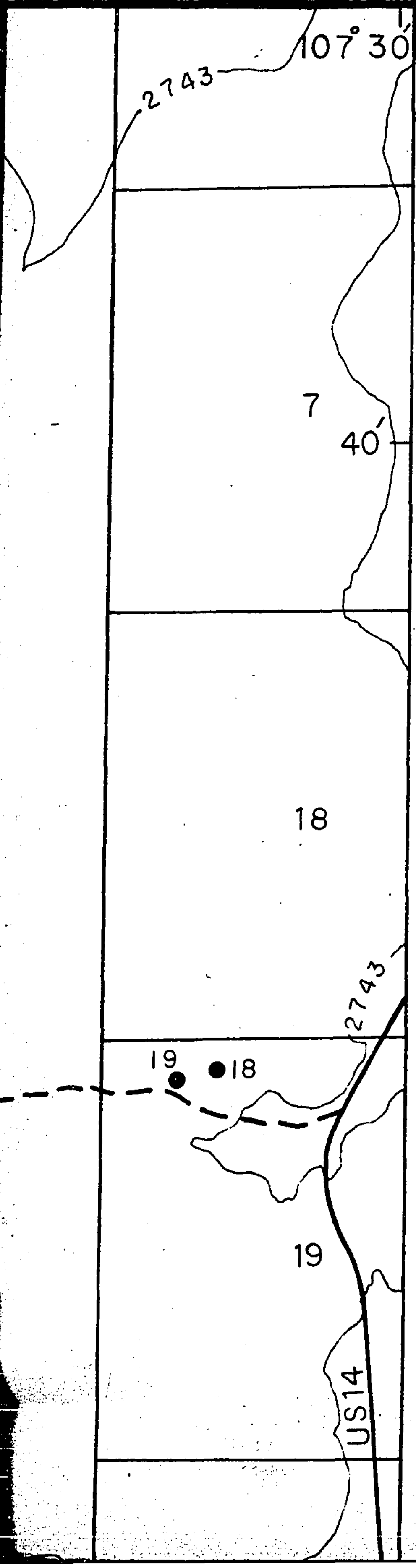


FIG. 51
GENERAL LOCA
SHELL CAN

LEGEN

● SOIL PIT
— ROAD CUT
■ PENETRATION TE
○ LANDSLIDES STAT
ANALYZED

SCALE

1 .5 0

CONTOUR INTERVAL 3

FIG. 51

GENERAL LOCATION MAP

SHELL CANYON

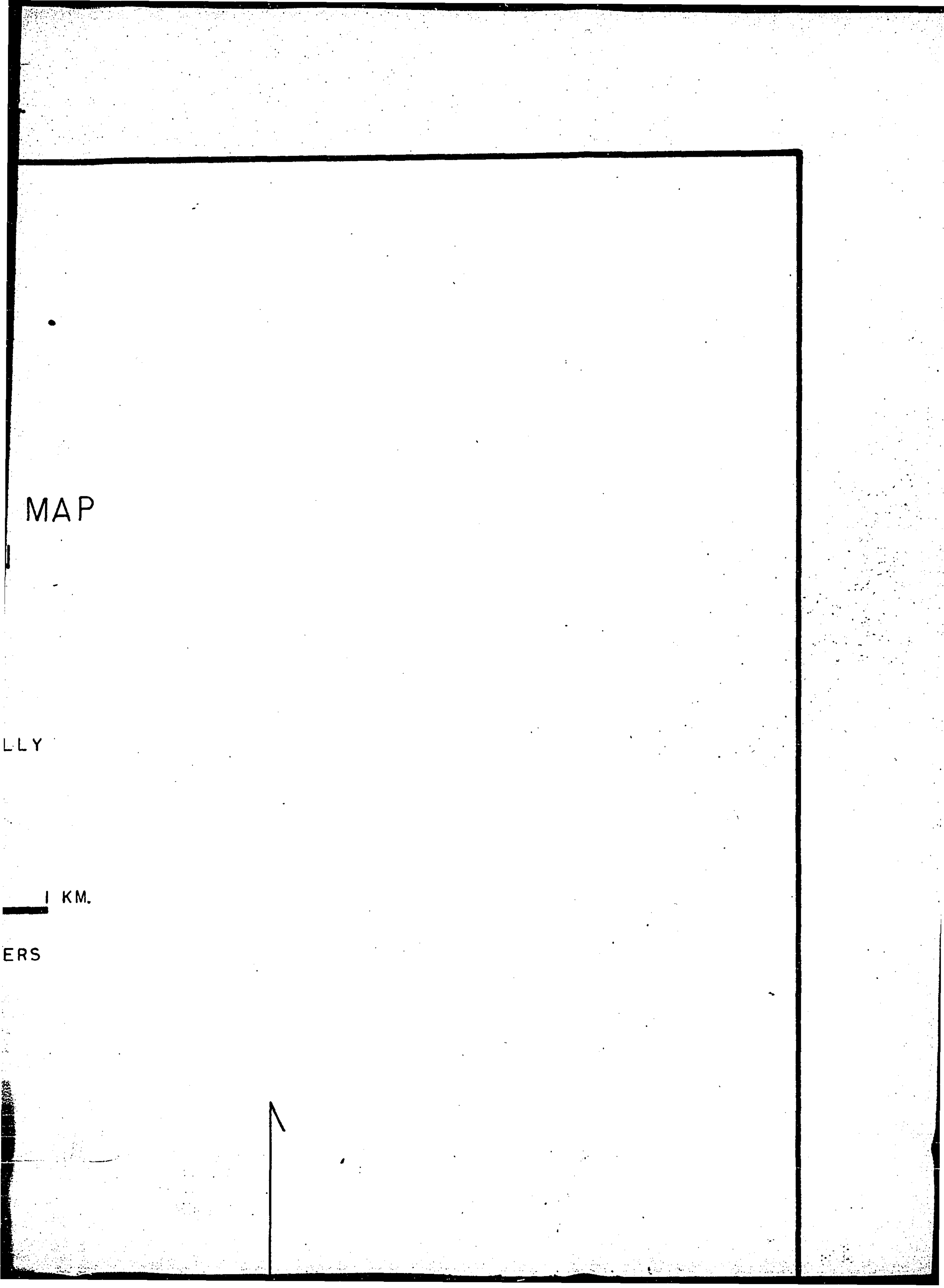
LEGEND

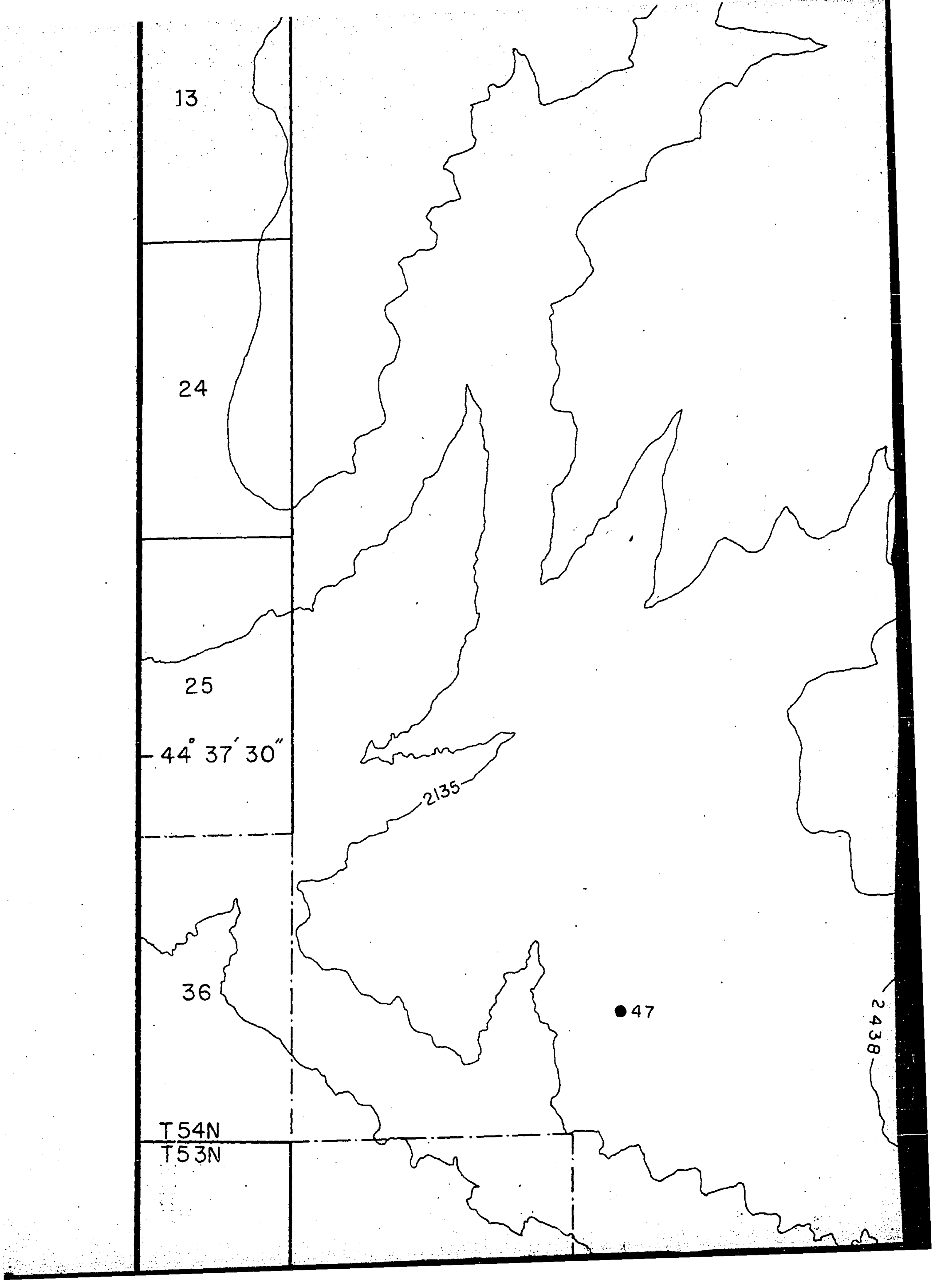
- ● SOIL PIT
- — ROAD CUT
- ■ PENETRATION TEST
- ○ LANDSLIDES STATISTICALLY ANALYZED

SCALE

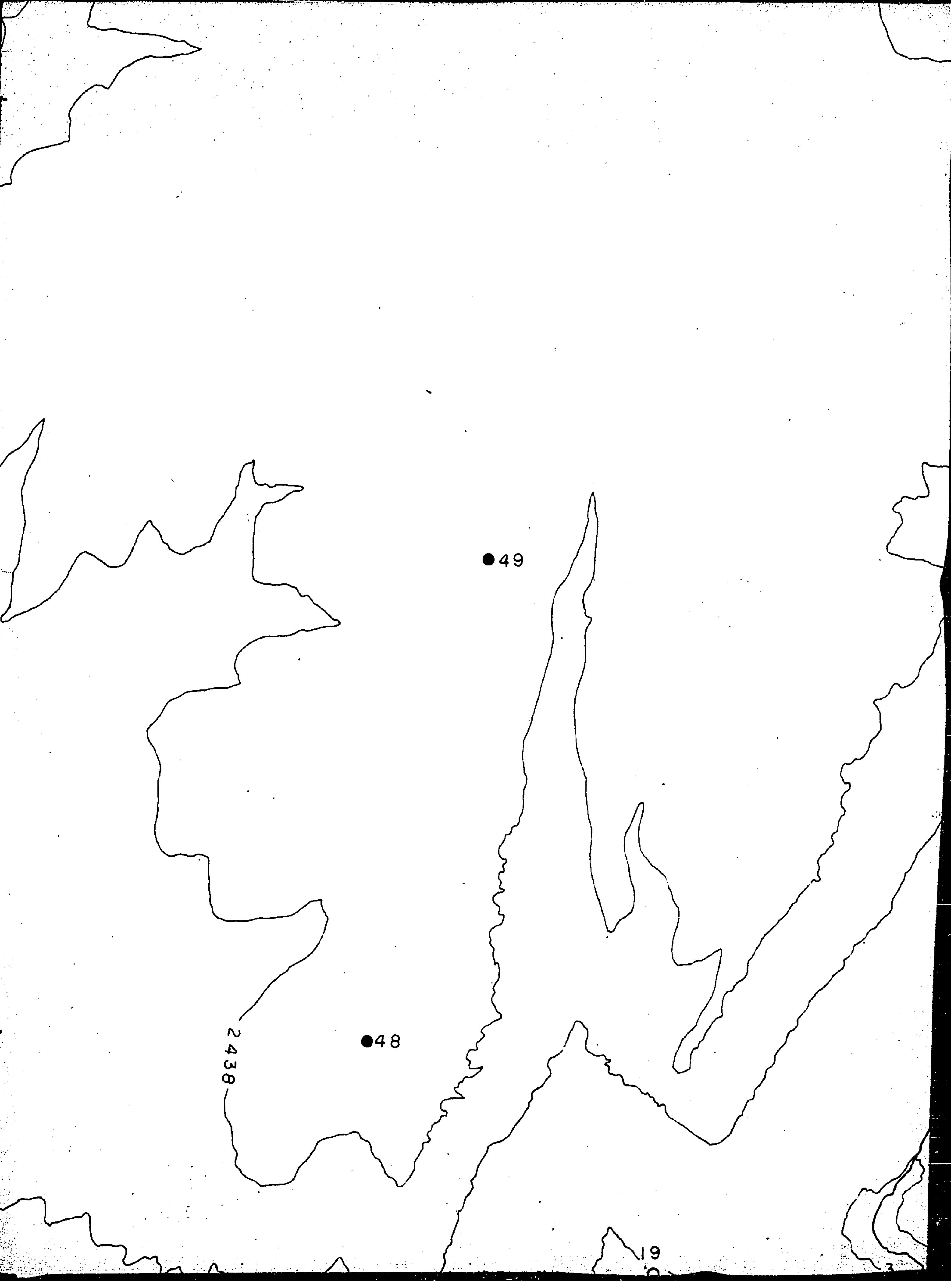
1 .5 0 1 KM.

CONTOUR INTERVAL 305 METERS

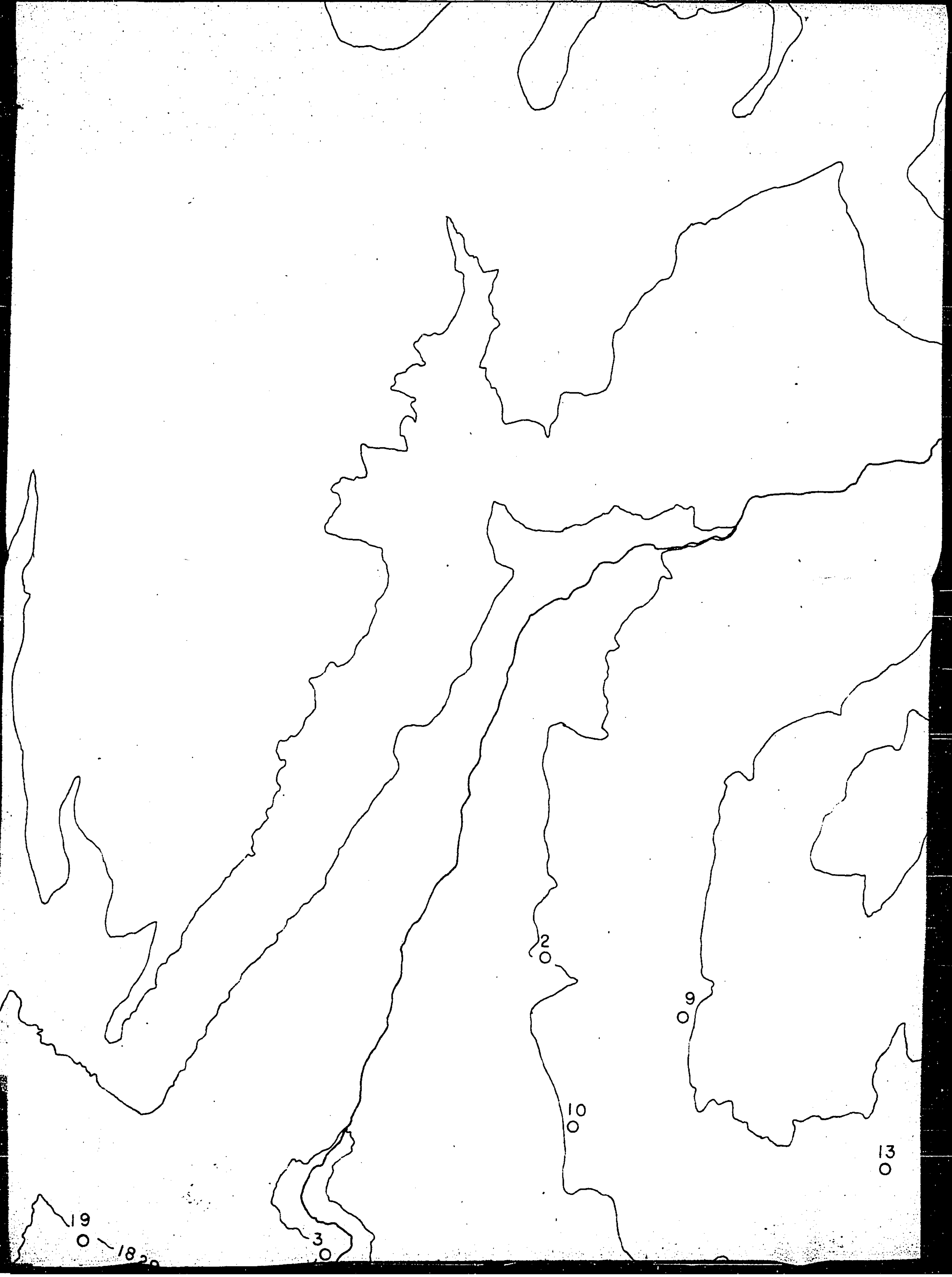

MAP
LLY
1 KM.
ERS



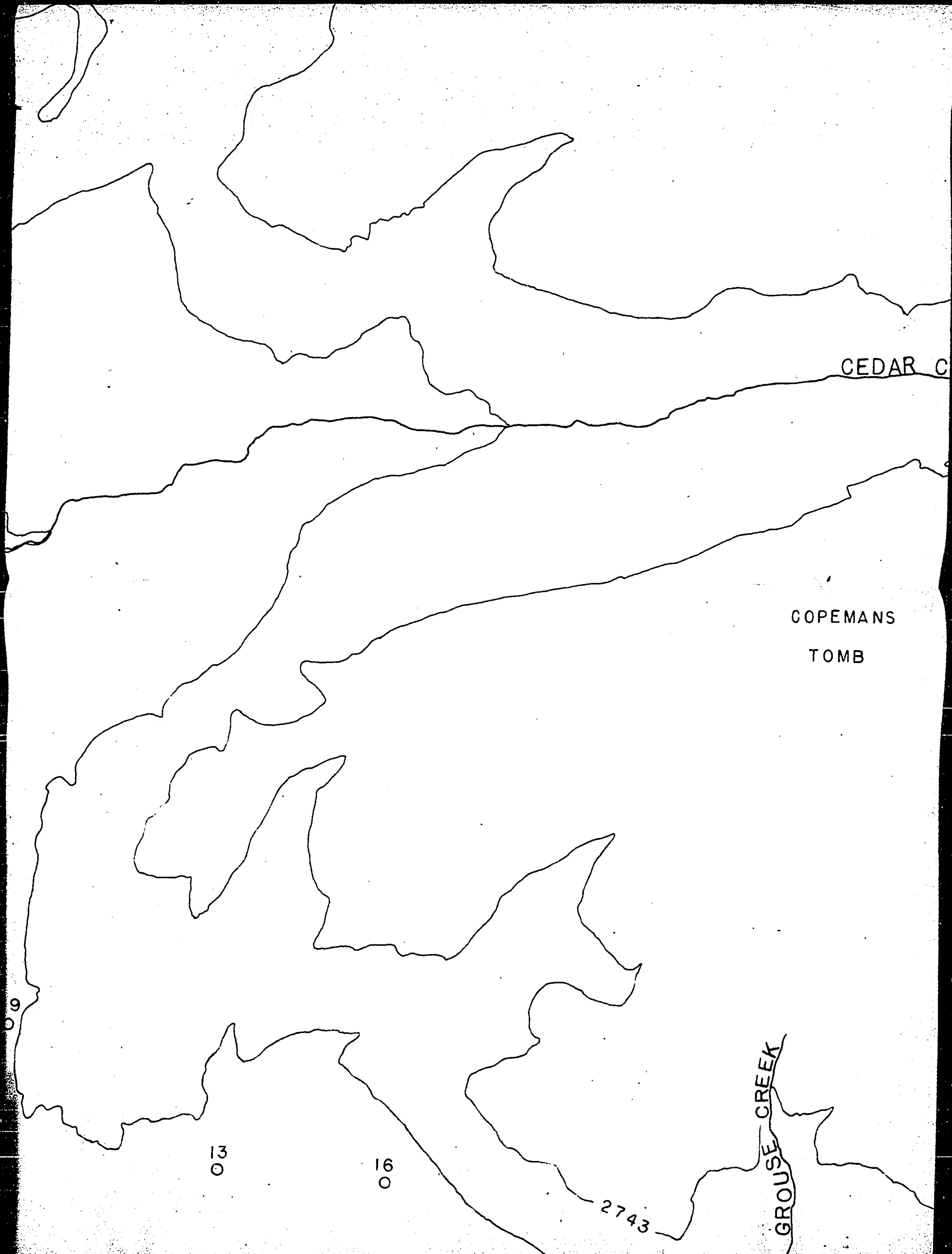
13
24
25
44° 37′ 30″
2135
36
47
2438
T54N
T53N



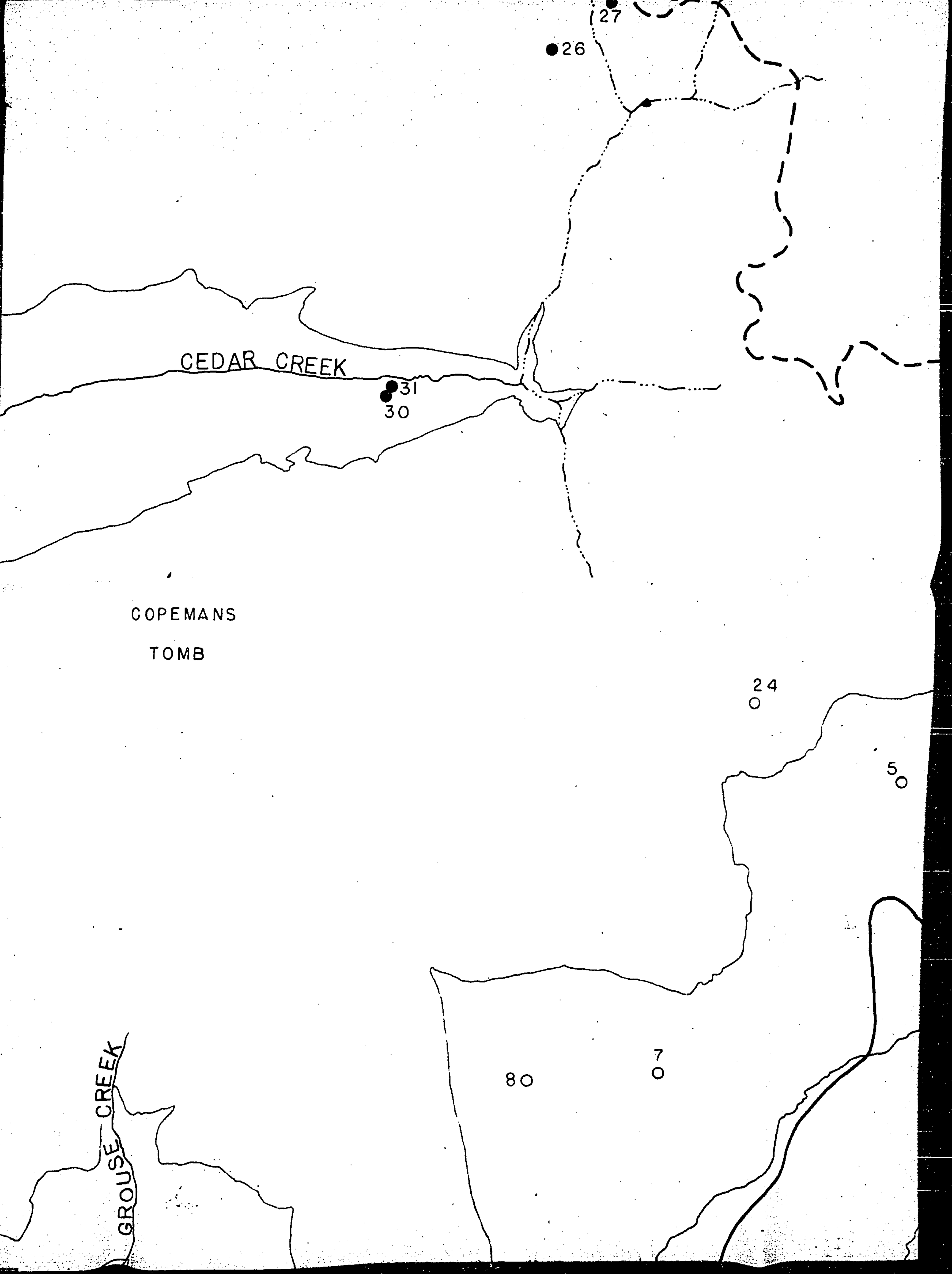
49
48
2438
19

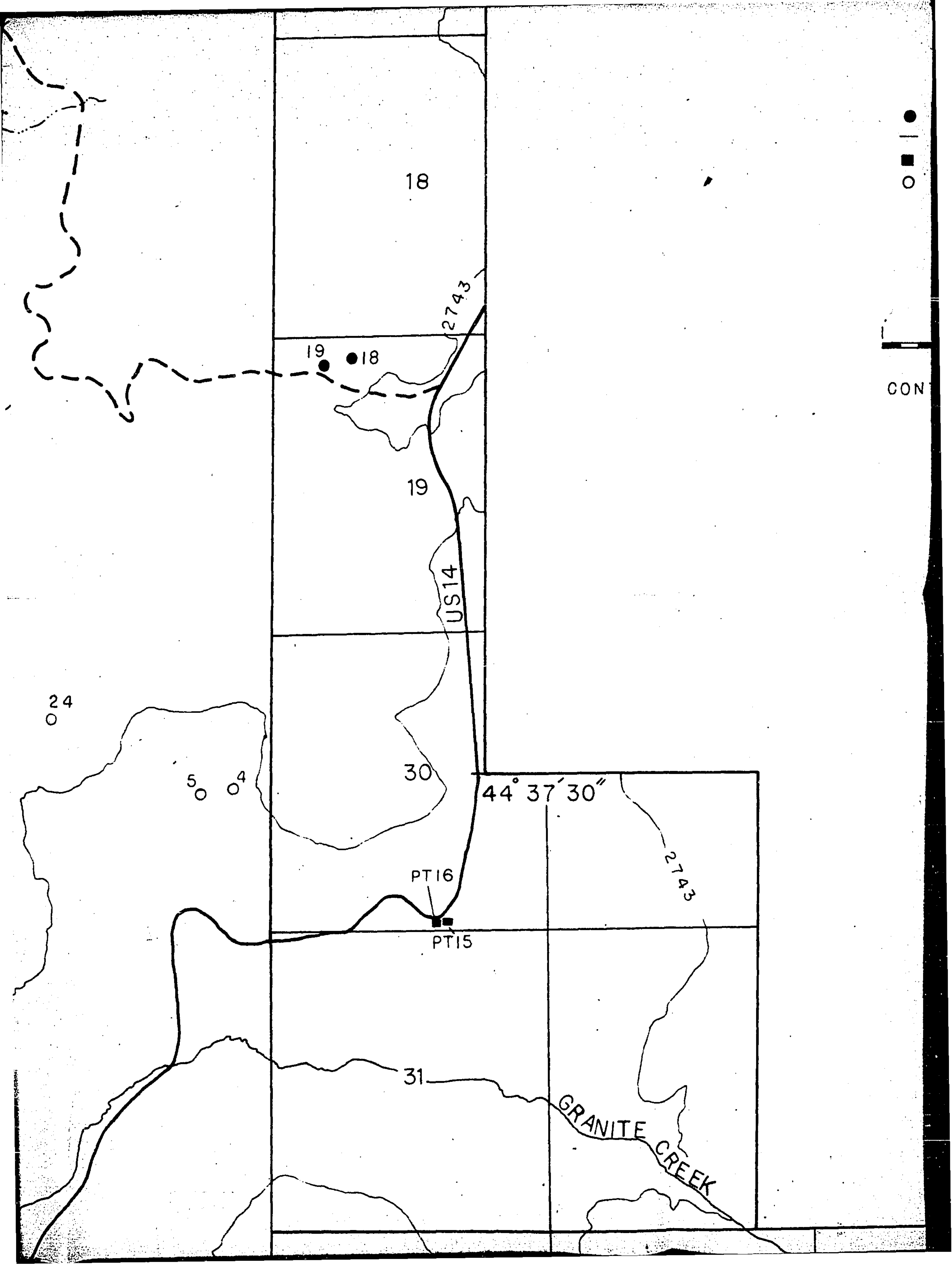


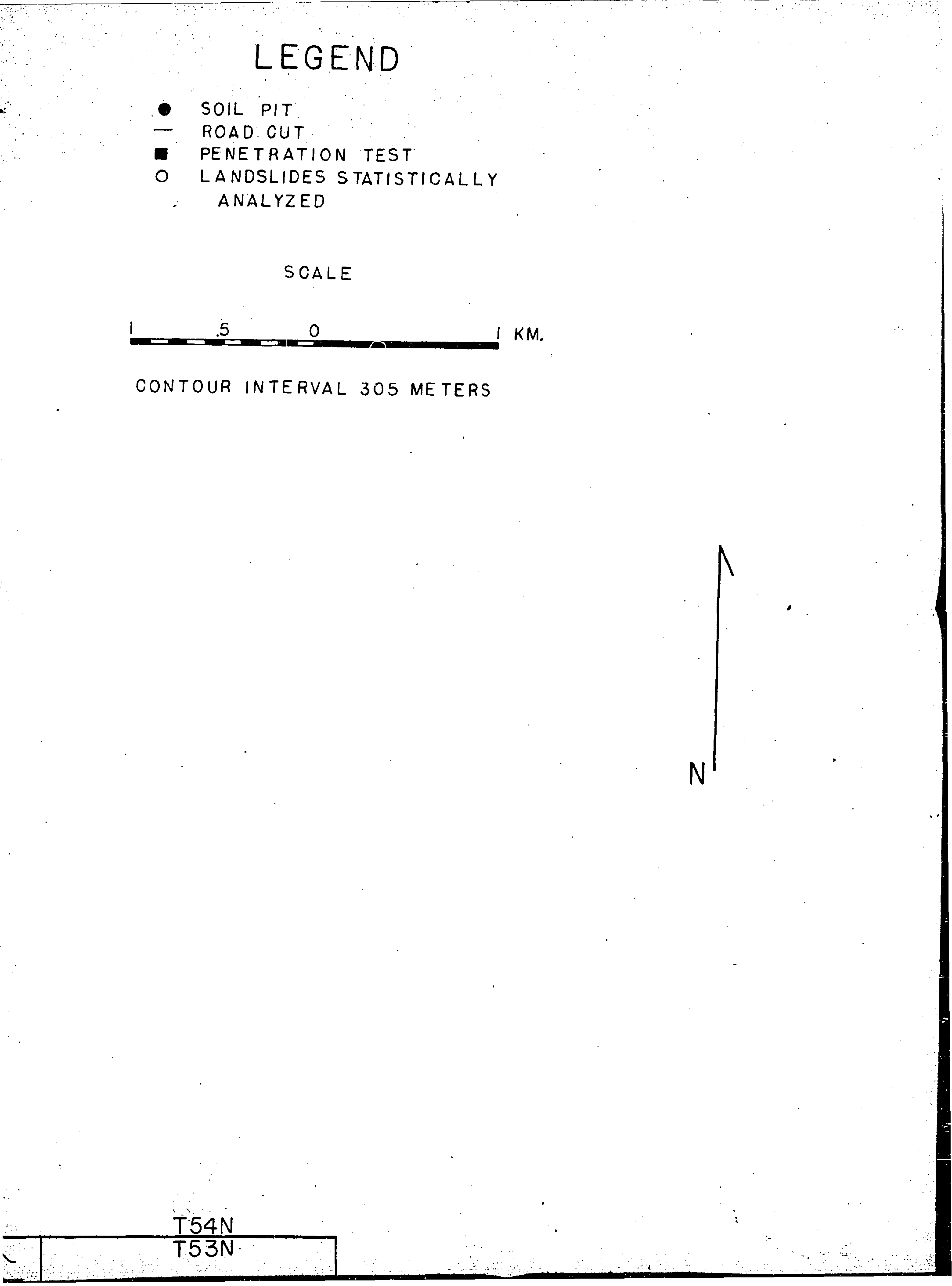
2
9
10
13
19
18
3

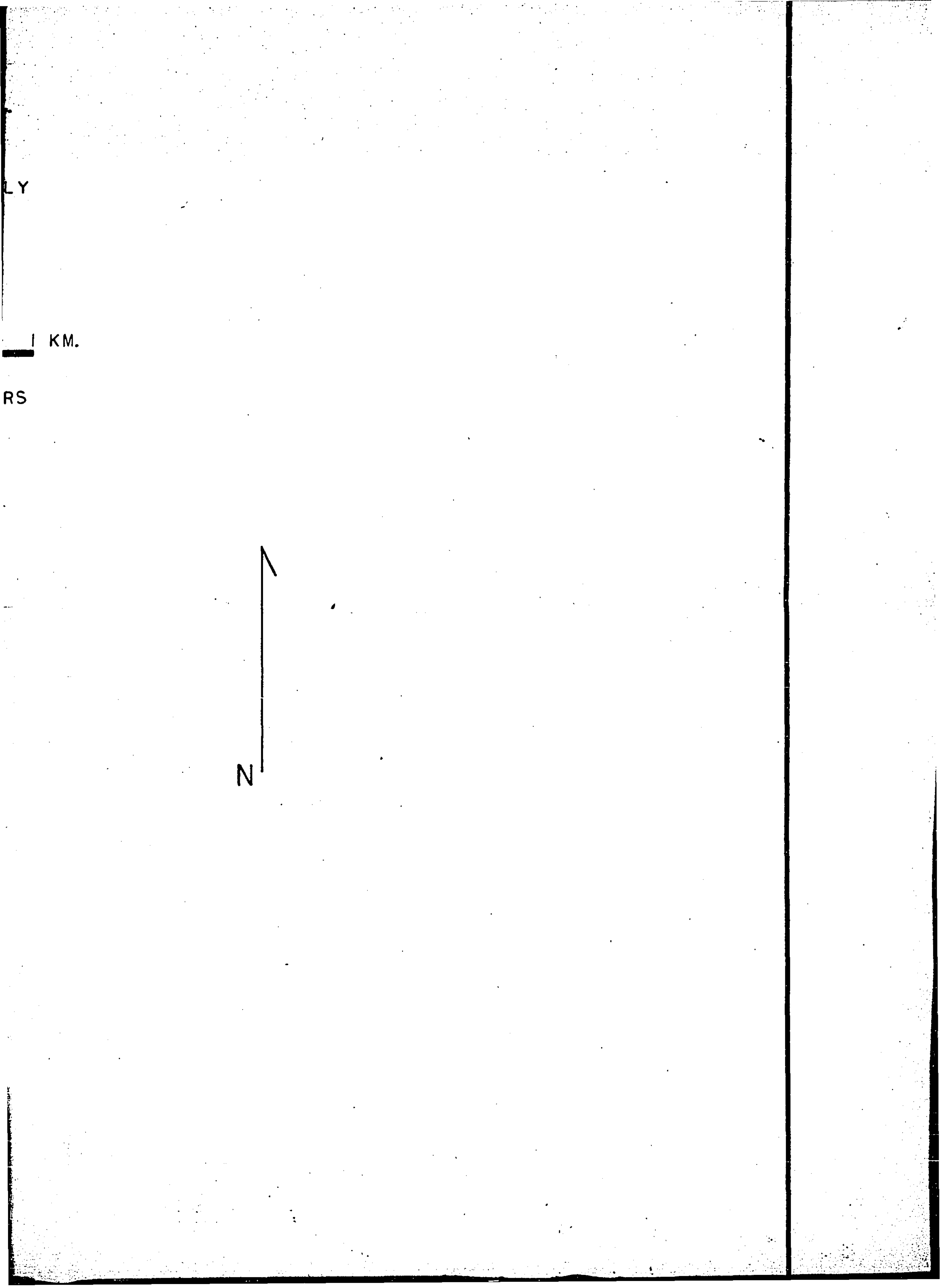


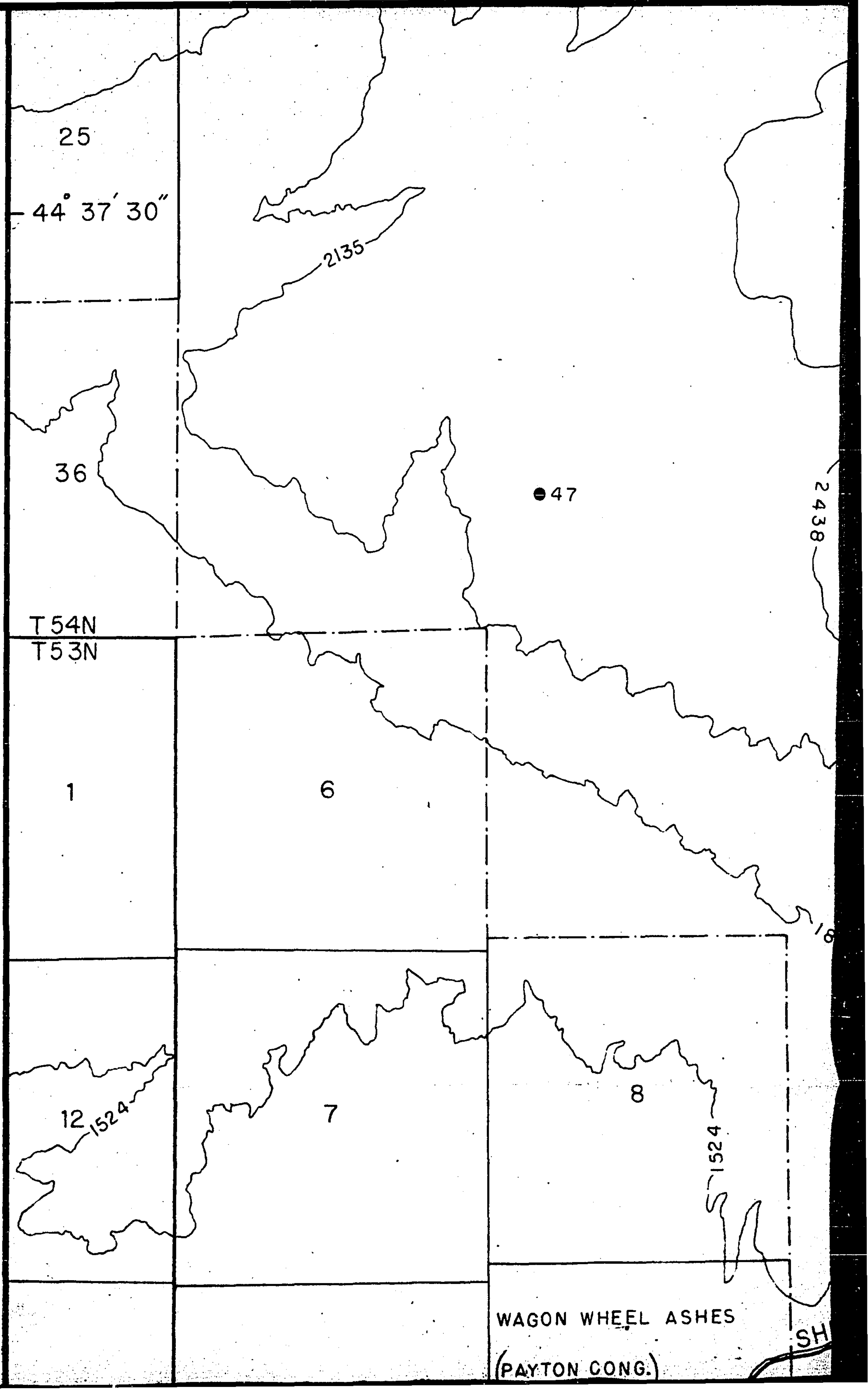
CEDAR C
COPEMANS
TOMB
9
13
16
2743
GROUSE CREEK

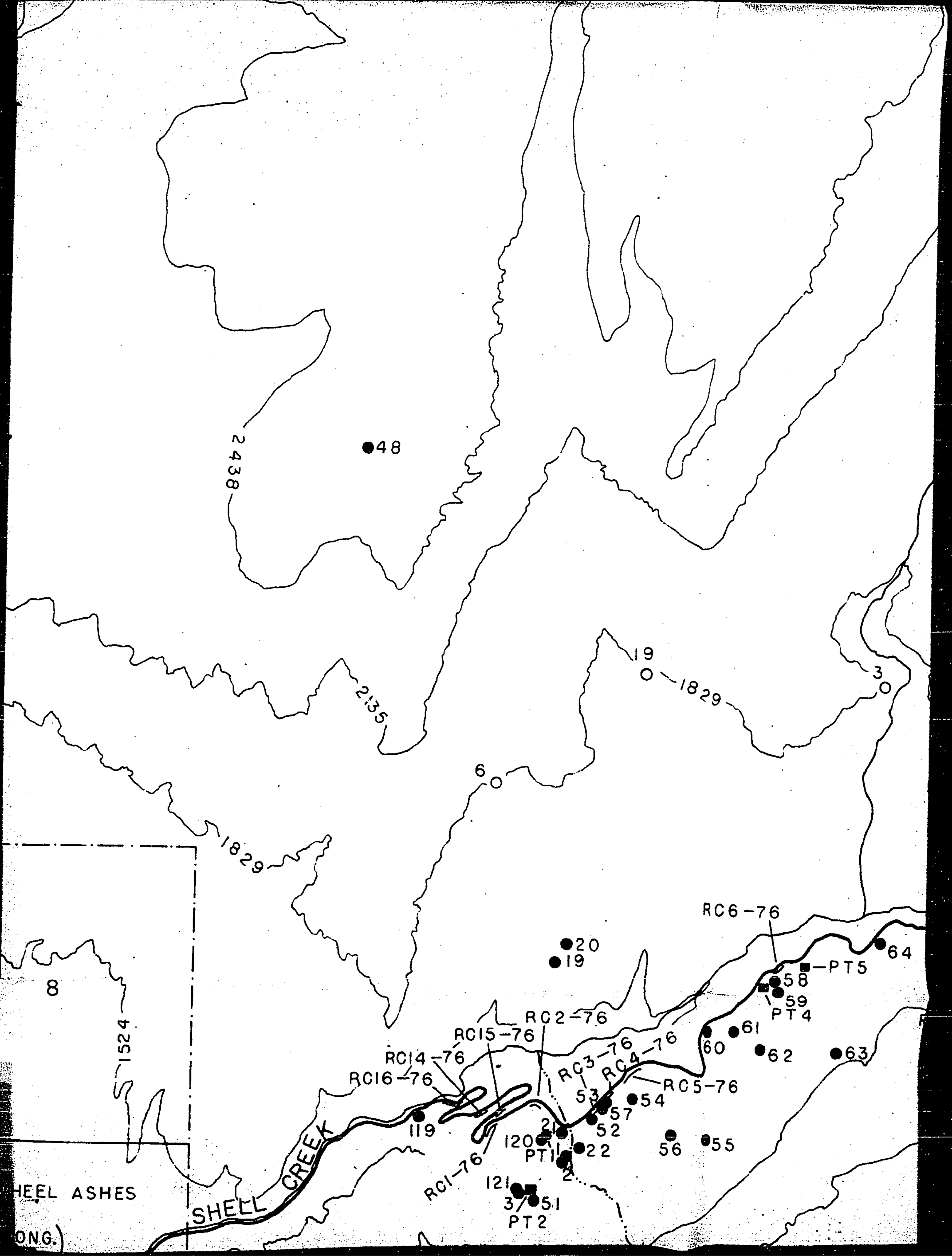

27
26
CEDAR CREEK
31
30
COPEMANS
TOMB
24
5
7
8
GROUSE CREEK


18
2743
19
18
19
US14
24
5
4
30
44° 37′ 30″
2743
PT16
PT15
31
GRANITE CREEK
CON

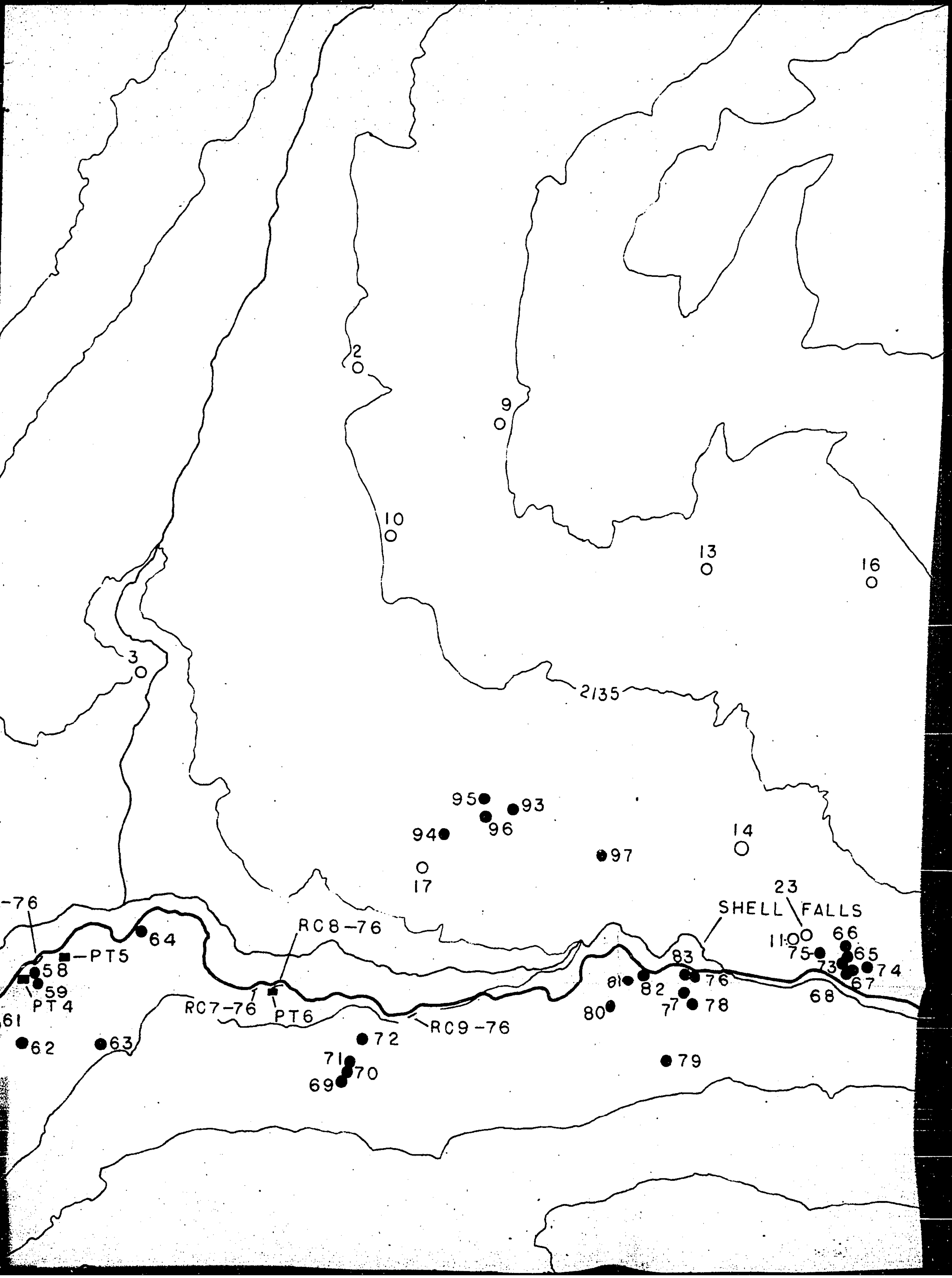

LEGEND
SOIL PIT
ROAD CUT
PENETRATION TEST
LANDSLIDES STATISTICALLY ANALYZED
SCALE
1 .5 0 1 KM.
CONTOUR INTERVAL 305 METERS
N
T54N
T53N


LY
1 KM.
RS
N


25
44° 37′ 30″
2135
36
47
2438
T54N
T53N
1
6
12
1524
7
8
1524
WAGON WHEEL ASHES
(PAYTON CONG.)
SH



2438
48
2135
19
1829
3
6
1829
8
1524
RC6-76
20
19
64
PT5
58
59
PT4
RC2-76
RC15-76
61
60
62
63
RC14-76
RC3-76
RC4-76
RC16-76
RC5-76
53
54
57
119
52
21
120
56
55
PT1
22
2
RC1-76
121
3
51
PT2
SHELL CREEK
HEEL ASHES
ONG.



2
9
10
13
16
3
2135
95
93
94
96
97
14
17
23
SHELL FALLS
-76
64
RC8-76
PT5
58
59
PT4
RC7-76
PT6
RC9-76
61
62
63
72
71
70
69
83
81
82
76
80
77
78
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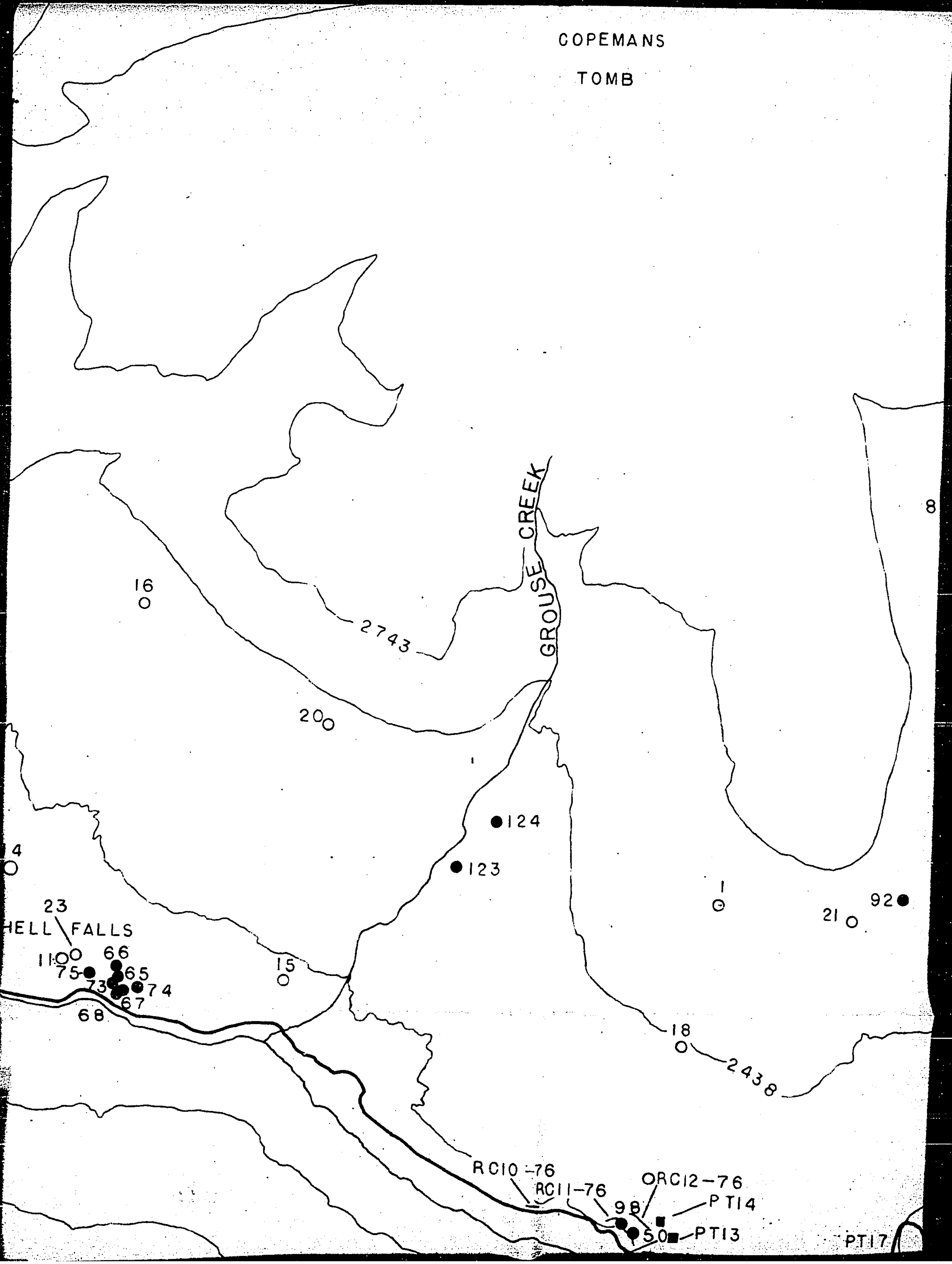
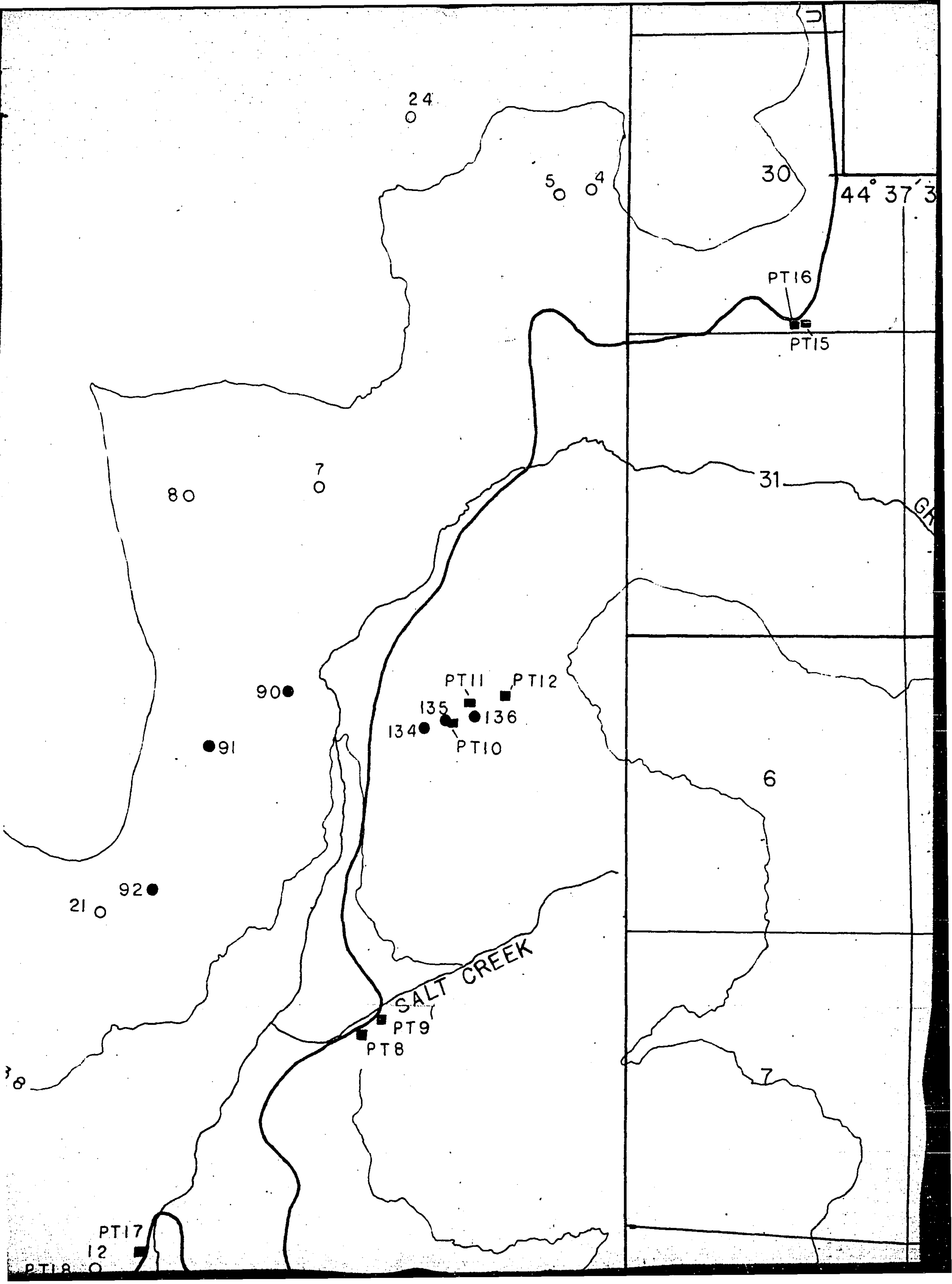
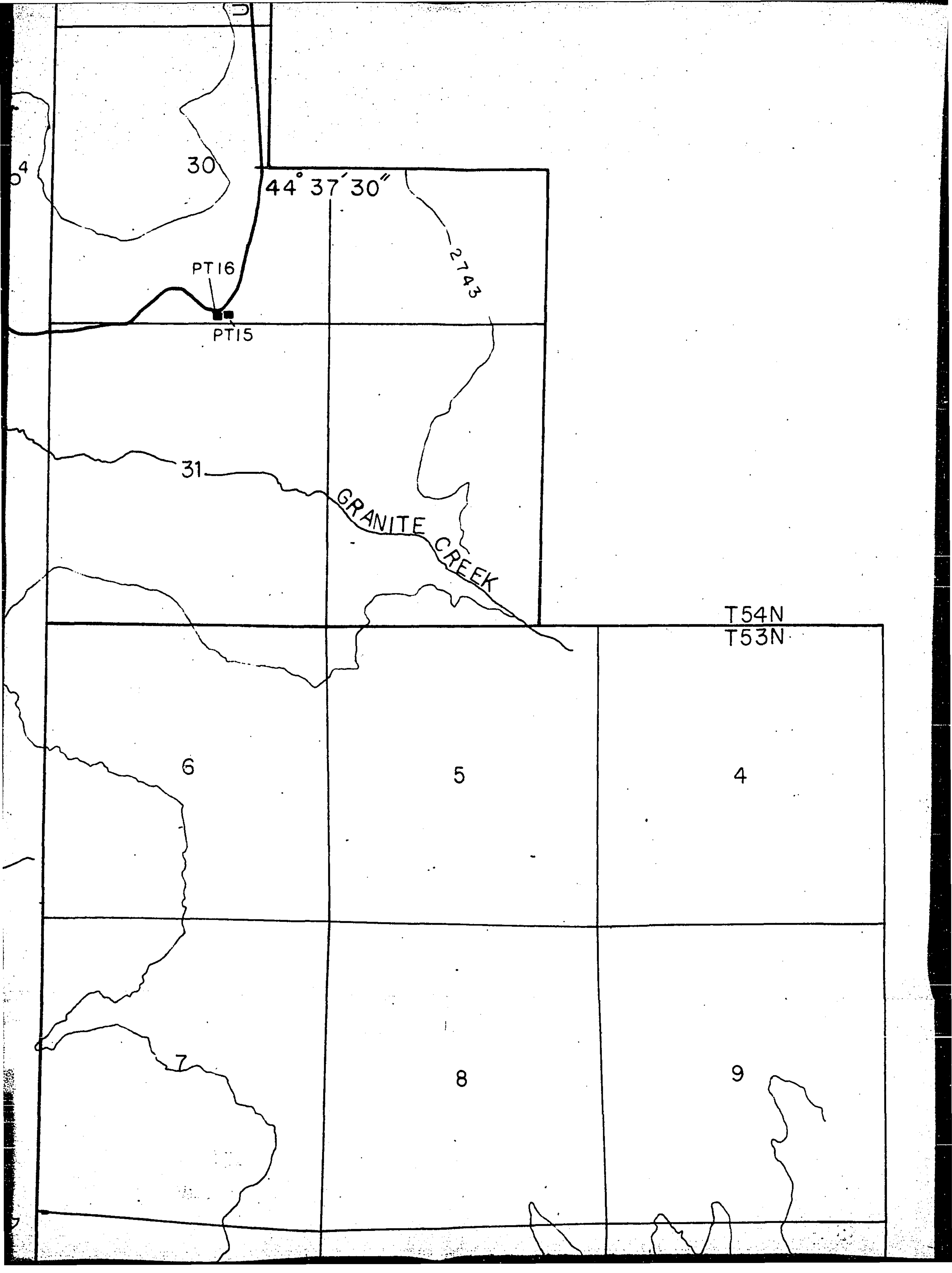
11
75
66
65
73
74
67
68

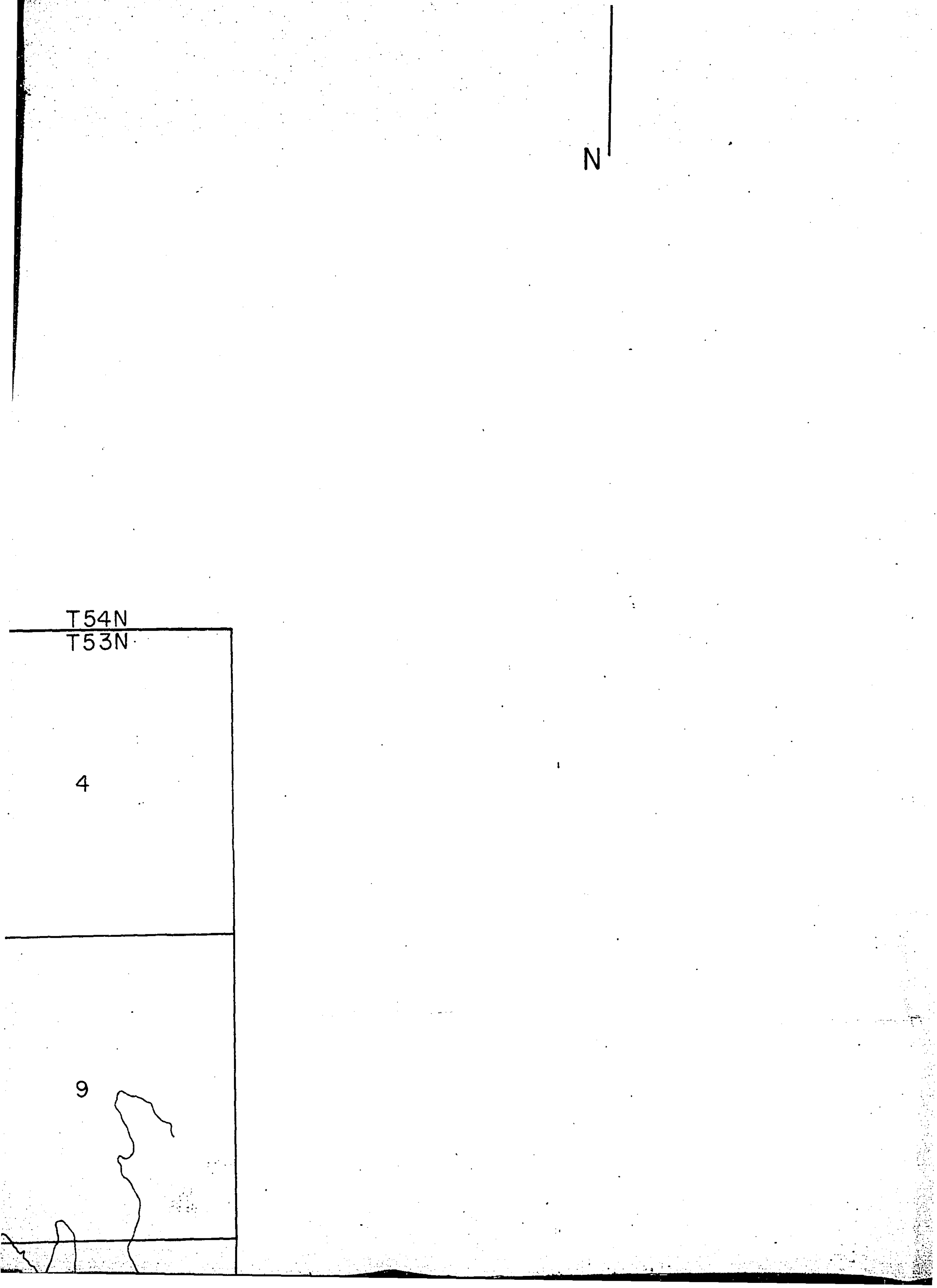

COPEMANS
TOMB
GROUSE CREEK
2743
2438
16
20
1
8
14
23
HELL FALLS
11
66
75
65
73
74
67
68
15
124
123
92
21
18
RC10-76
RC11-76
RC12-76
98
50
PT14
PT13
PT17



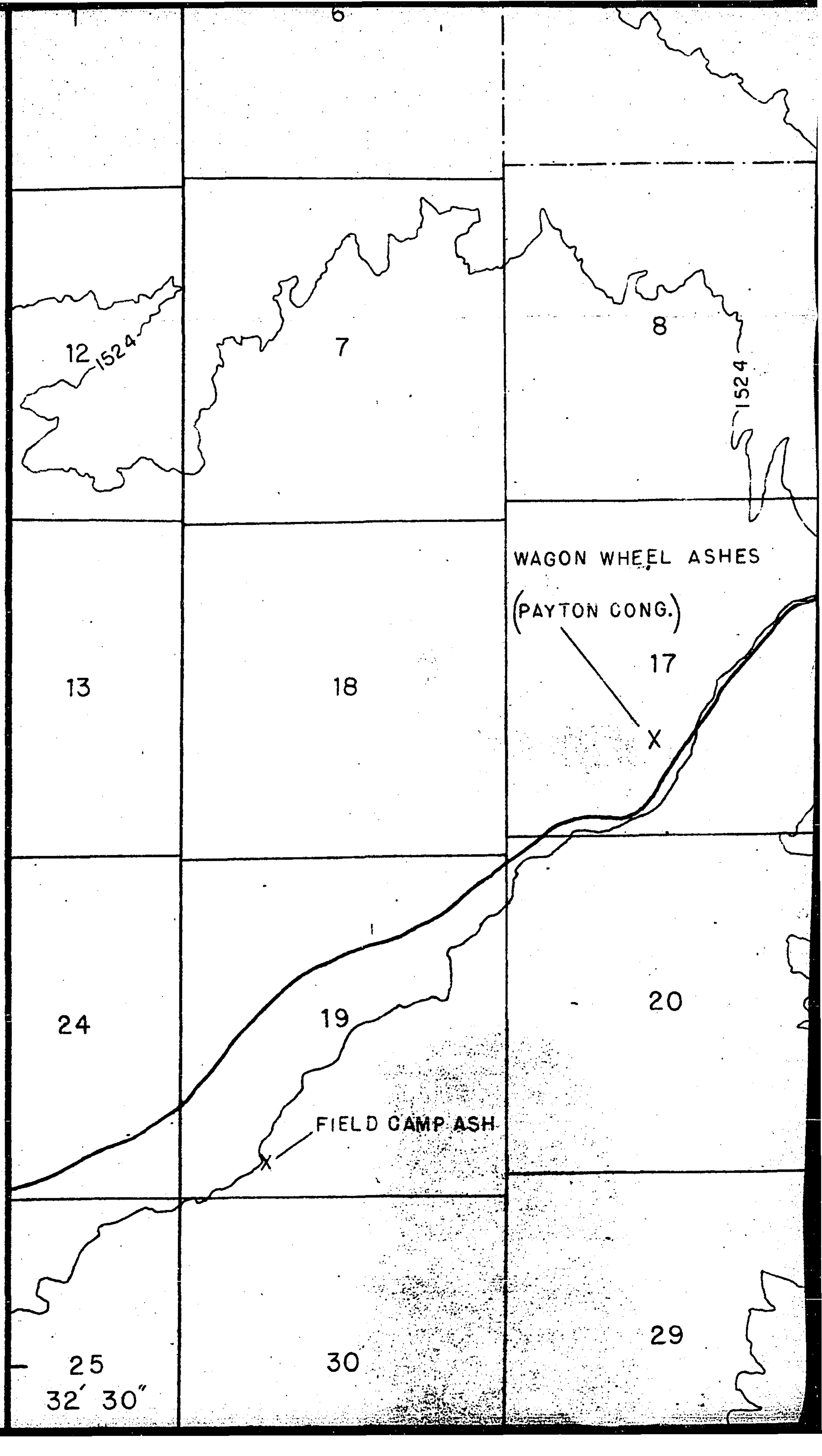
24
5
4
30
44° 37' 3
PT16
PT15
7
8
31
GR
90
91
PT11
PT12
135
136
134
PT10
6
92
21
SALT CREEK
PT9
PT8
8
7
PT17
12
PT18



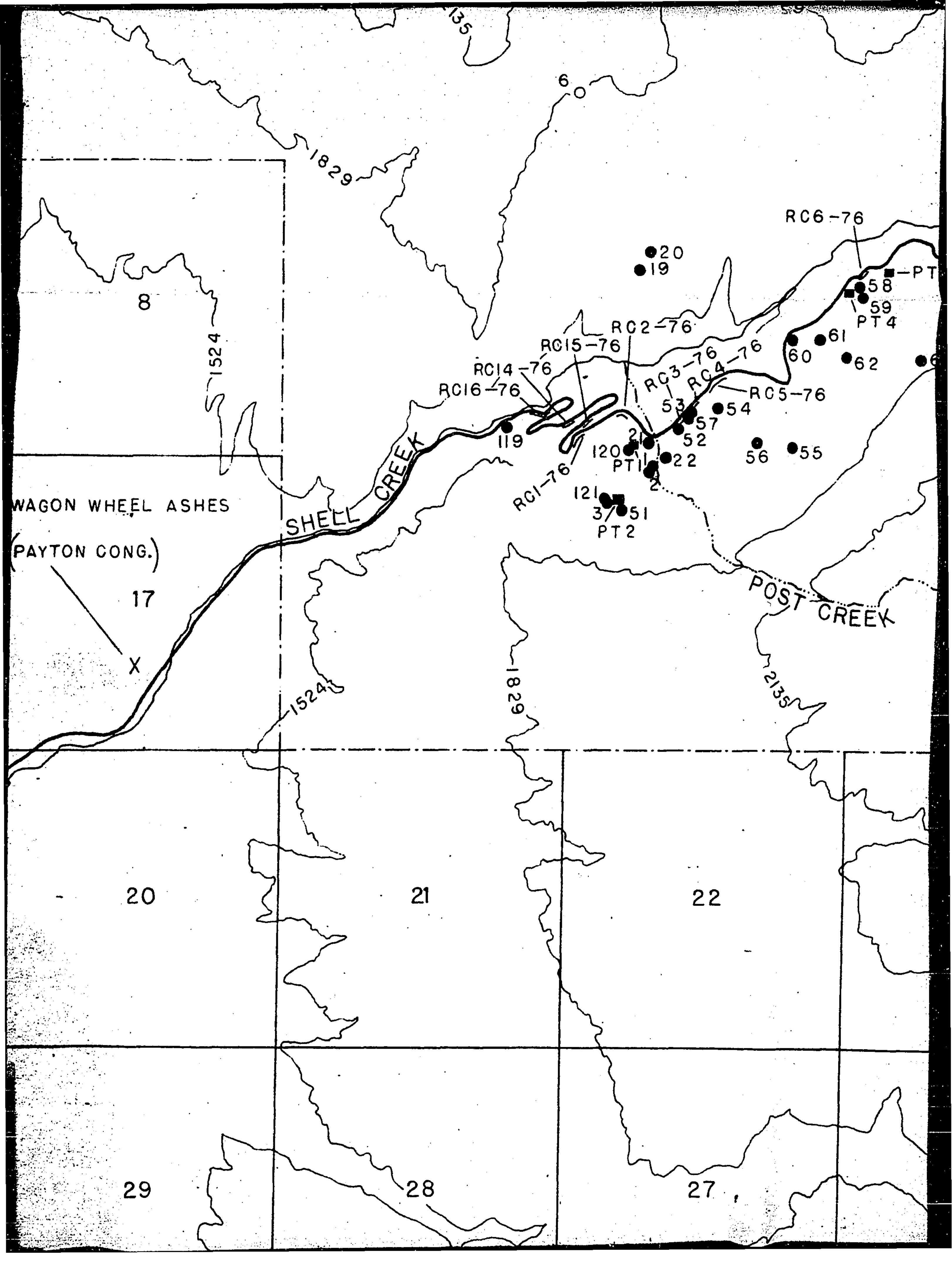
30
44° 37' 30"
2743
PT16
PT15
31
GRANITE CREEK
T54N
T53N
6
5
4
7
8
9


N
T54N
T53N
4
9

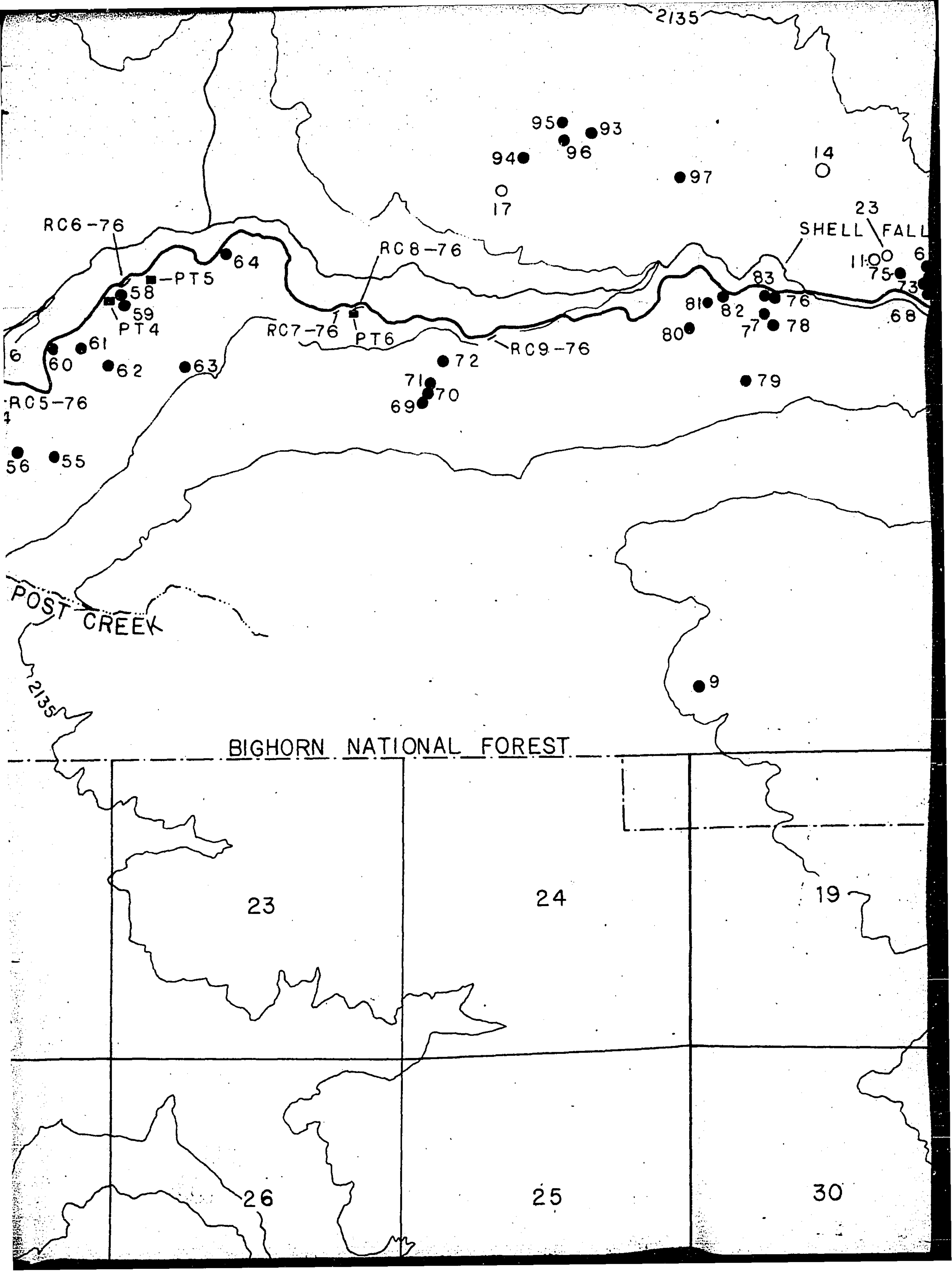

N



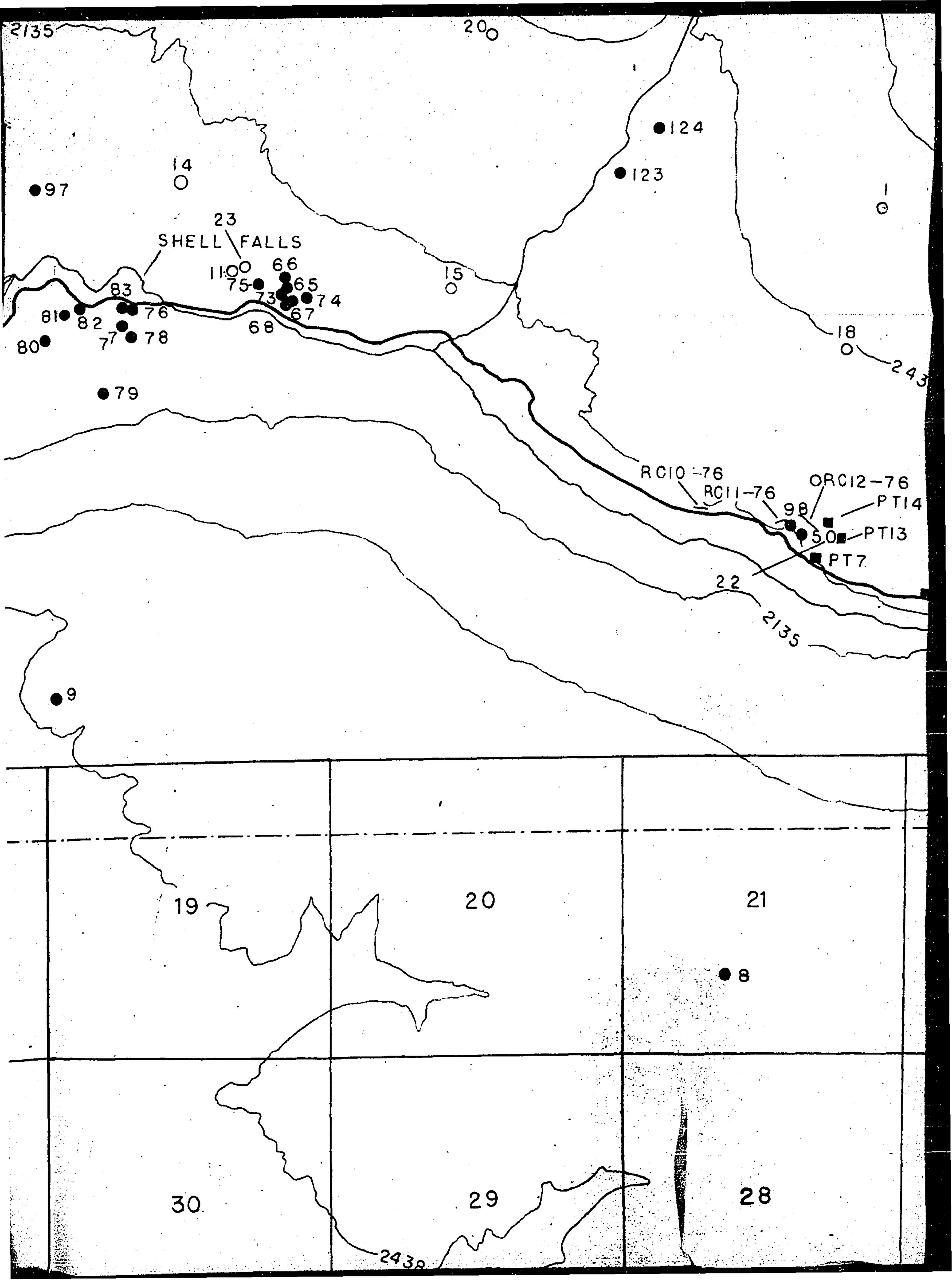
6
12
1524
7
8
1524
WAGON WHEEL ASHES
(PAYTON CONG.)
17
13
18
24
19
20
FIELD CAMP ASH
25
30
29
32′ 30″

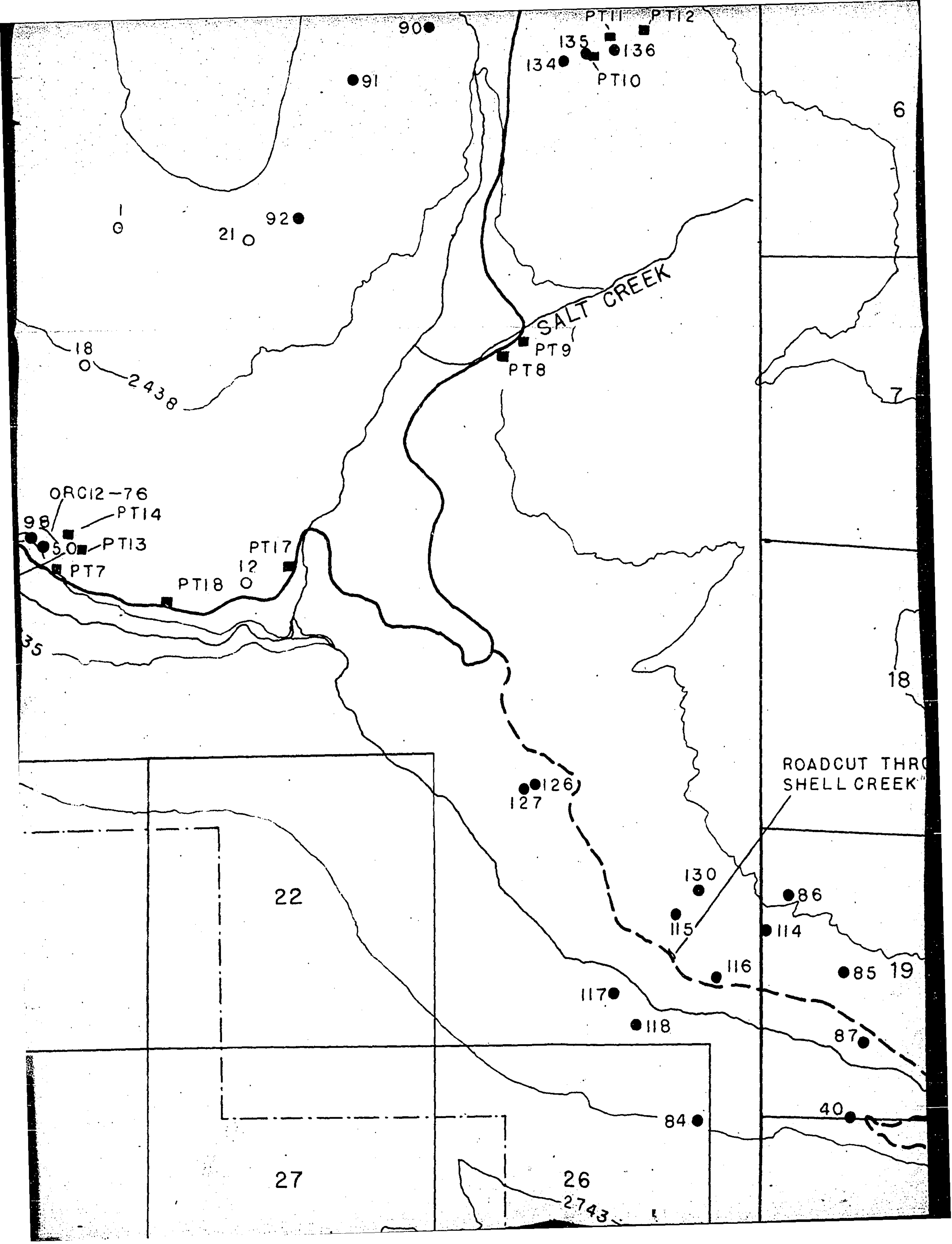


135
6
1829
8
1524
RC6-76
20
19
PT
58
59
PT4
RC2-76
RC15-76
RC14-76
RC16-76
RC3-76
RC4-76
RC5-76
61
60
62
53
54
57
52
119
21
120
PT1
22
56
55
RC1-76
2
121
3
51
PT2
WAGON WHEEL ASHES
(PAYTON CONG.)
SHELL CREEK
POST CREEK
17
X
1524
1829
2135
20
21
22
29
28
27

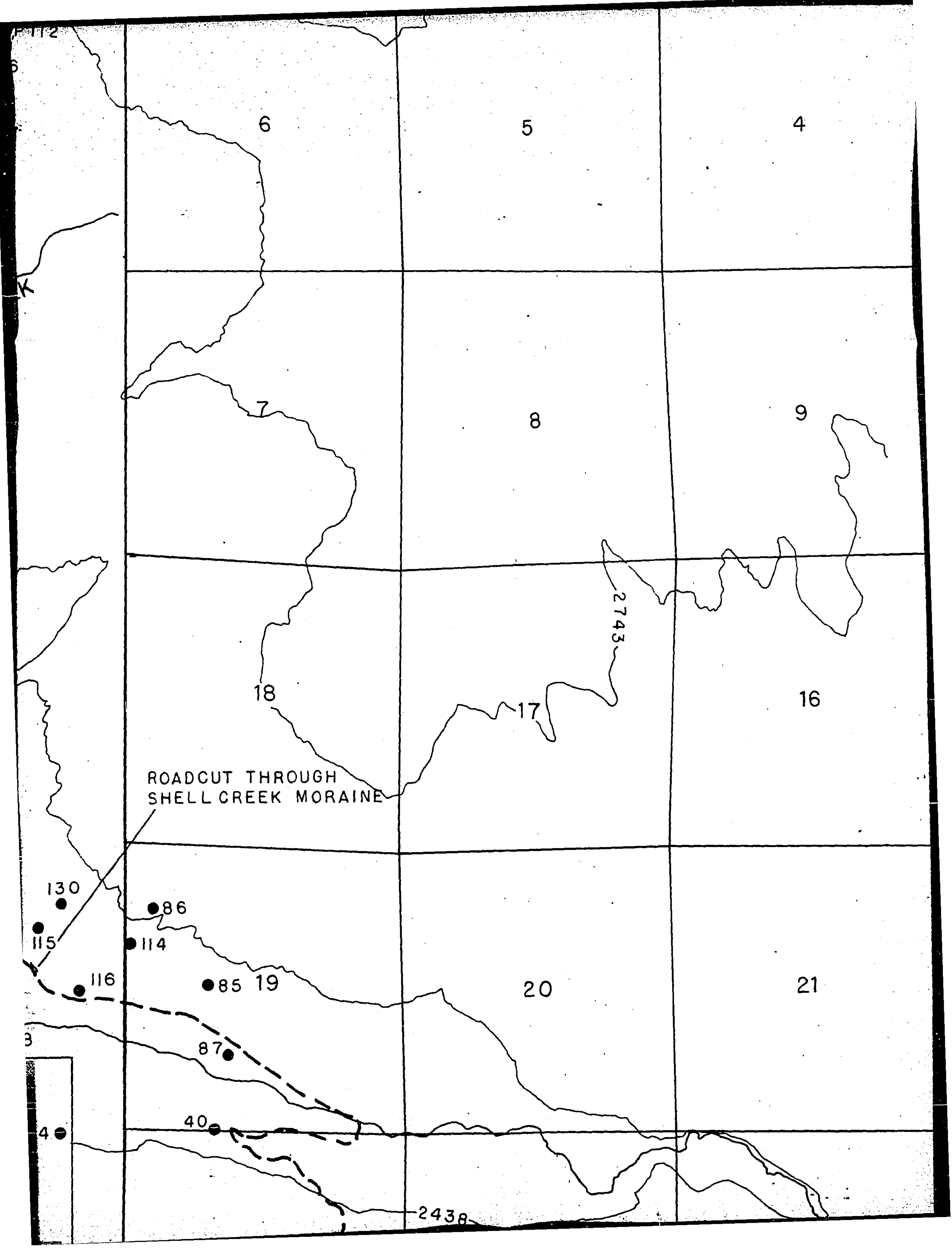


2135
95
93
96
94
97
14
17
23
RC6-76
SHELL
FALL
64
RC8-76
PT5
11
75
58
83
73
59
81
82
76
PT4
RC7-76
PT6
80
77
78
68
61
RC9-76
60
62
63
72
79
71
70
RC5-76
69
56
55
POST CREEK
2135
9
BIGHORN NATIONAL FOREST
23
24
19
26
25
30


2135
20
14
97
124
123
1
23
SHELL FALLS
11
66
65
75
73
74
67
15
83
81
82
76
80
77
78
68
18
243
79
RC10-76
RC11-76
RC12-76
98
PT14
50
PT13
PT7
22
2135
9
19
20
21
8
30
29
28
2438



PT11
PT12
90
135
136
134
PT10
91
6
92
1
21
SALT CREEK
PT9
18
PT8
2438
7
ORC12-76
PT14
98
50
PT13
PT17
PT7
12
PT18
35
18
ROADCUT THRO
SHELL CREEK"
126
127
130
86
22
115
114
116
85
19
117
118
87
40
84
27
26
2743



P112
6
K
6
5
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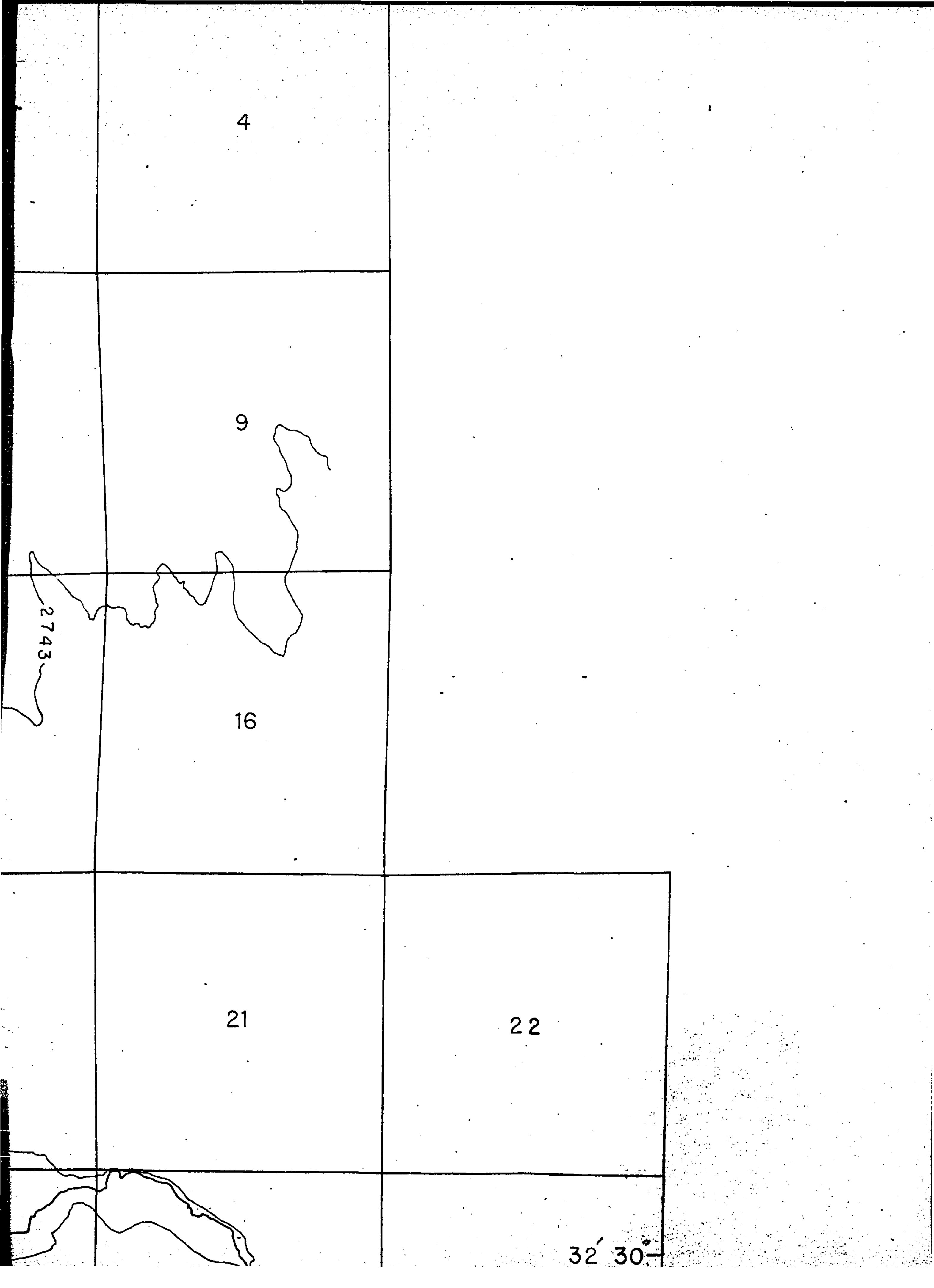
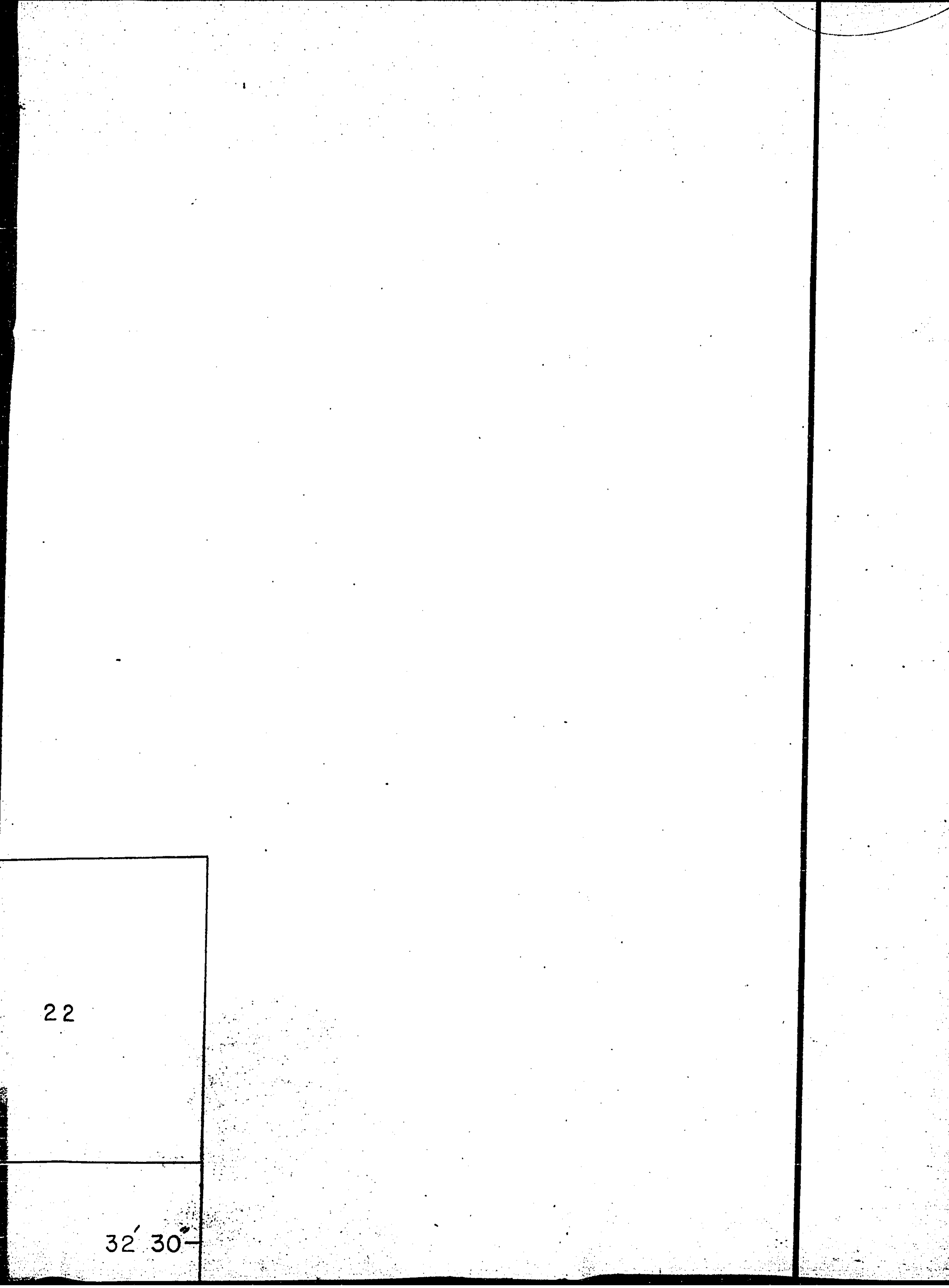
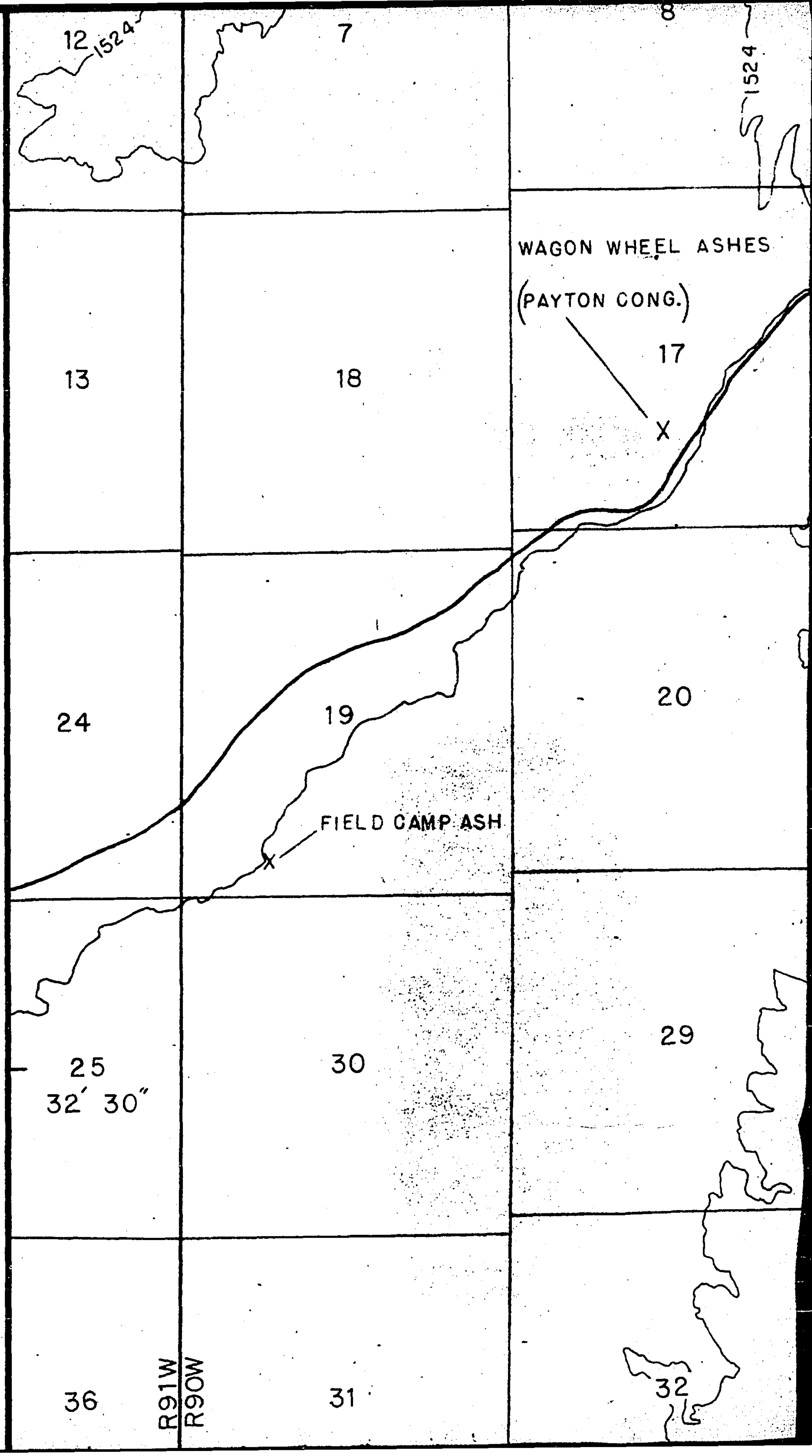
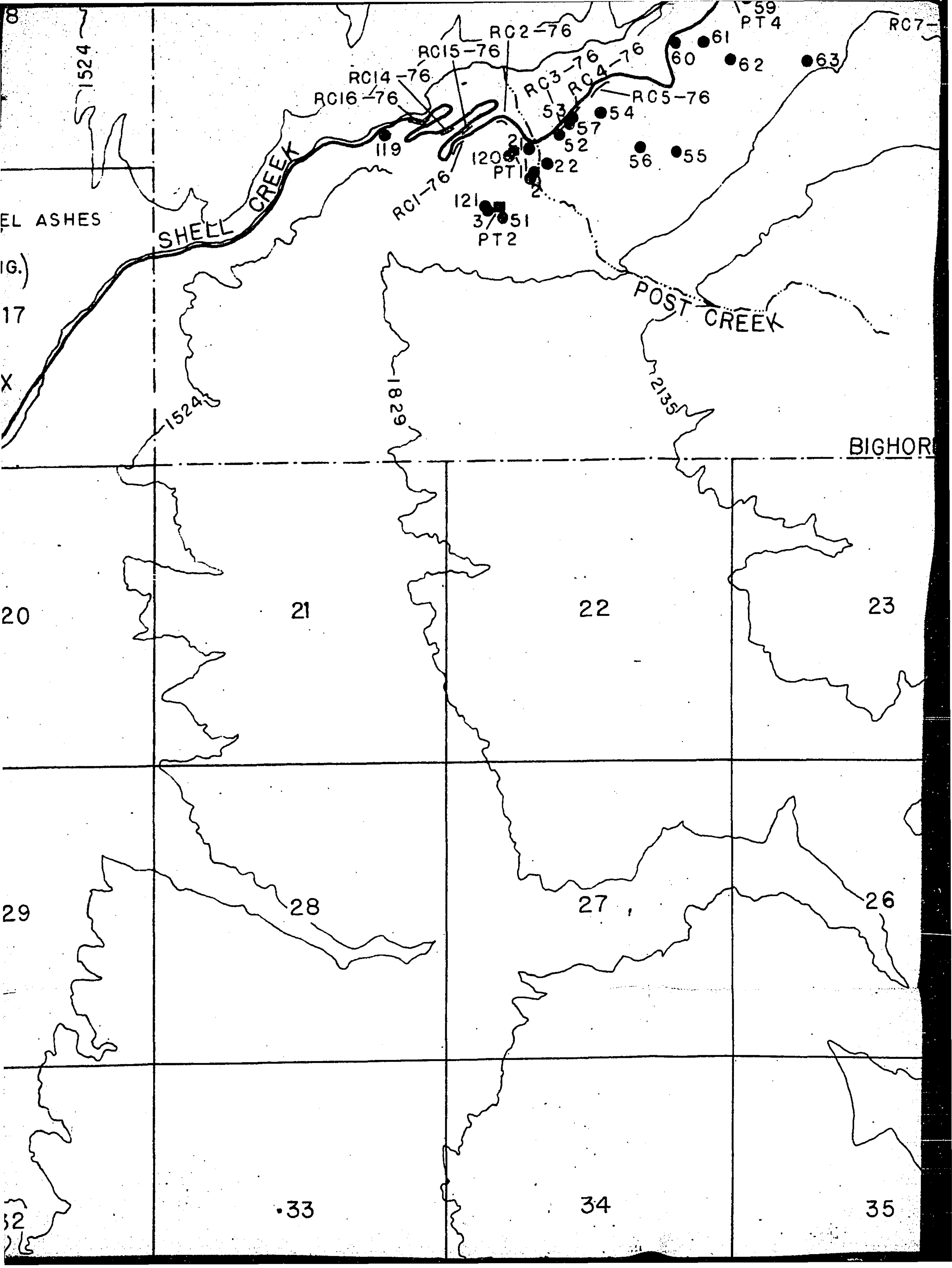
9
2743
18
17
16
ROADCUT THROUGH
SHELL CREEK MORAINE
130
86
115
114
116
85
19
20
21
3
87
40
4
2438


4
9
2743
16
21
22
32' 30"


22
32′ 30″



12
1524
7
8
1524
WAGON WHEEL ASHES
(PAYTON CONG.)
13
18
17
24
19
20
FIELD CAMP ASH
25
32′ 30″
30
29
36
R91W
R90W
31
32



RC2-76
RC15-76
RC14-76
RC16-76
RC3-76
RC4-76
RC5-76
RC7-
RC1-76
59
PT4
60
61
62
63
53
54
57
52
56
55
119
21
120
PT1
22
2
121
3
51
PT2
1524
EL ASHES
SHELL CREEK
IG.)
17
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POST CREEK
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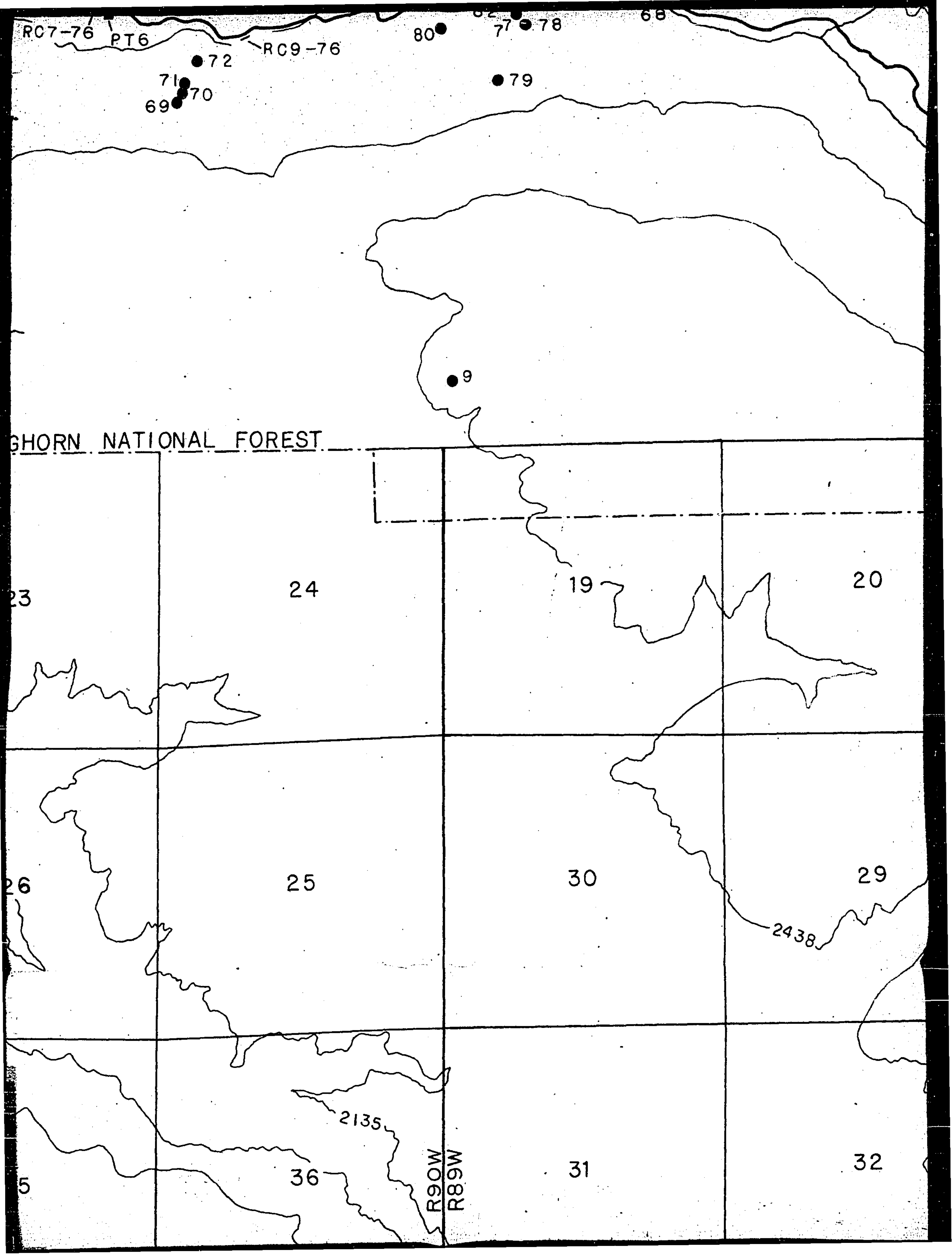

RC7-76
PT6
RC9-76
72
71
70
69
80
77
78
68
79
9
GHORN NATIONAL FOREST
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24
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26
25
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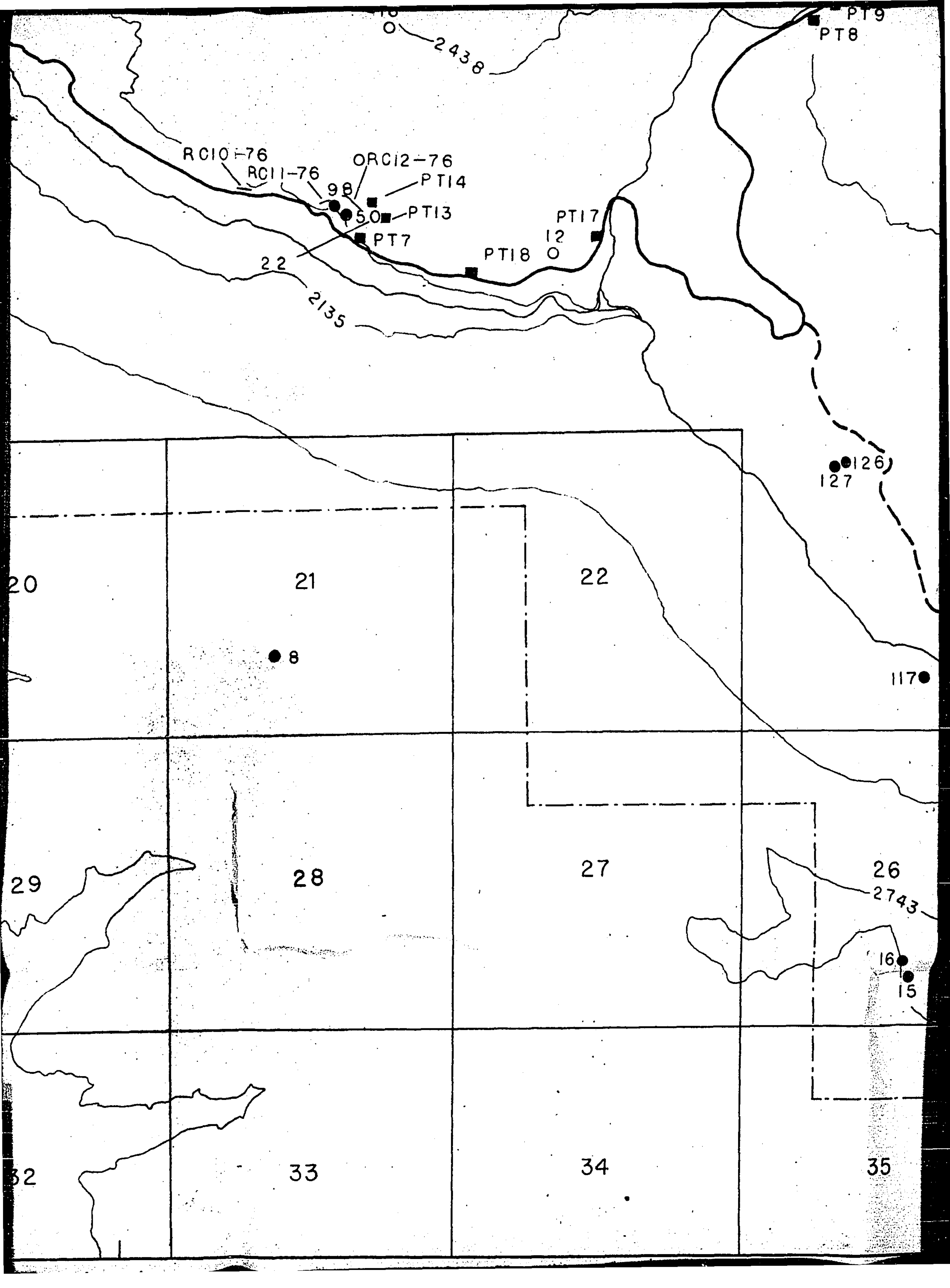
29
2438
2135
5
36
R90W
R89W
31
32



PT9
PT8
2438
RC10-76
RC11-76
ORC12-76
98
PT14
50
PT13
PT7
22
2135
PT17
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PT18
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15
32
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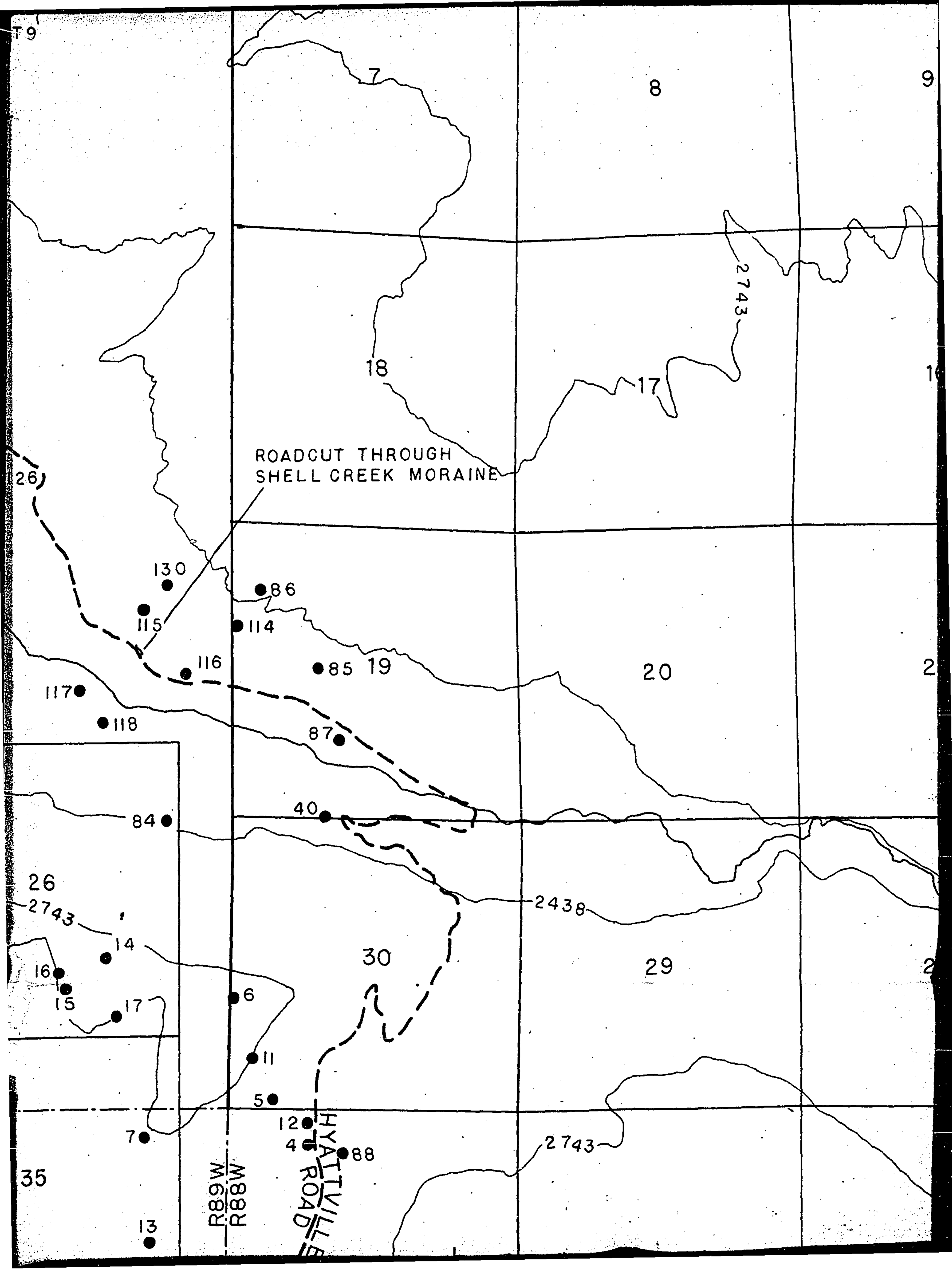
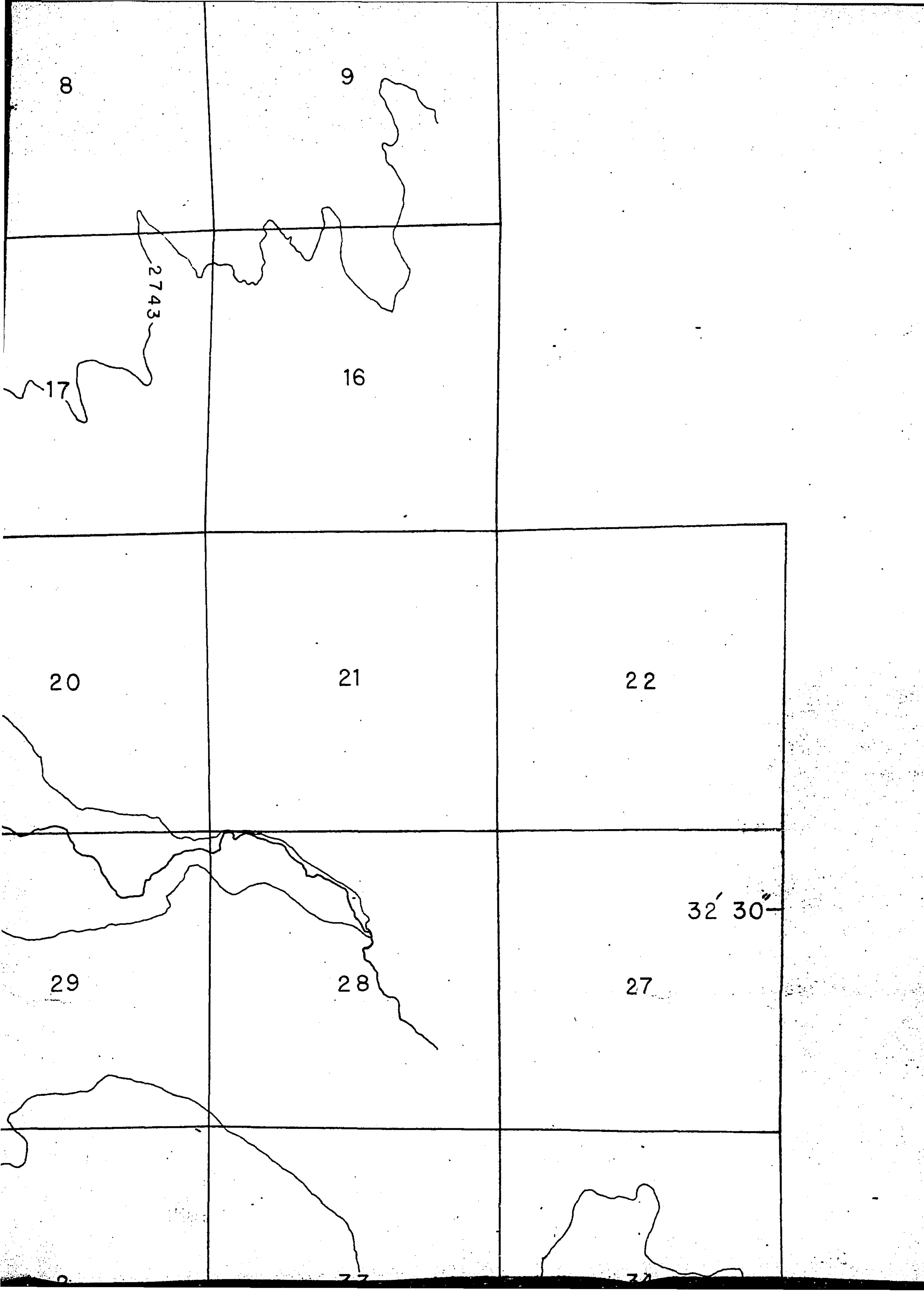
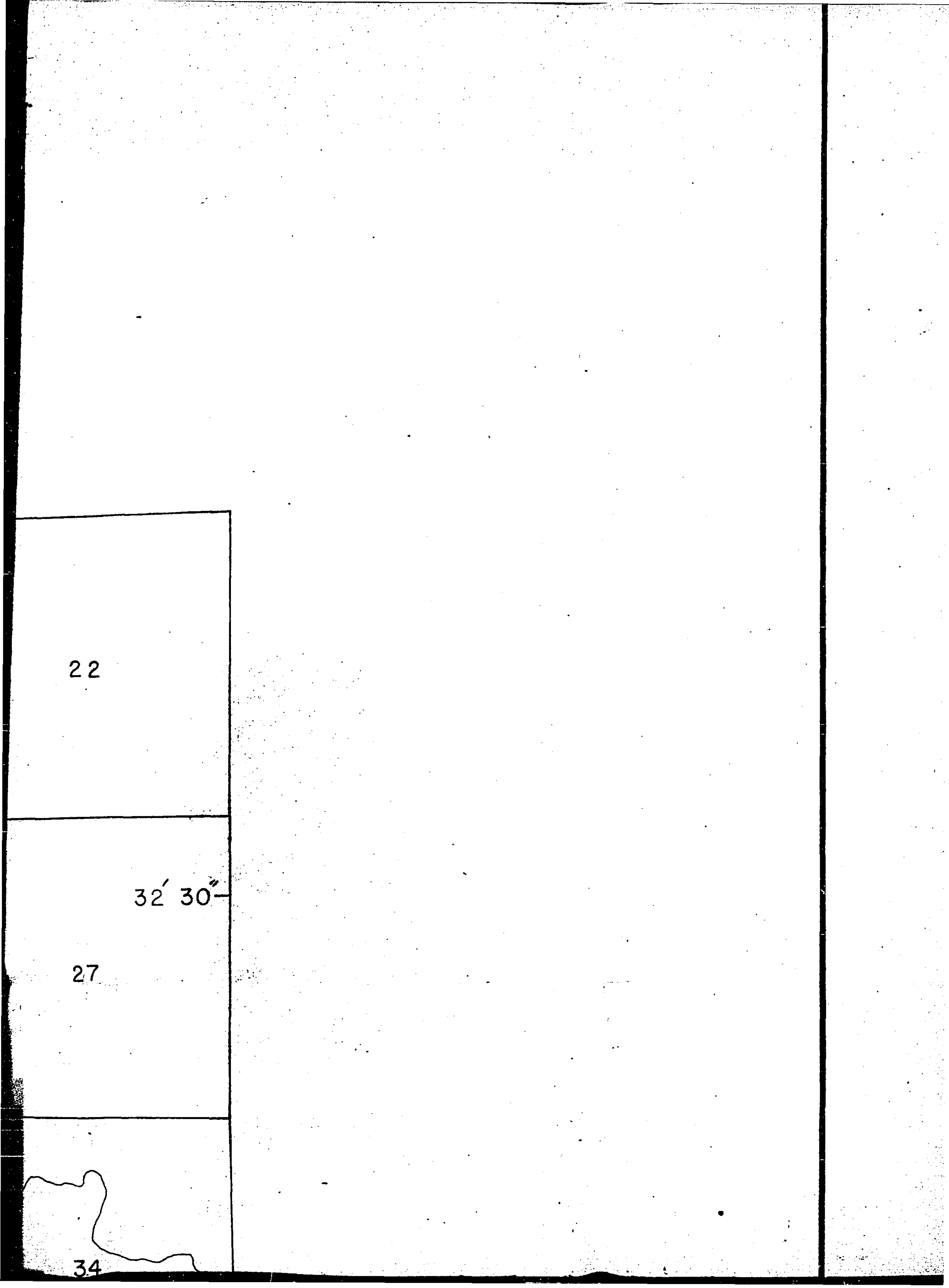
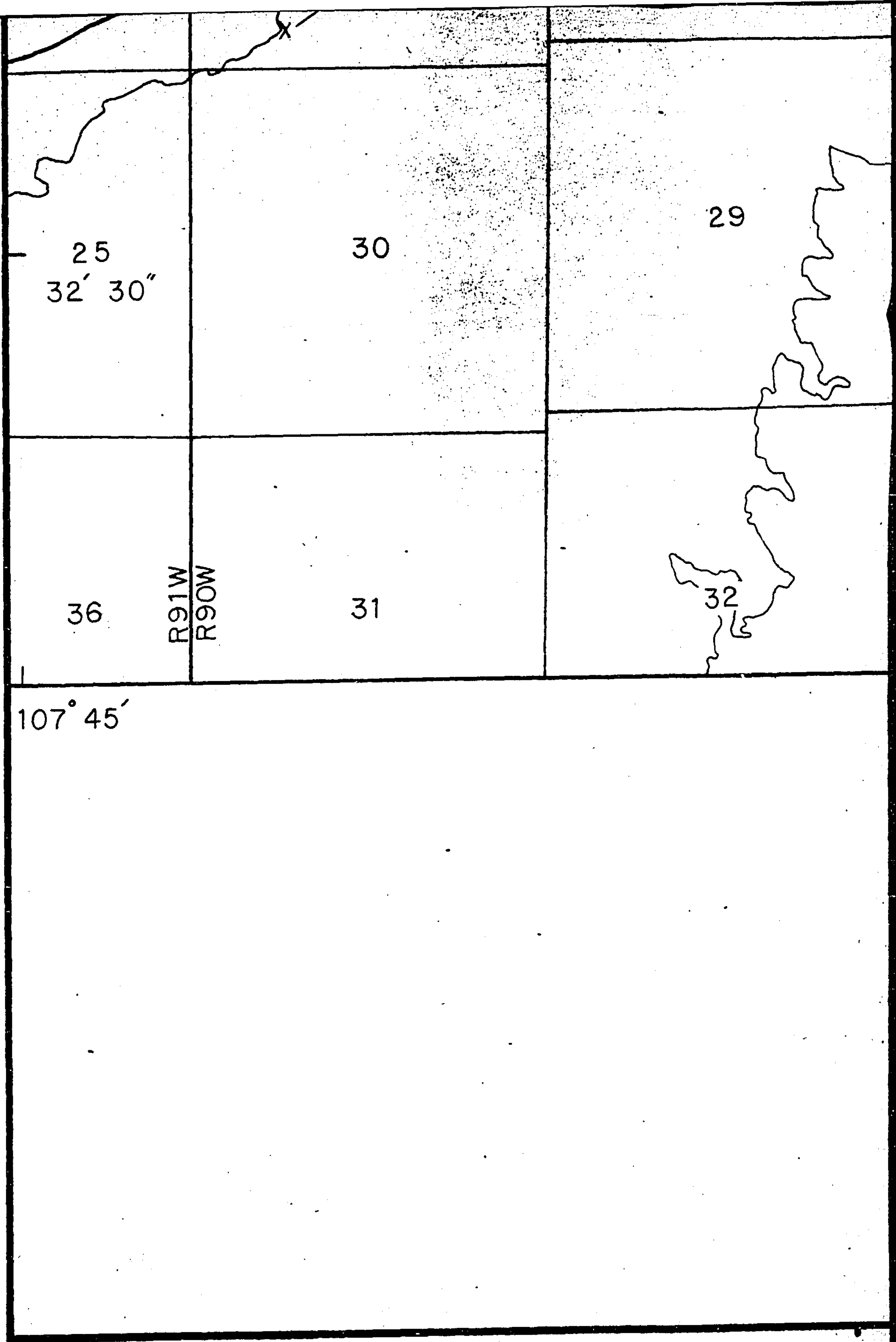
34
35

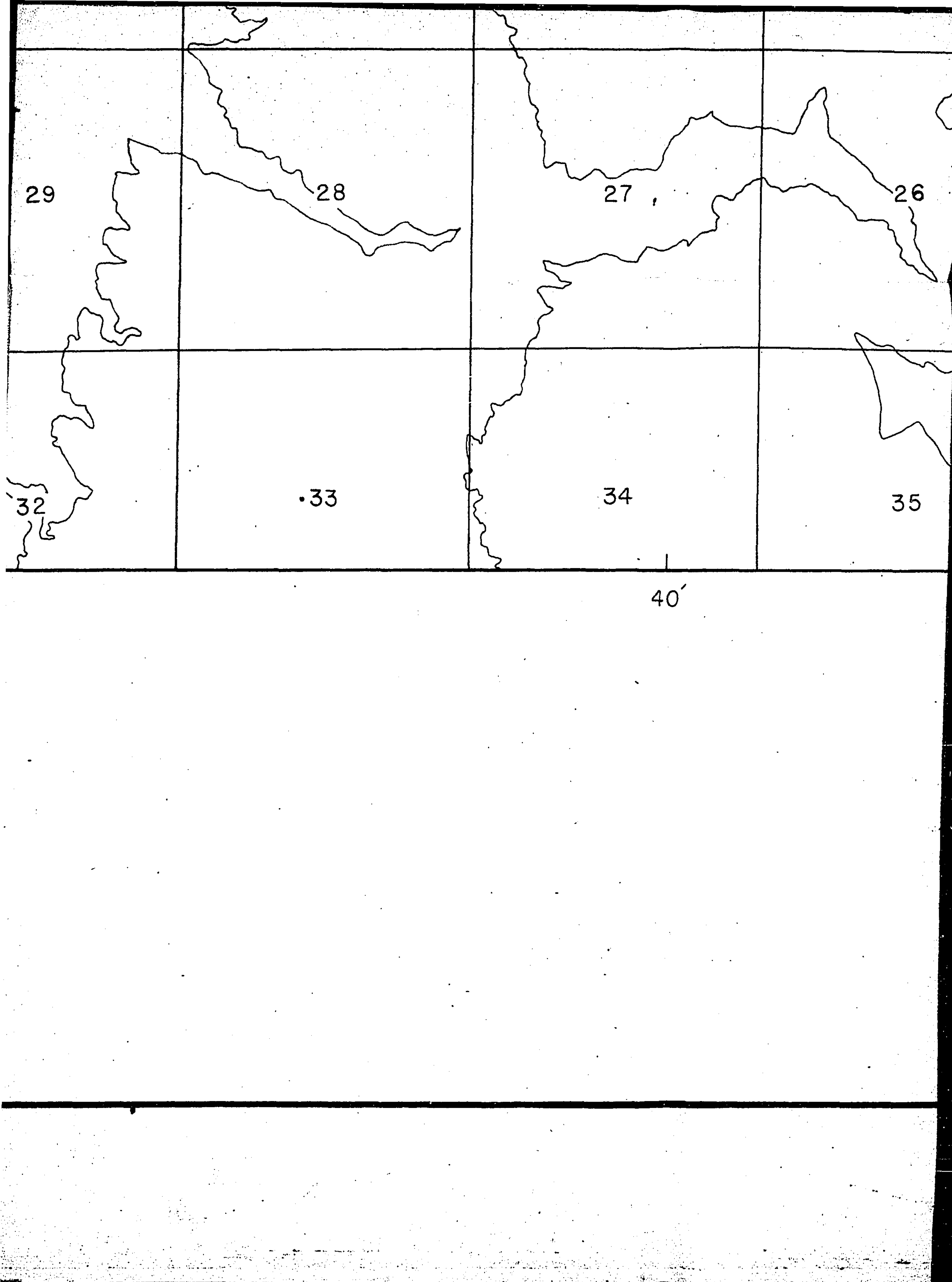

T9
7
8
9
2743
18
17
ROADCUT THROUGH
SHELL CREEK MORAINE
26
130
86
115
114
116
85
19
20
117
118
87
40
84
26
2743
14
2438
30
29
16
15
6
17
11
5
12
HYATTVILLE ROAD
7
4
88
2743
35
R89W
R88W
13



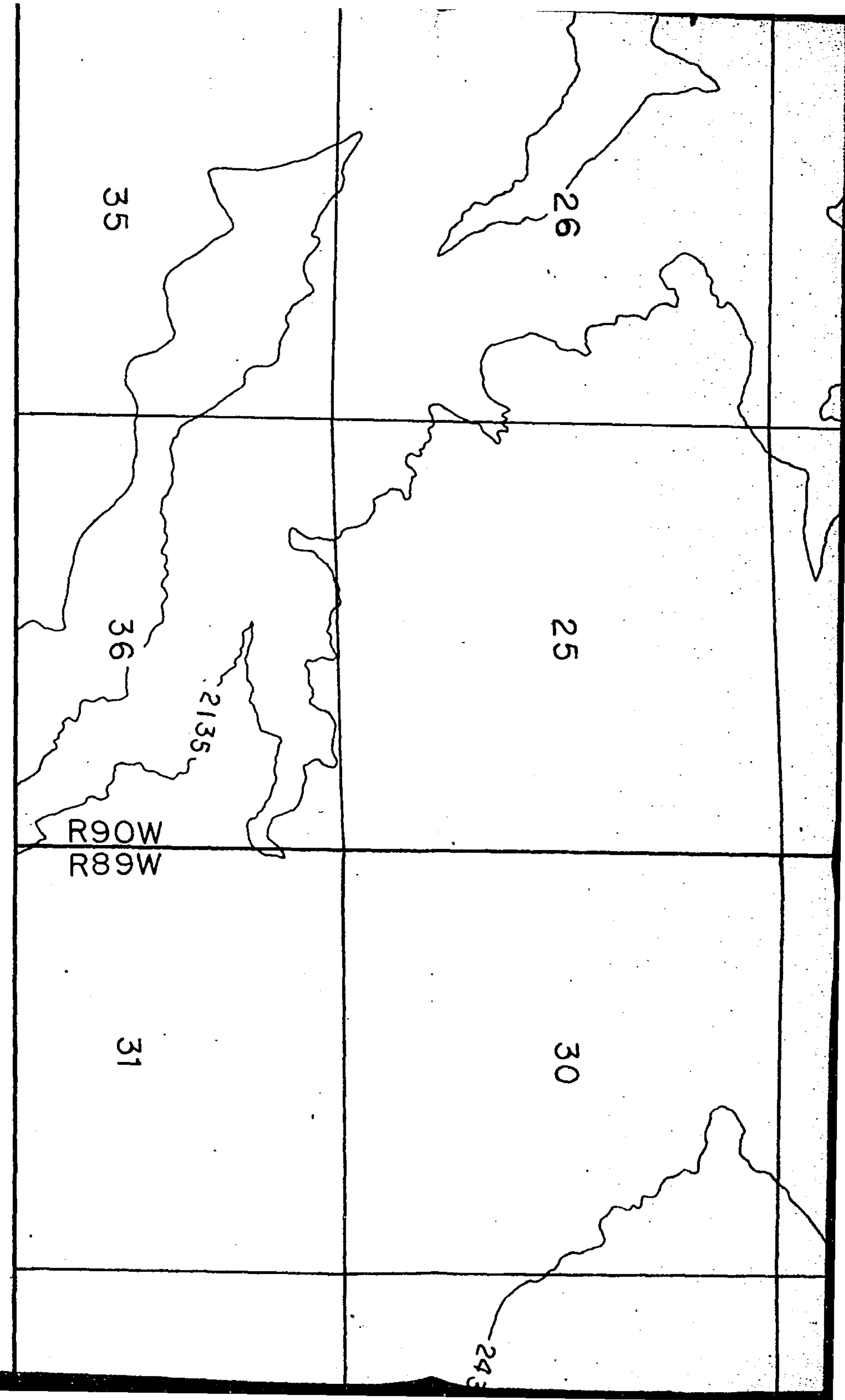
8
9
2743
17
16
20
21
22
32′ 30″
29
28
27

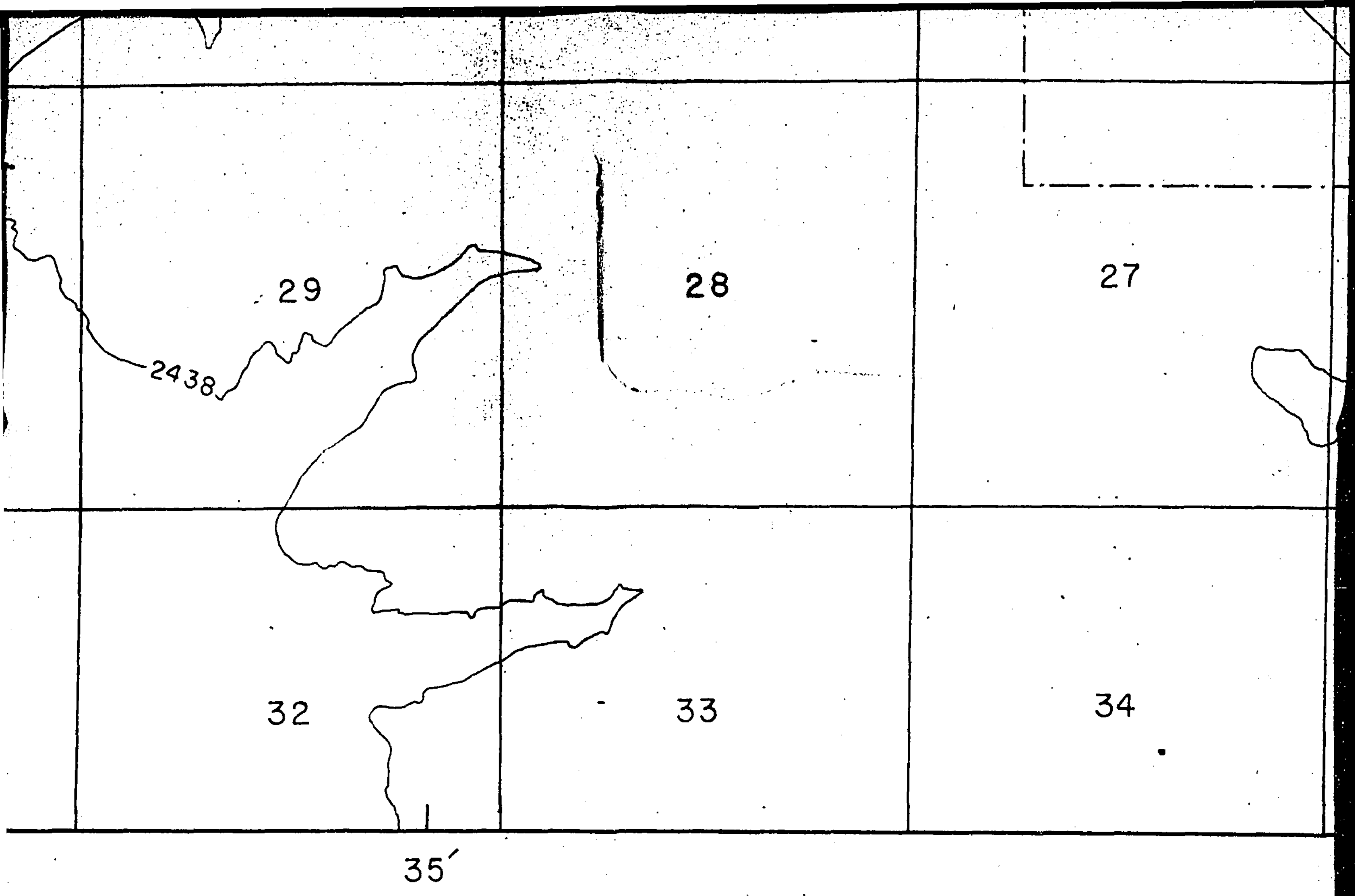

22
32′ 30″
27
34


25
32´ 30″
30
29
36
R91W
R90W
31
32
107° 45´

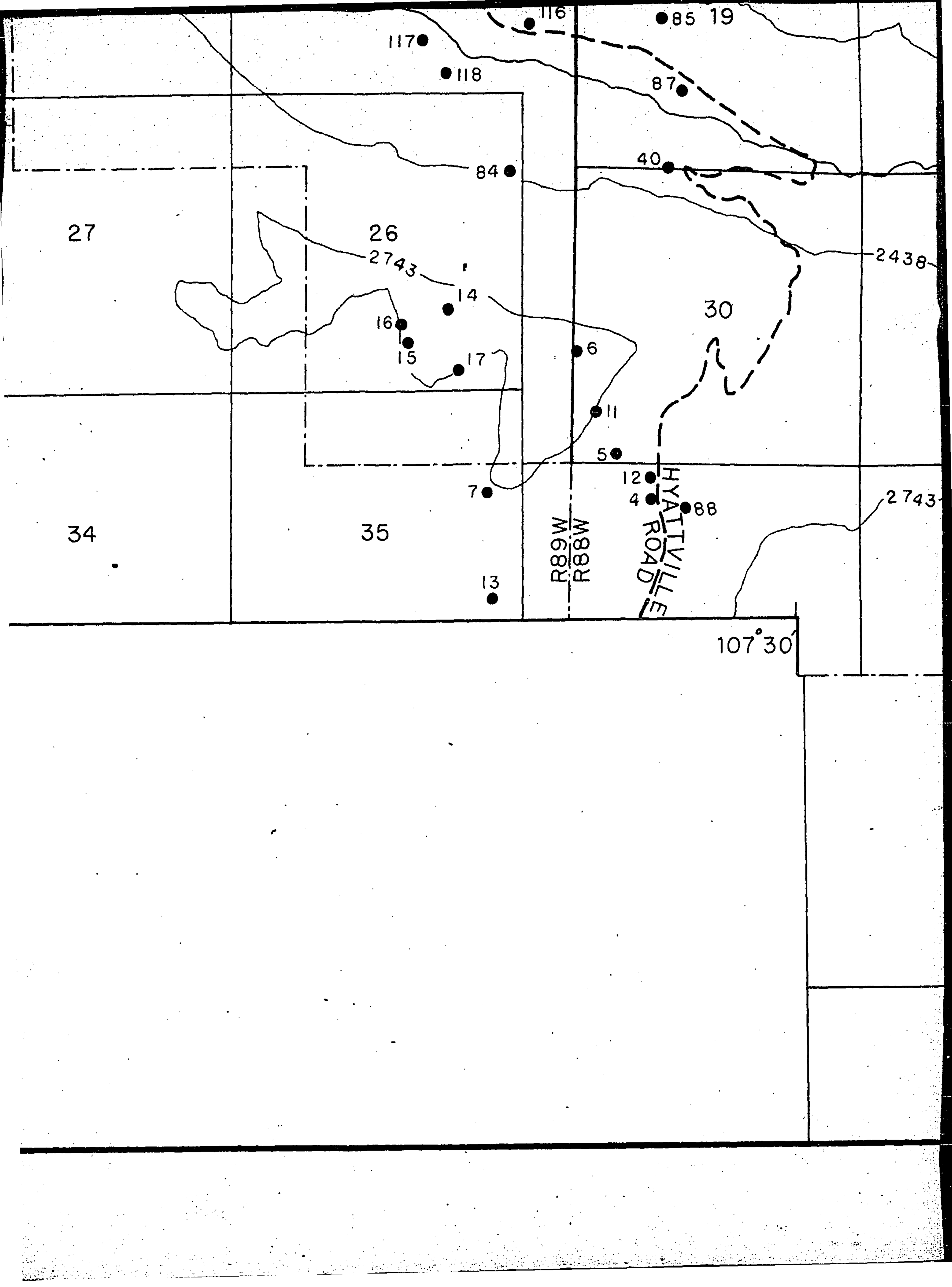


29
28
27
26
32
33
34
35
40'

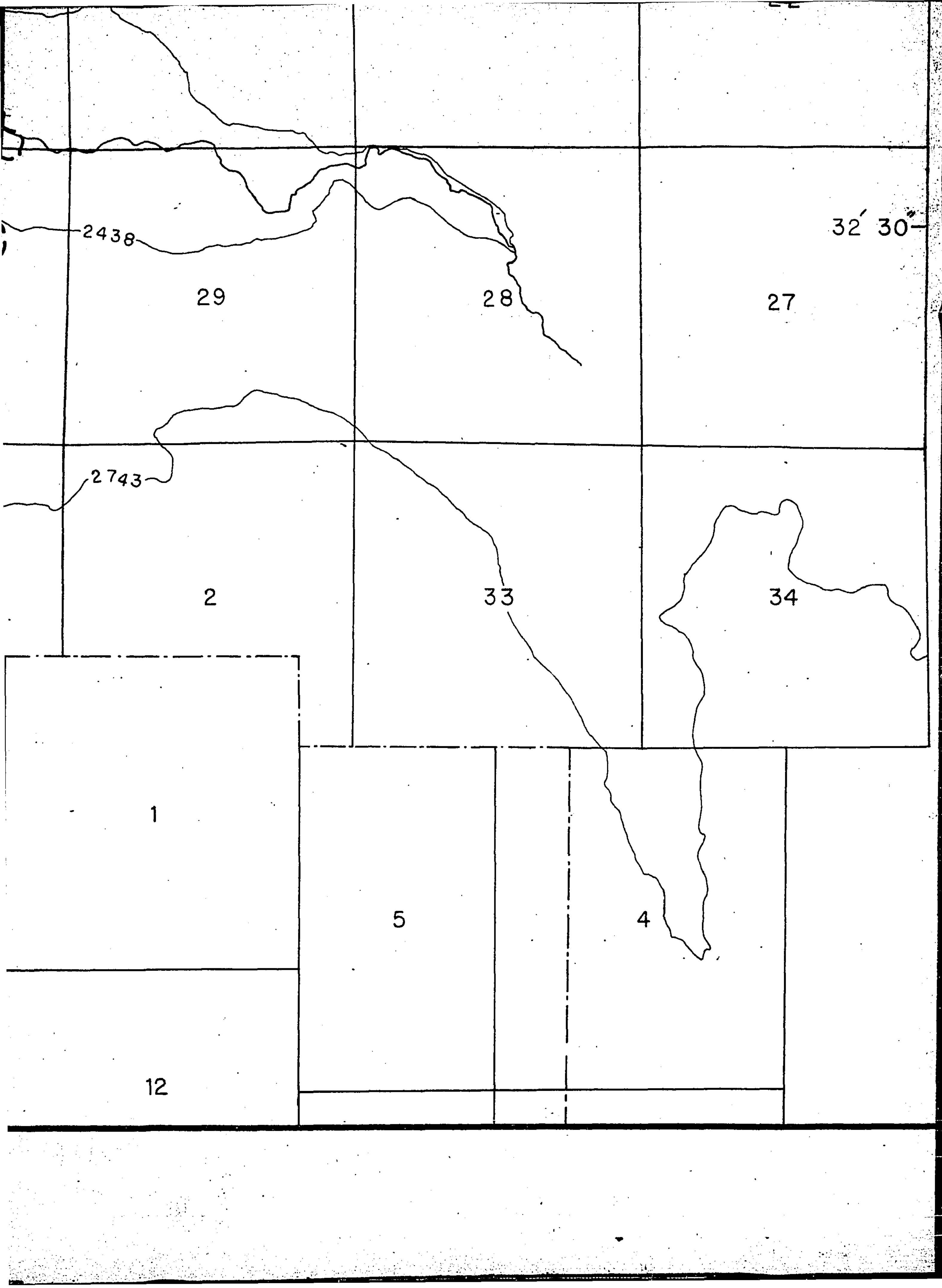

35
26
36
25
2135
R90W
R89W
31
30



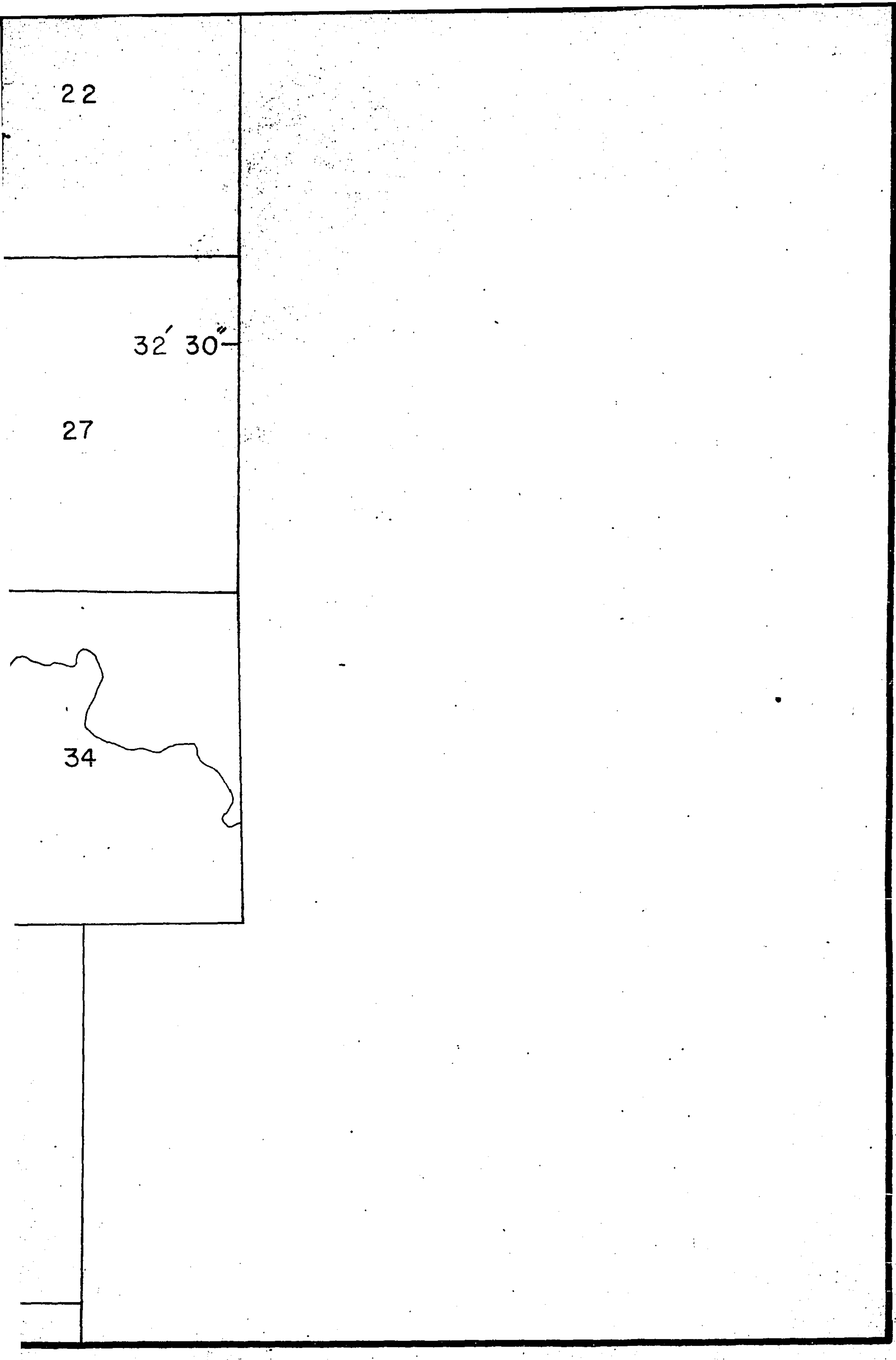
29
28
27
2438
32
33
34
35′



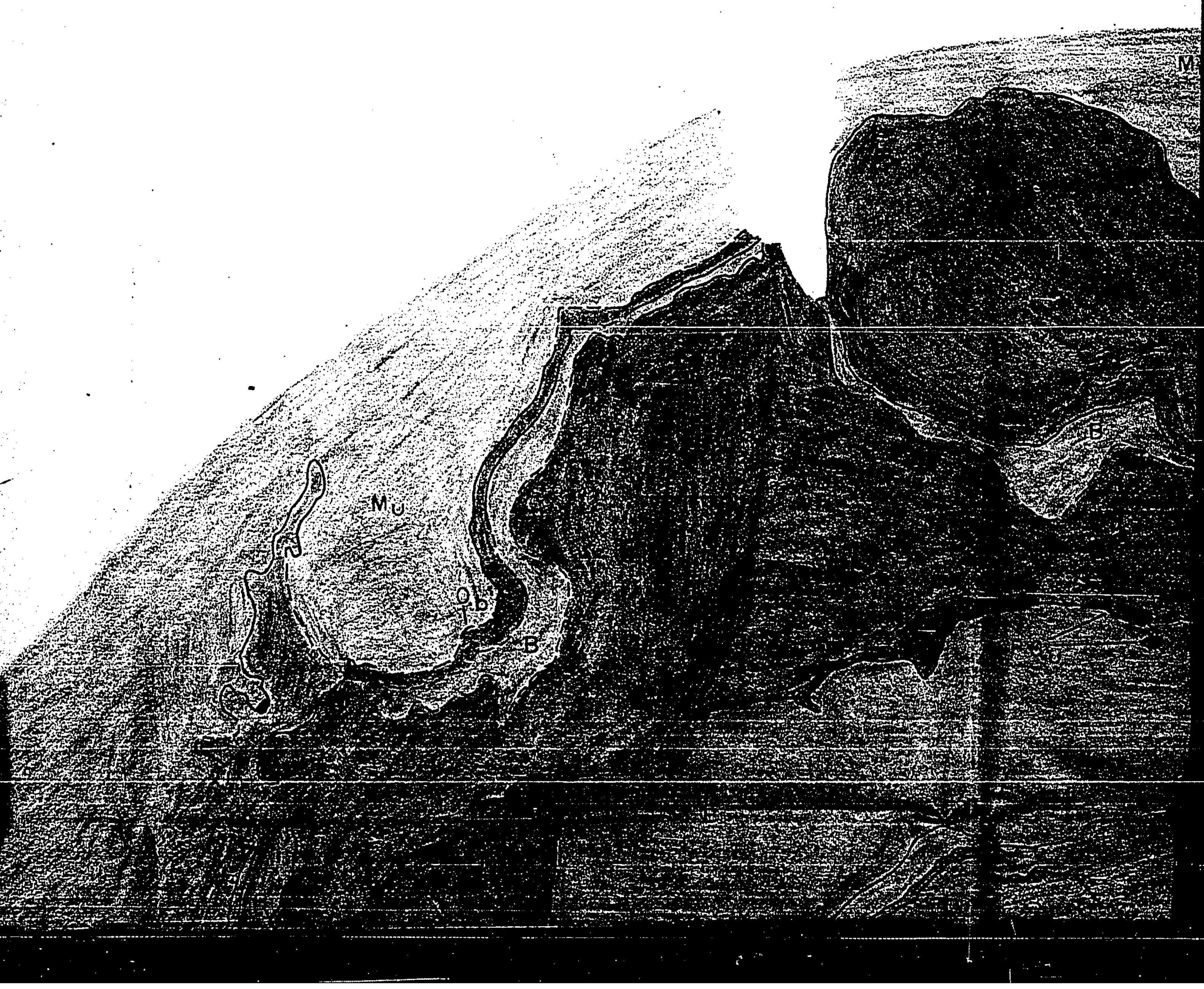
116
85
19
117
118
87
84
40
27
26
2743
2438
14
30
16
15
17
6
11
5
12
4
88
7
2743
34
35
R89W
R88W
HYATTVILLE ROAD
13
107°30'



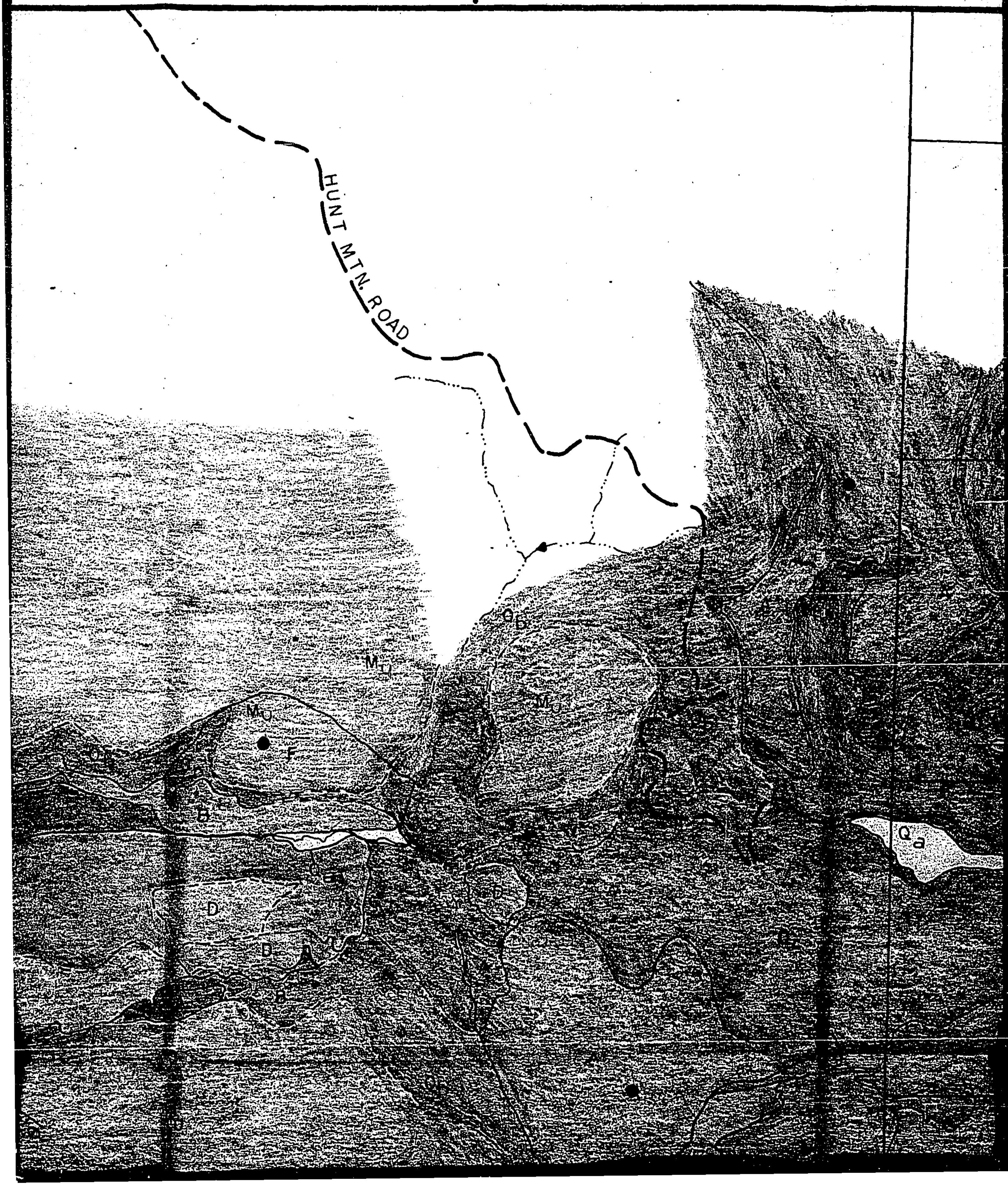
32′ 30″
2438
29
28
27
2743
2
33
34
1
5
4
12


22
32′ 30″
27
34

12	
13	
24	


Mu
O.b
B
M
B


B
E
B
D


HUNT MTN. ROAD
Qb
Mu
Mu
Mu
F
B
D
B
A
B
Qa

FI
GEOLO
SHELL

1 .5

● INDICAT
OR BL
STRIKE

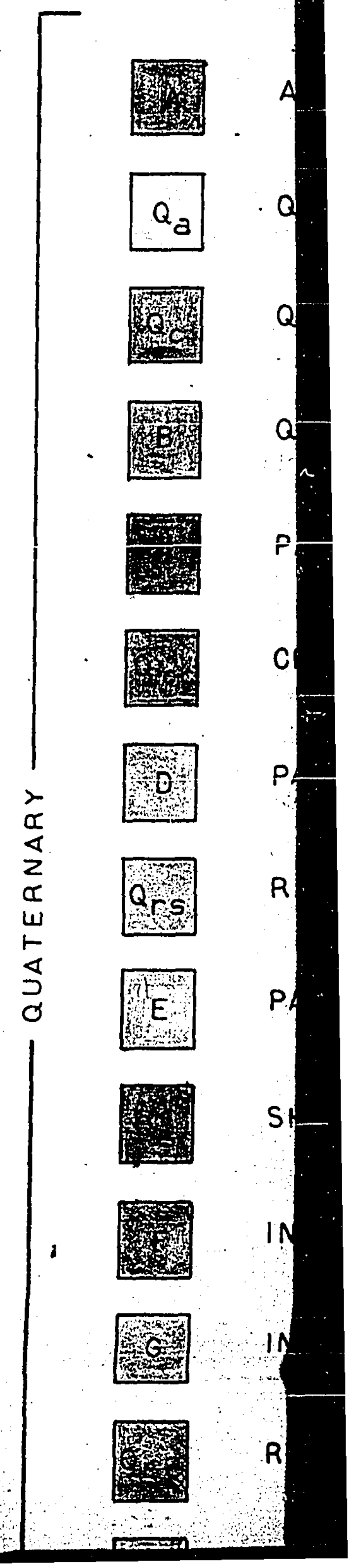
FIG. 52
GEOLOGIC MAP
SHELL CANYON

SCALE

1 .5 0 1 KM.

● INDICATES BEDROCK SLUMP, OR BLOCK GLIDE

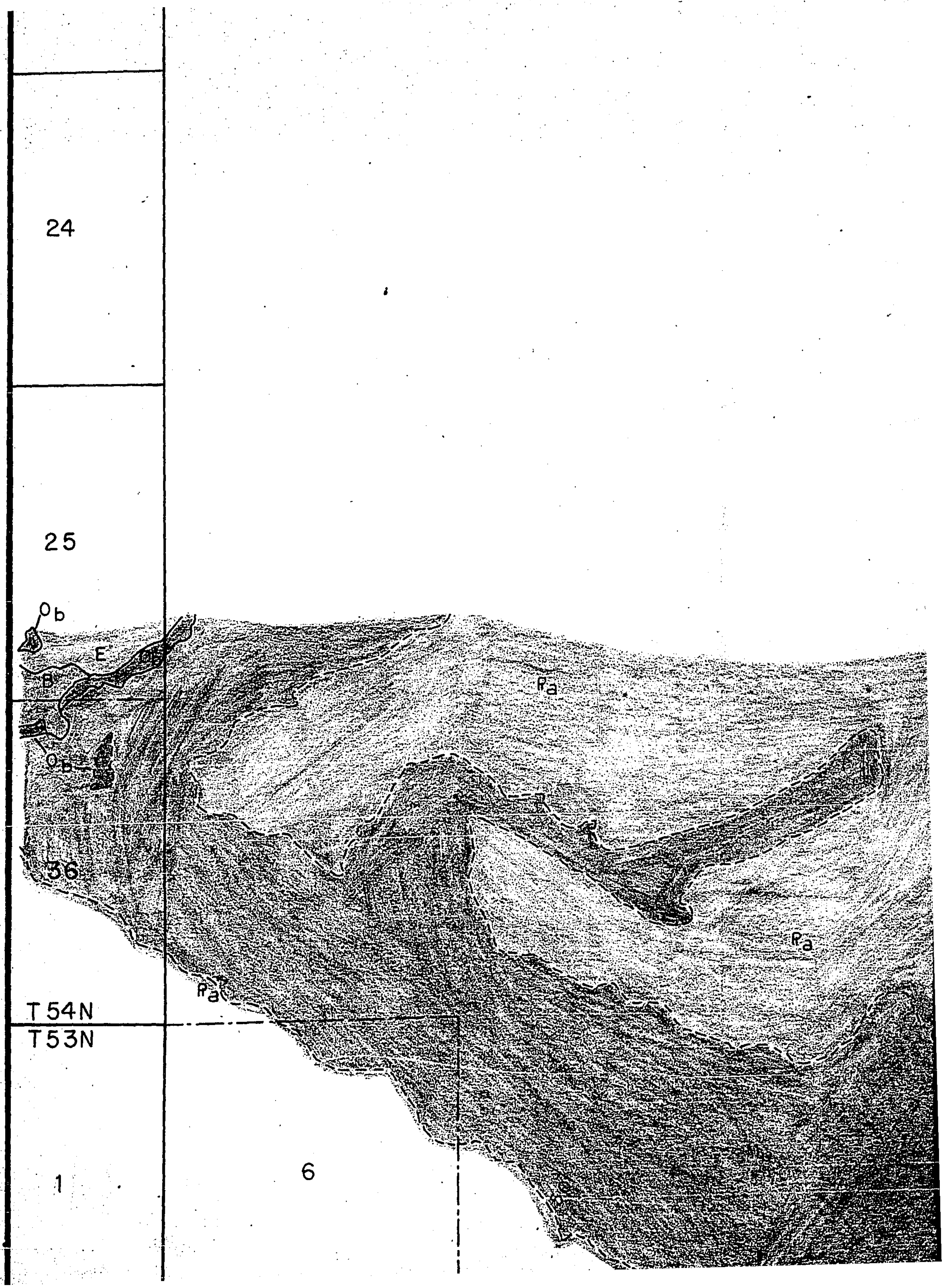
STRIKE AND DIP



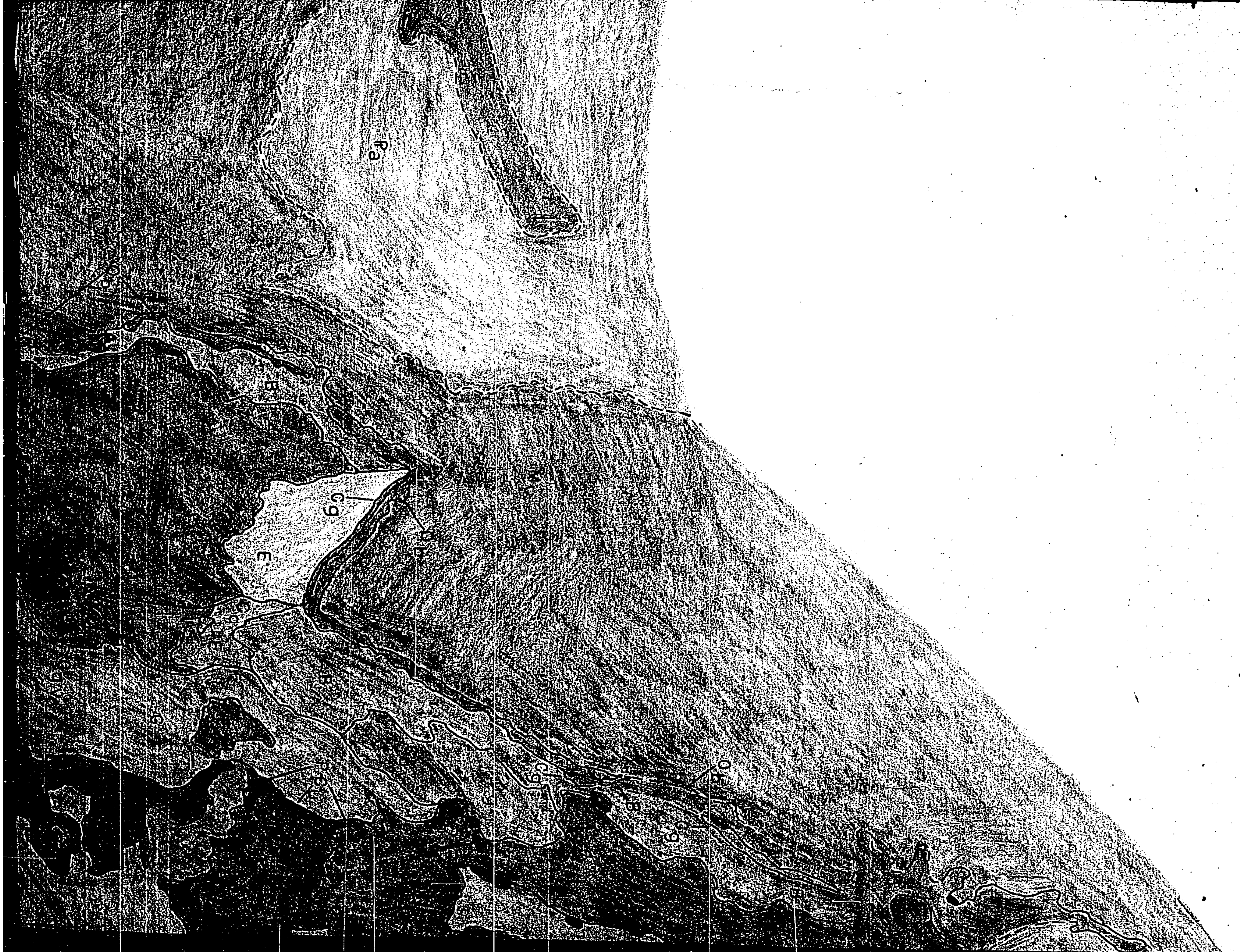
LEGEND

QUATERNARY

- ACTIVE LANDSLIDE COMPLEX
- Q_a QUATERNARY ALLUVIUM
- Q_c QUATERNARY COLLUVIUM
- B QUATERNARY TALUS
- PASSIVE I LANDSLIDE COMPLEX
- CROOKED CREEK MORAINE
- D PASSIVE-2 LANDSLIDE COMPLEX
- Q_{rs} RANGER STATION MORAINE
- E PASSIVE-3 LANDSLIDE COMPLEX
- SHELL CREEK MORAINE
- INACTIVE-I LANDSLIDE COMPLEX
- G INACTIVE-2 LANDSLIDE COMPLEX
- RUBLE CREEK MORAINE
- INACTIVE-3 LANDSLIDE COMPLEX

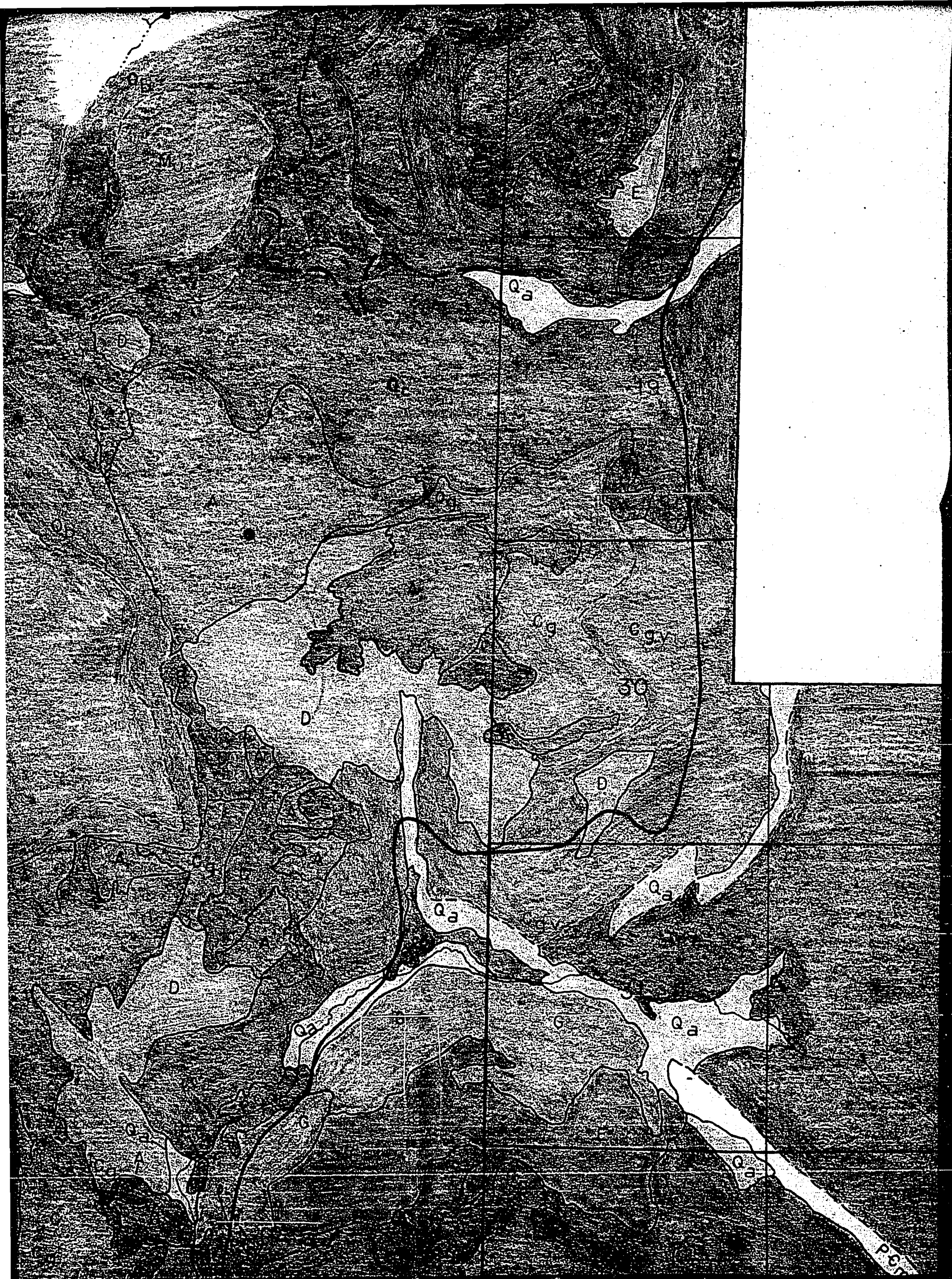


24
25
Ob
E
B
Ob
Ra
36
Ra
Ra
T54N
T53N
1
6

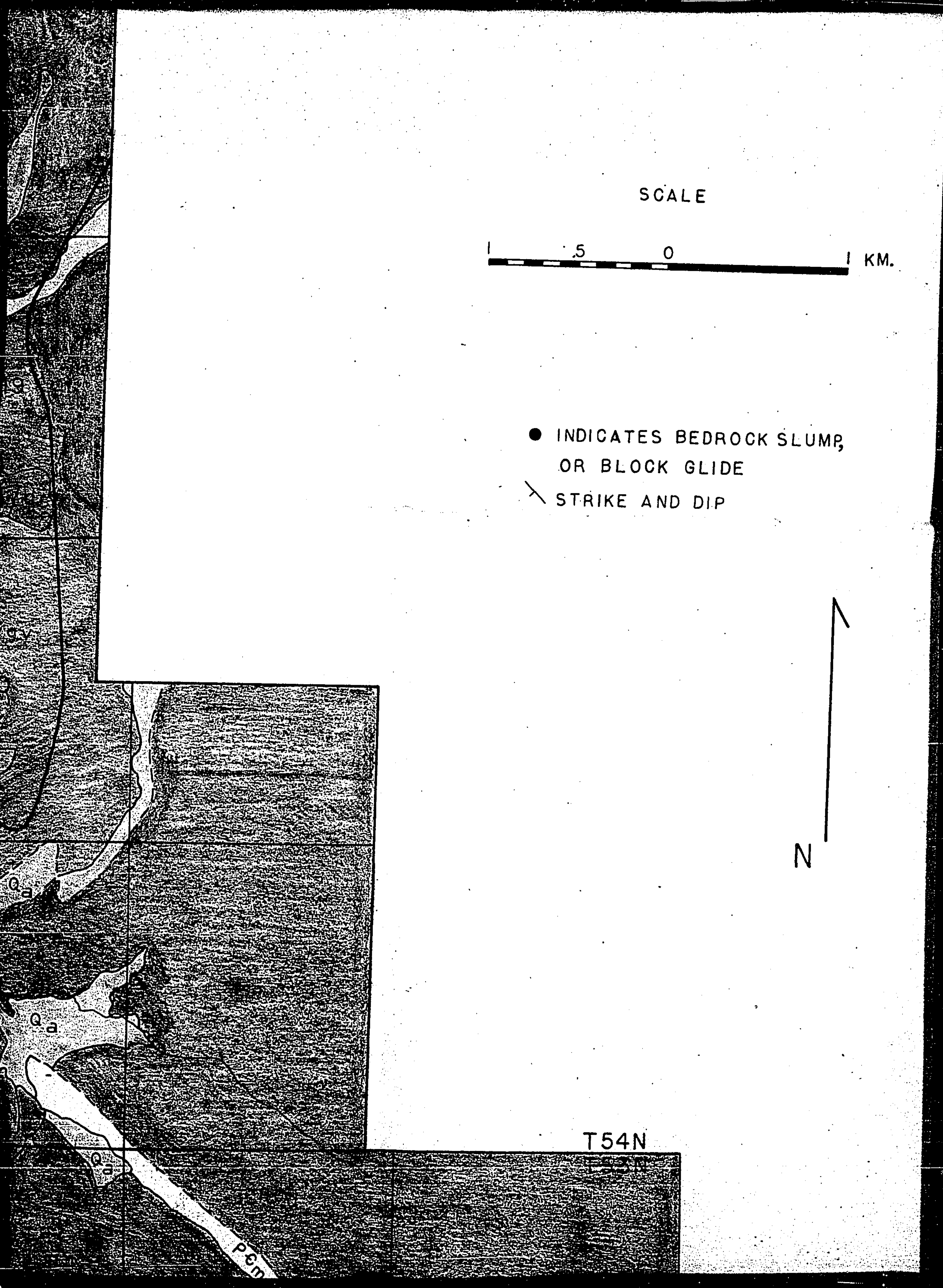


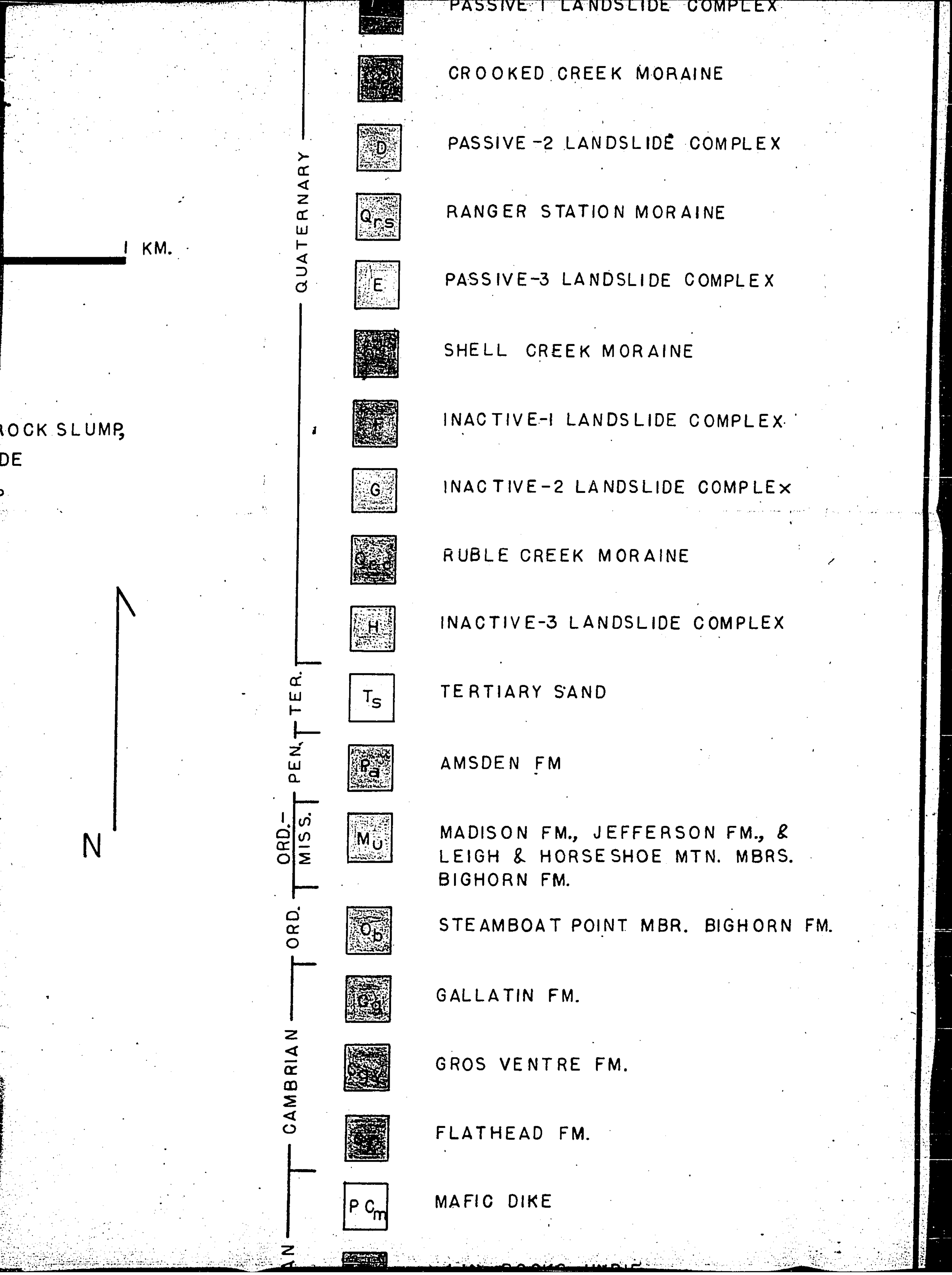

Mu
Ob
B
Cg
D
B
Ob
Cg
B


GROUSE CREEK
Mu
Mu
Mu
Mu
F
E
D
D
D
B
B
B
B
B
A
Ob

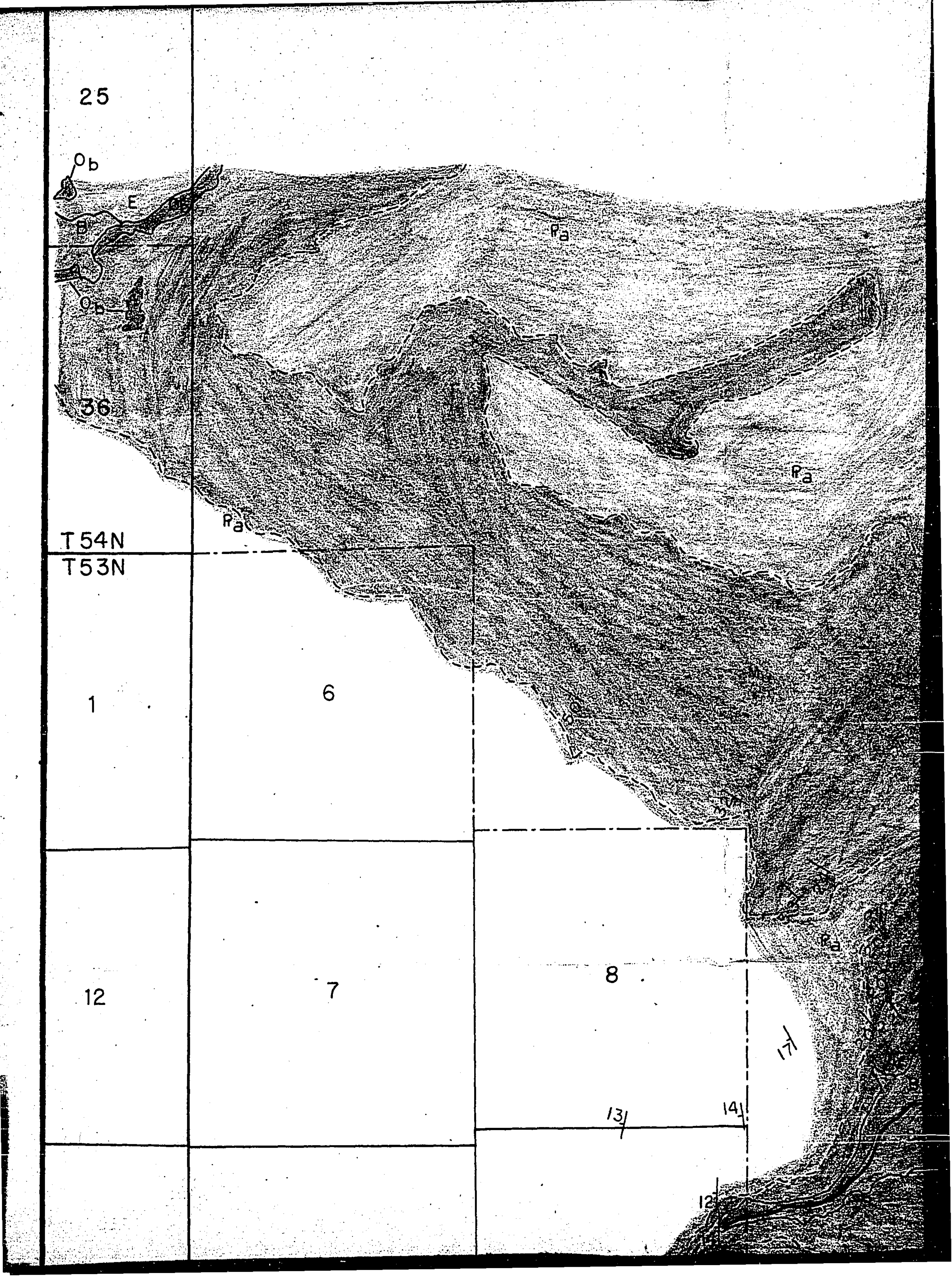


Qa
E
19
D
A
Cg
Cgv
30
D
D
Qa
Qa
Qa
Qa
Qa
Qa


SCALE
1 .5 0 1 KM.
INDICATES BEDROCK SLUMP, OR BLOCK GLIDE
STRIKE AND DIP
N
T54N
Qa
Qa
Qa
Qa
pЄm


PASSIVE-1 LANDSLIDE COMPLEX
CROOKED CREEK MORAINE
D
PASSIVE-2 LANDSLIDE COMPLEX
Qrs
RANGER STATION MORAINE
E
PASSIVE-3 LANDSLIDE COMPLEX
SHELL CREEK MORAINE
F
INACTIVE-1 LANDSLIDE COMPLEX
G
INACTIVE-2 LANDSLIDE COMPLEX
RUBLE CREEK MORAINE
H
INACTIVE-3 LANDSLIDE COMPLEX
Ts
TERTIARY SAND
Pa
AMSDEN FM
Mu
MADISON FM., JEFFERSON FM., & LEIGH & HORSESHOE MTN. MBRS. BIGHORN FM.
Ob
STEAMBOAT POINT MBR. BIGHORN FM.
Cg
GALLATIN FM.
GROS VENTRE FM.
FLATHEAD FM.
PCm
MAFIC DIKE
QUATERNARY
TER.
PEN.
ORD.–MISS.
ORD.
CAMBRIAN
1 KM.
N
ROCK SLUMP,
DE

	PASSIVE-1 LANDSLIDE COMPLEX
	CROOKED CREEK MORAINE
D	PASSIVE-2 LANDSLIDE COMPLEX
Qrs	RANGER STATION MORAINE
E	PASSIVE-3 LANDSLIDE COMPLEX
	SHELL CREEK MORAINE
F	INACTIVE-1 LANDSLIDE COMPLEX
G	INACTIVE-2 LANDSLIDE COMPLEX
	RUBLE CREEK MORAINE
H	INACTIVE-3 LANDSLIDE COMPLEX
T_s	TERTIARY SAND
Pa	AMSDEN FM
Mu	MADISON FM., JEFFERSON FM., & LEIGH & HORSESHOE MTN. MBRS. BIGHORN FM.
Ob	STEAMBOAT POINT MBR. BIGHORN FM.
	GALLATIN FM.
	GROS VENTRE FM.
	FLATHEAD FM.
PC_m	MAFIC DIKE
	XLIN. ROCKS UNDIF.



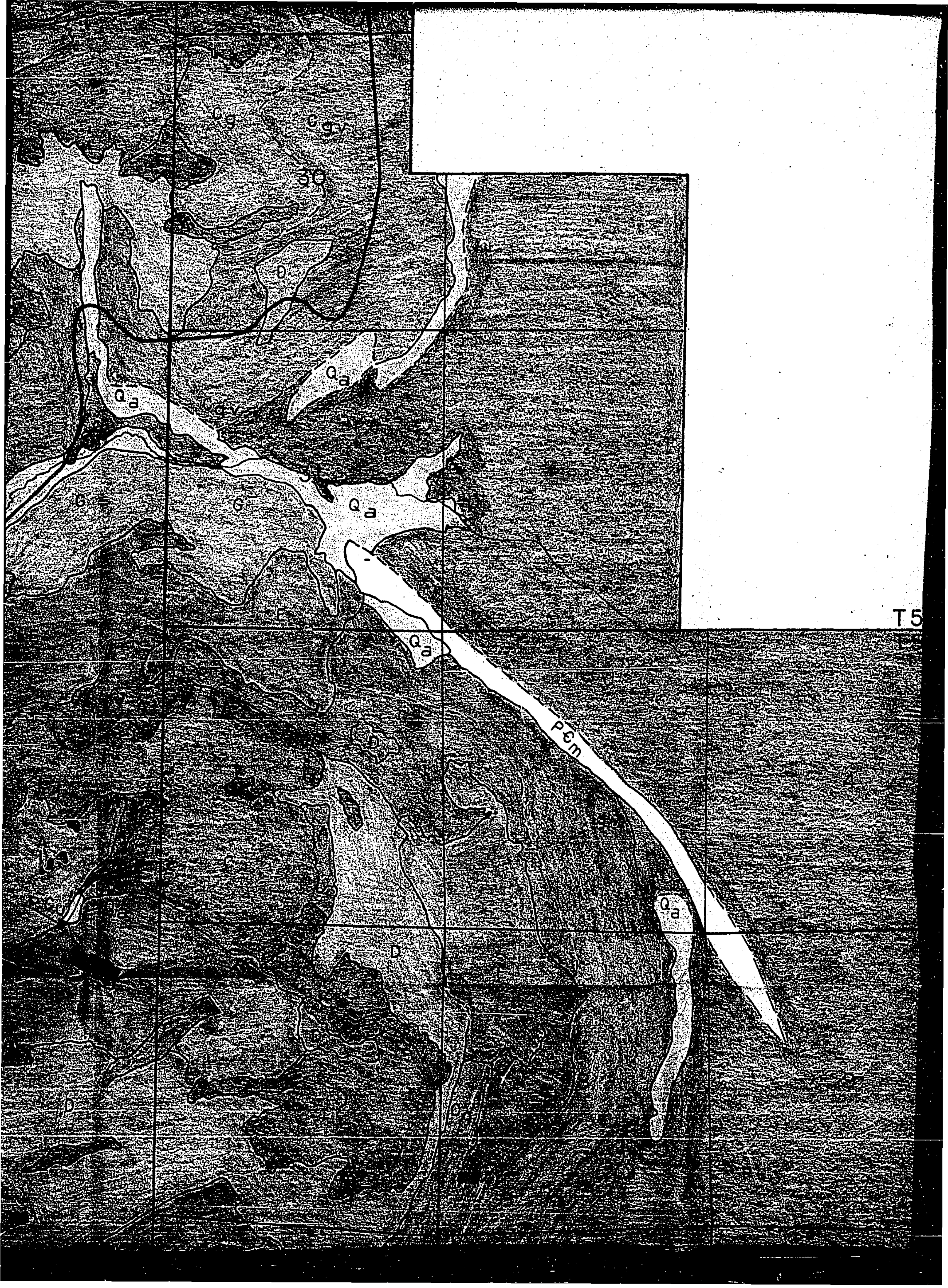
25
Ob
E
Ob
36
Ra
Ra
Ra
T54N
T53N
1
6
12
7
8
17
13
14
12


Ob
Cg
B
D
Ra
E
G
Ggy
17

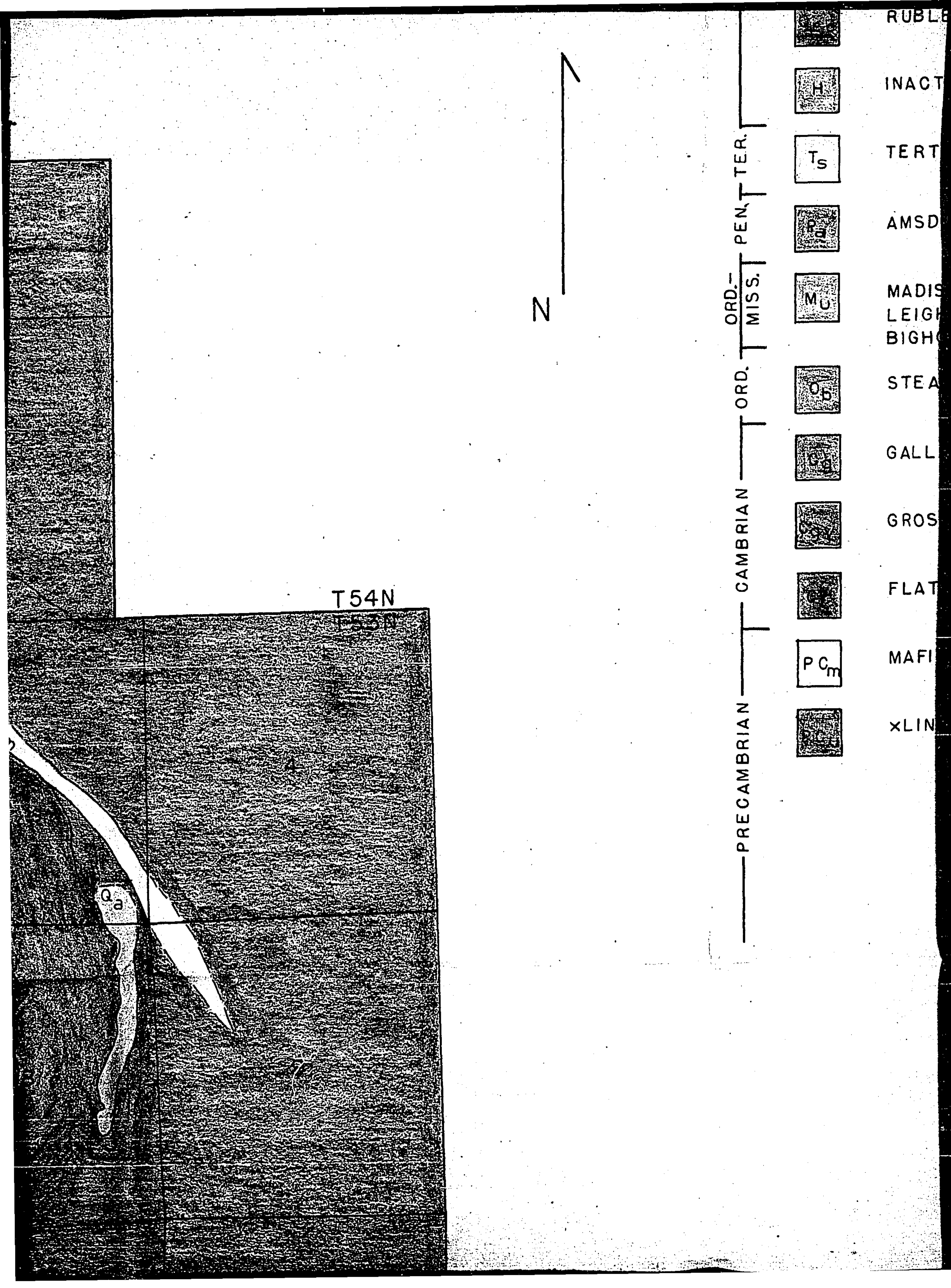
B
D
B
E
Cg
G
D
G
E
Qa
G
D
D
D
E
Cg


CROUSE CREEK
Mo
Ob
B
D
E
Cg
Qa


Mu
Cg
30
D
Qa
D
Mu
G
Ç
B
G
Qa
A
Cg
E
C
Cg
Ob
D
E
G
D
E
Pc
D

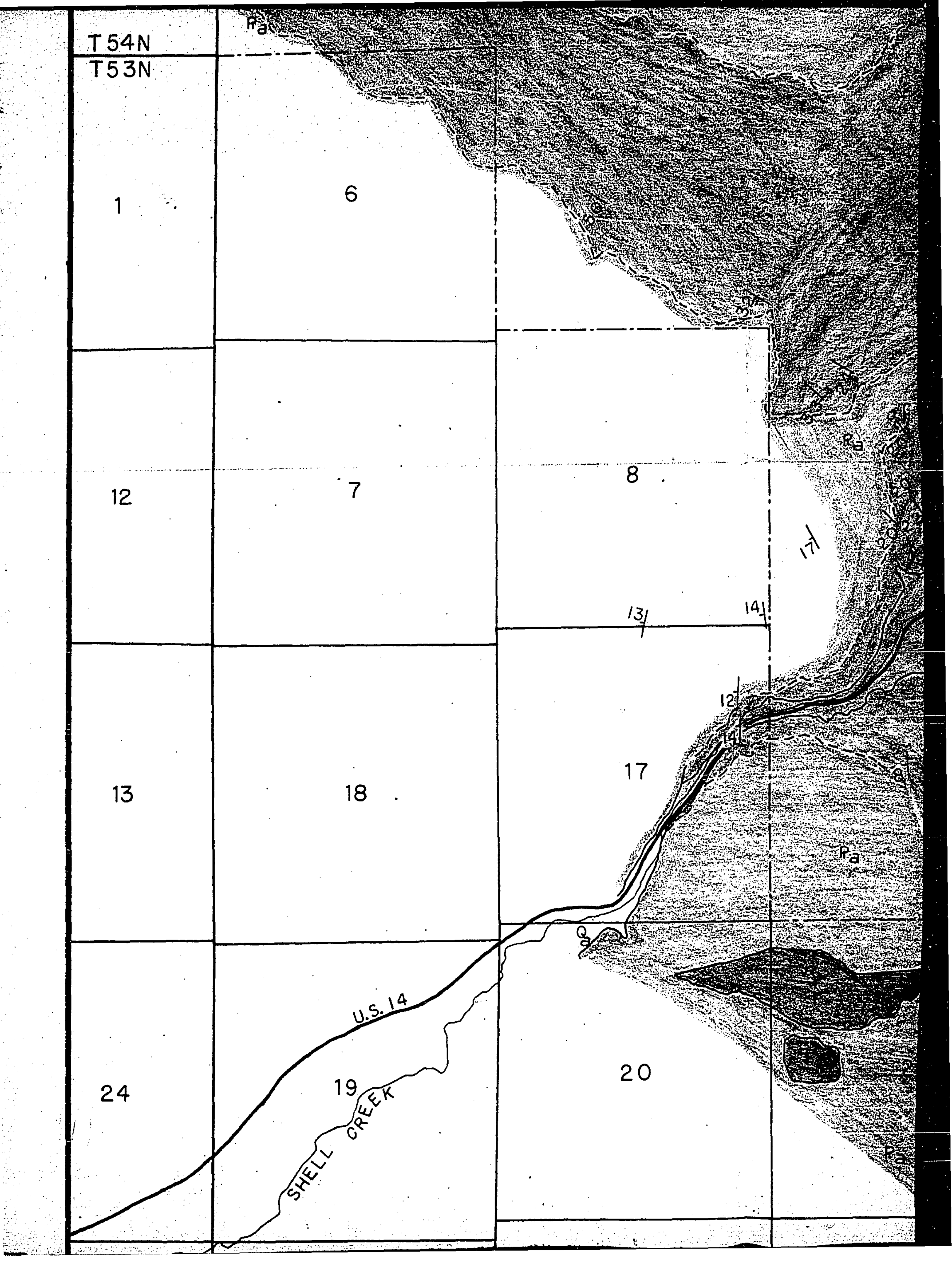


Єg
Єgv
Qa
Єgv
D
Qa
Qa
Qa
Є
Є
Qa
P€m
Qa
D
D
T5

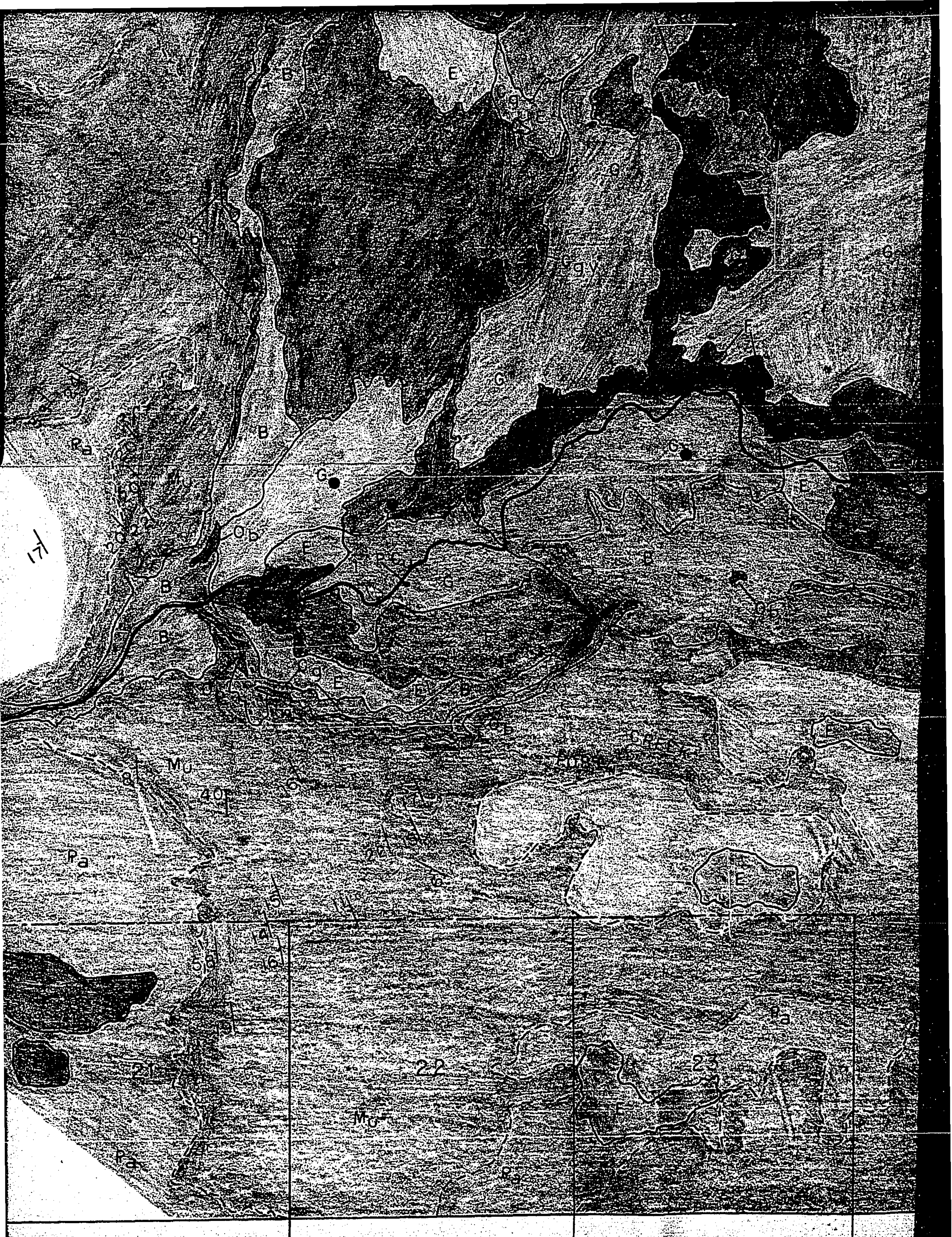


N
T54N
T53N
Qa
RUBLE
H
INACT
TER.
Ts
TERT
PEN.
Pa
AMSD
ORD.-MISS.
Mu
MADIS
LEIGH
BIGH
ORD.
Ob
STEA
CAMBRIAN
Cg
GALL
GROS
FLAT
PRECAMBRIAN
PCm
MAFI
xLIN

		RUBLE CREEK MORAINE
	H	INACTIVE-3 LANDSLIDE COMPLEX
TER.	Ts	TERTIARY SAND
PEN.	Pa	AMSDEN FM
ORD.–MISS.	Mu	MADISON FM., JEFFERSON FM., & LEIGH & HORSESHOE MTN. MBRS. BIGHORN FM.
ORD.	Ob	STEAMBOAT POINT MBR. BIGHORN FM.
CAMBRIAN	Cg	GALLATIN FM.
CAMBRIAN	Cgv	GROS VENTRE FM.
CAMBRIAN		FLATHEAD FM.
PRECAMBRIAN	P Cm	MAFIC DIKE
PRECAMBRIAN	PCu	xLIN. ROCKS UNDIF.



T54N
T53N
1
6
12
7
8
13
18
17
24
19
20
U.S. 14
SHELL CREEK



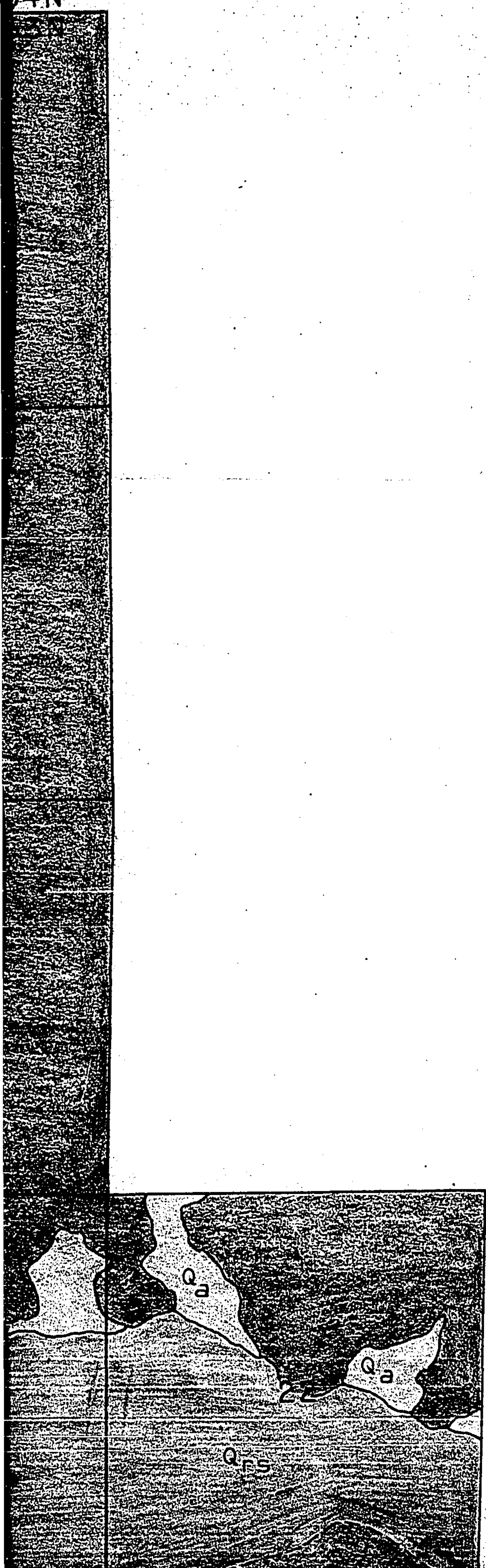
B
E
Cg
Cgv
G
Ob
Pa
Mu
21
22
23
40


G
D
Qa
E
Ob
Ra
24
19
20


B
D
Ob
Qa
Cg
C
E
B
D
D
D
B
Qa


Qa
D
E
G
C
H
18


T54N
T53N
P€m
Qa
Qa
D
Qa
Qa
Qa
Qa
18
20
21
Qrs



CAMB

FLATHEAD FM.

PRECAMBRIAN

P Cm MAFIC DIKE

xLIN. ROCKS UNDIF.

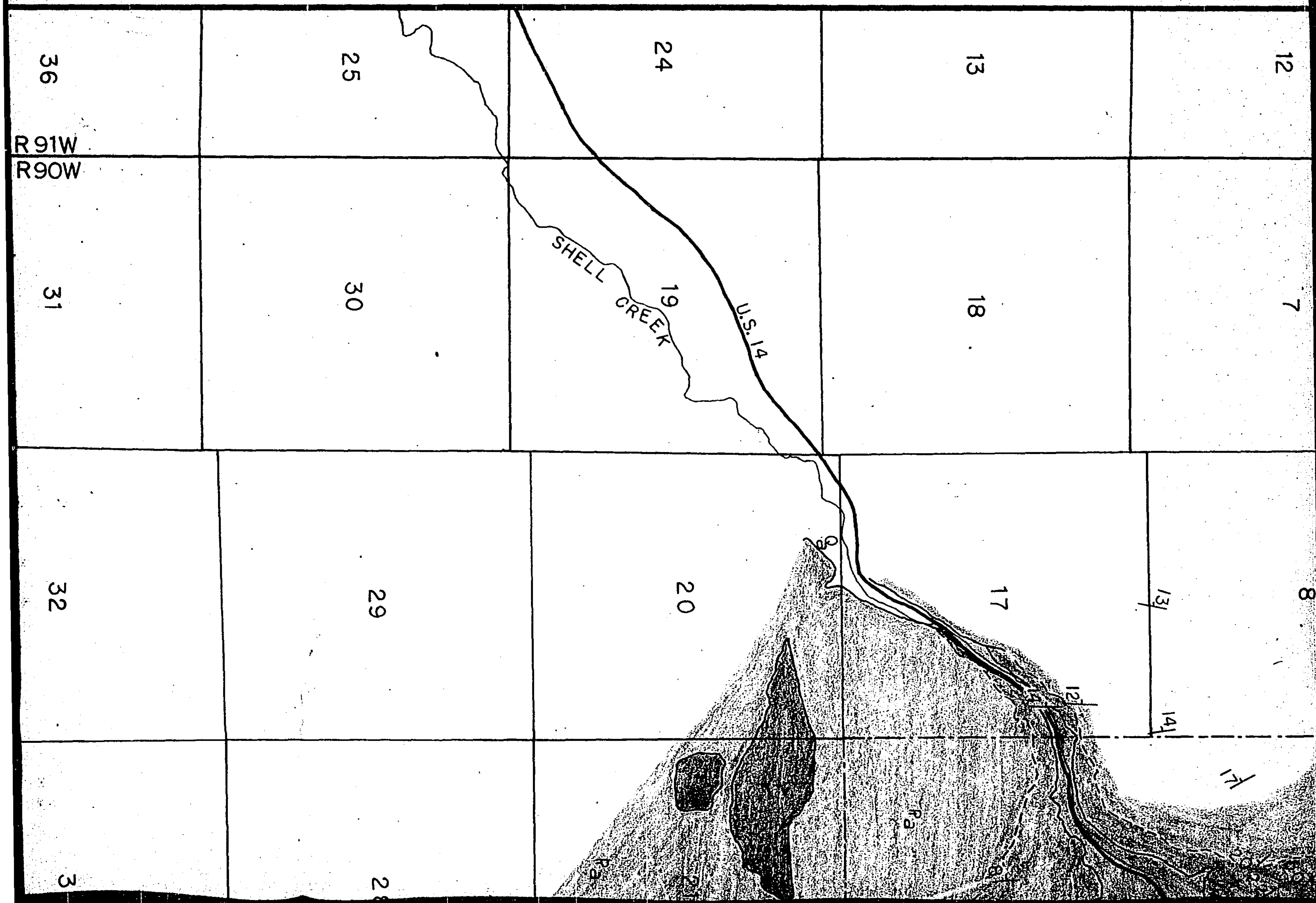
CAM

PRECAMBRIAN

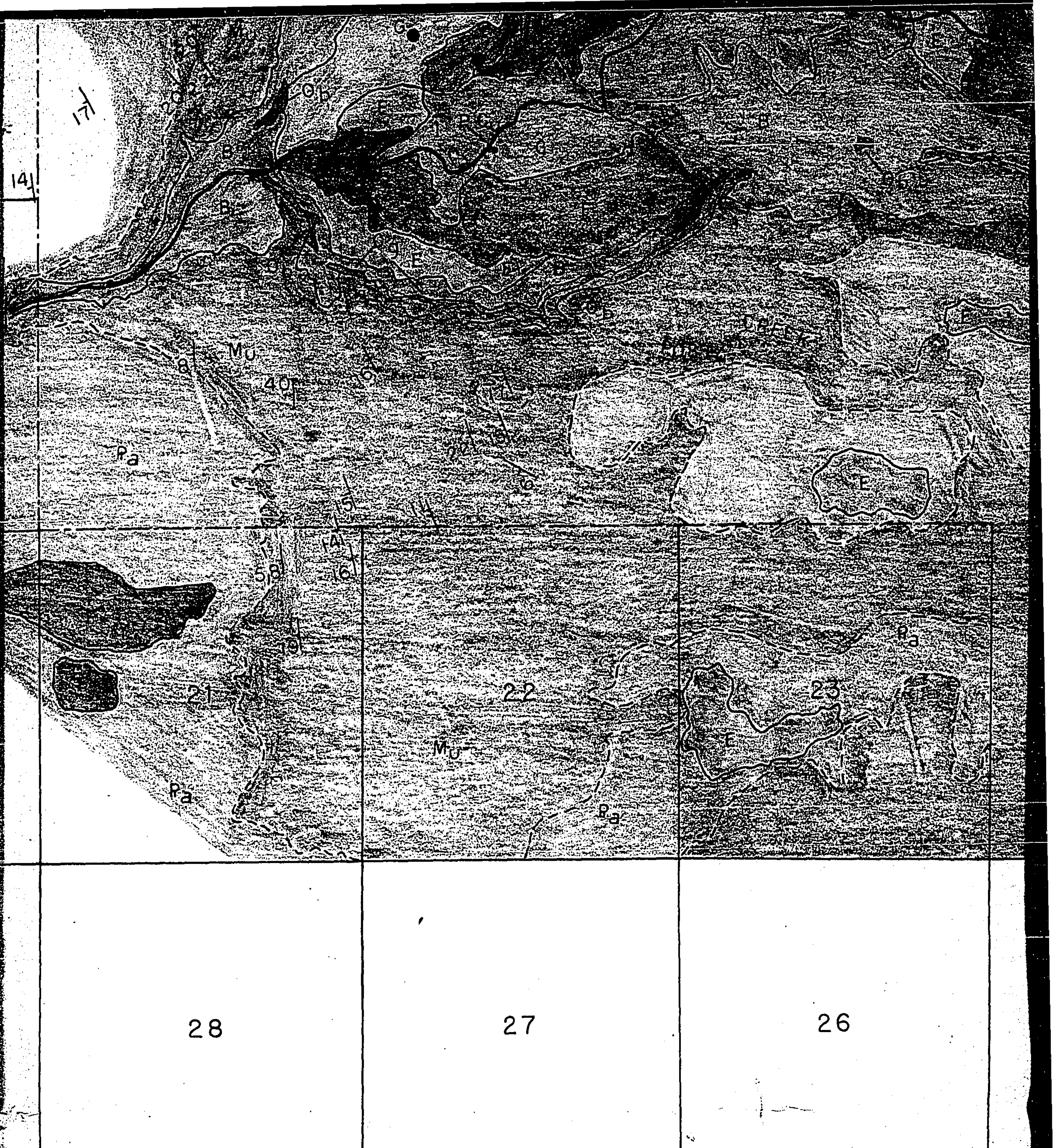
FLATHEAD FM.

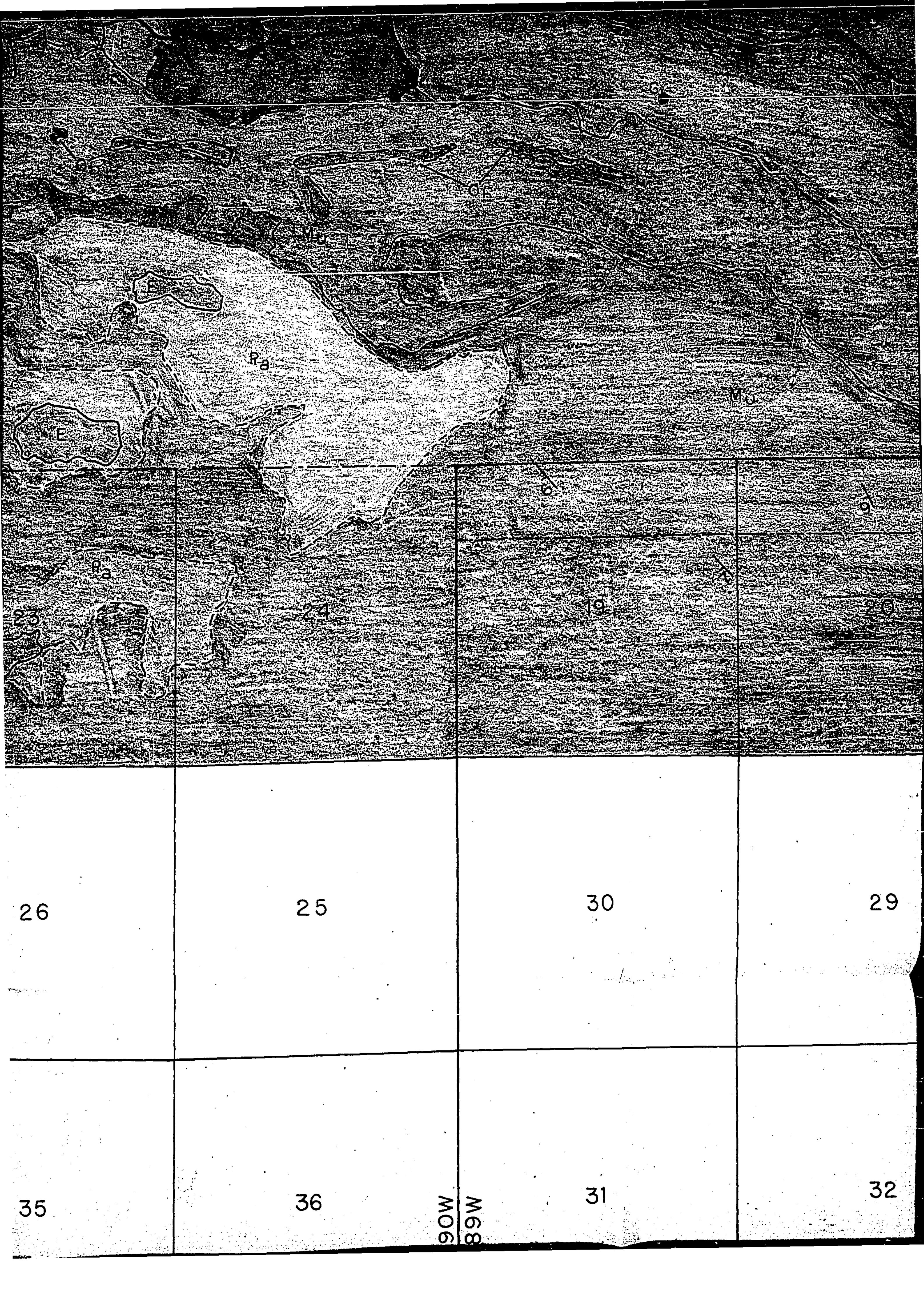
P C$_m$ MAFIC DIKE

xLIN. ROCKS UNDIF.

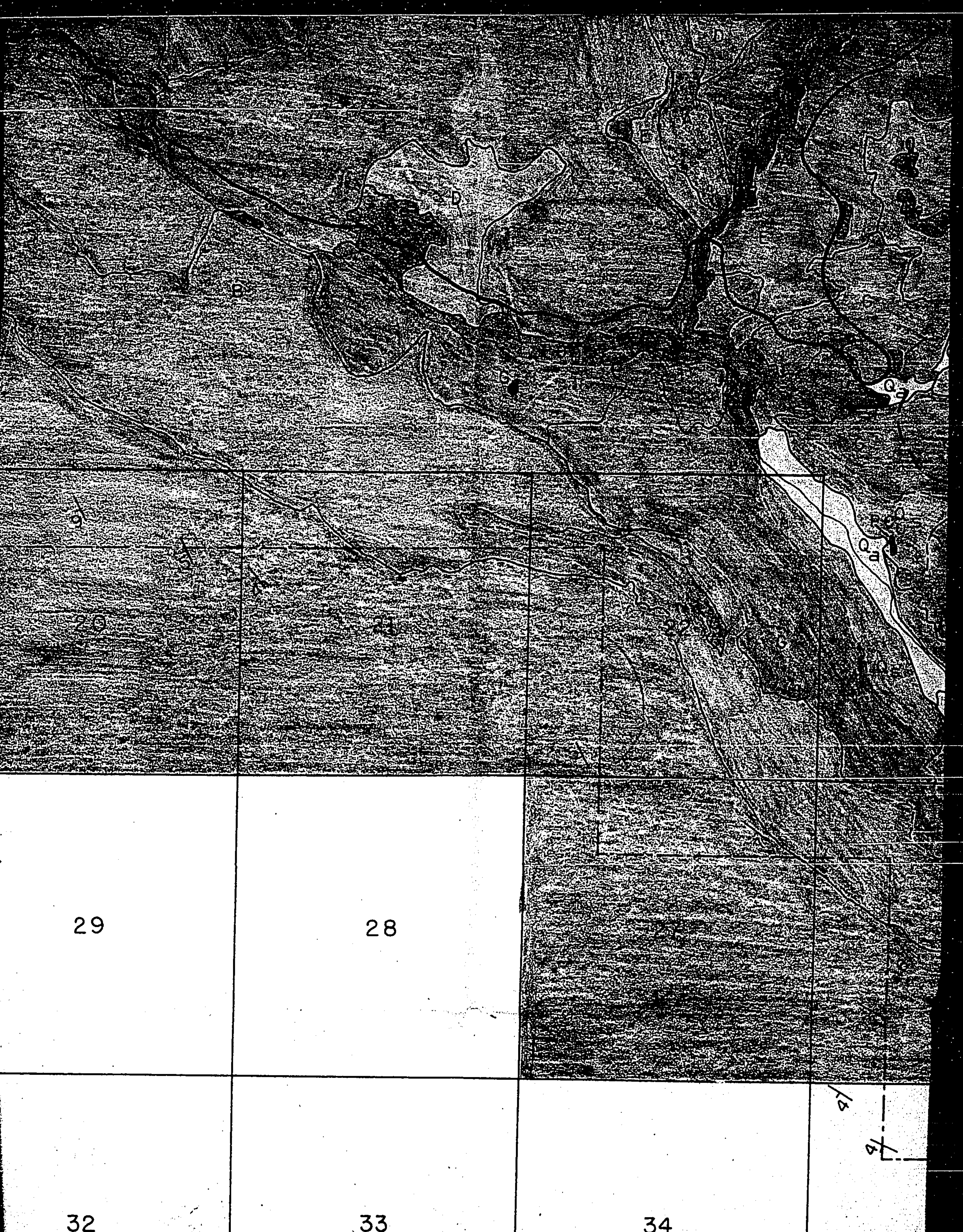


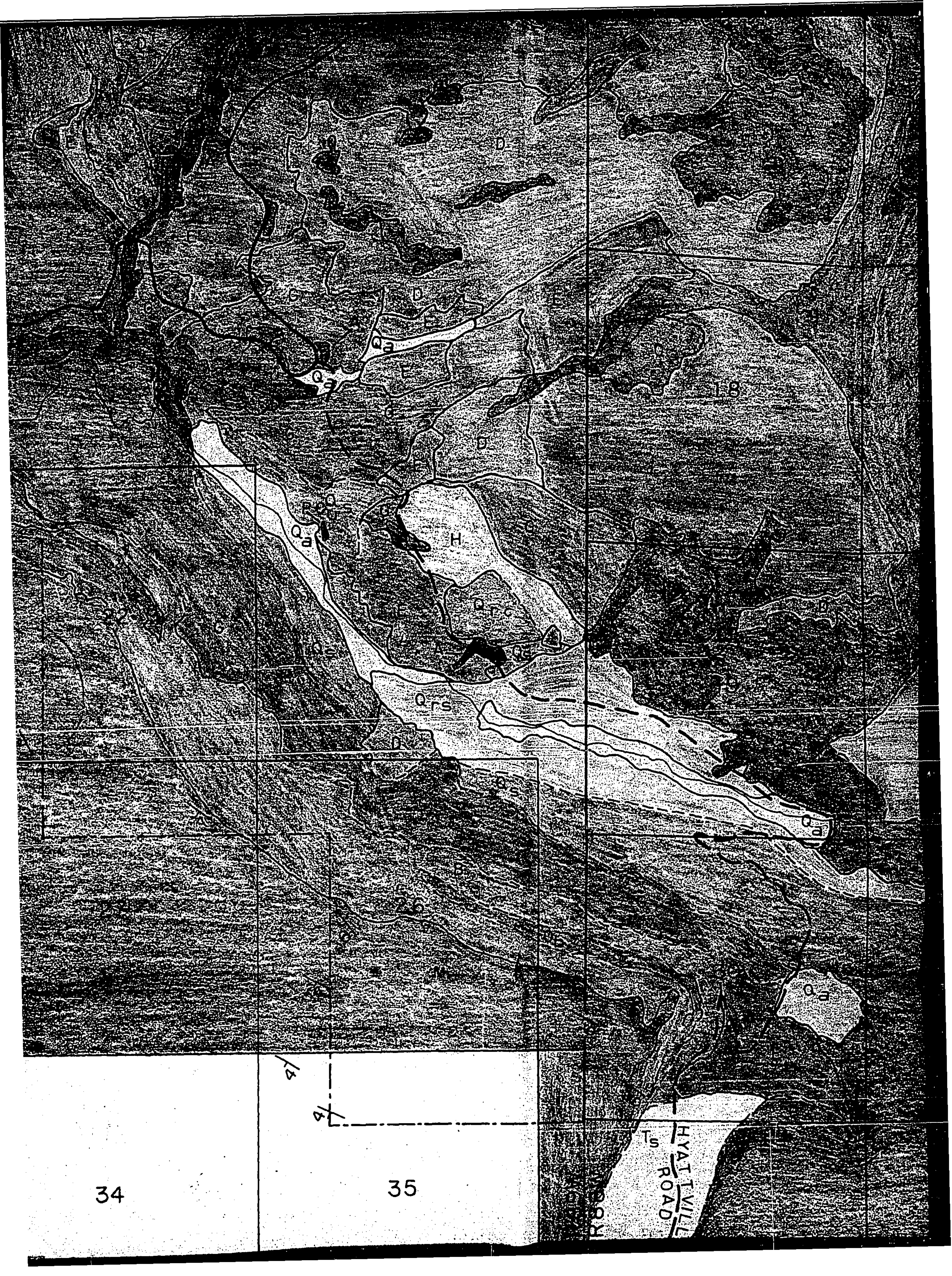
R 91W
R90W
36
25
24
13
12
31
30
19
18
7
32
29
20
17
8
SHELL CREEK
U.S. 14
Qa
Pa
Pa


17
14
B
E
Mu
40
Pa
5
6
58
16
19
21
22
23
Pa
Mu
E
Pa
Pa
28
27
26
33
34
35



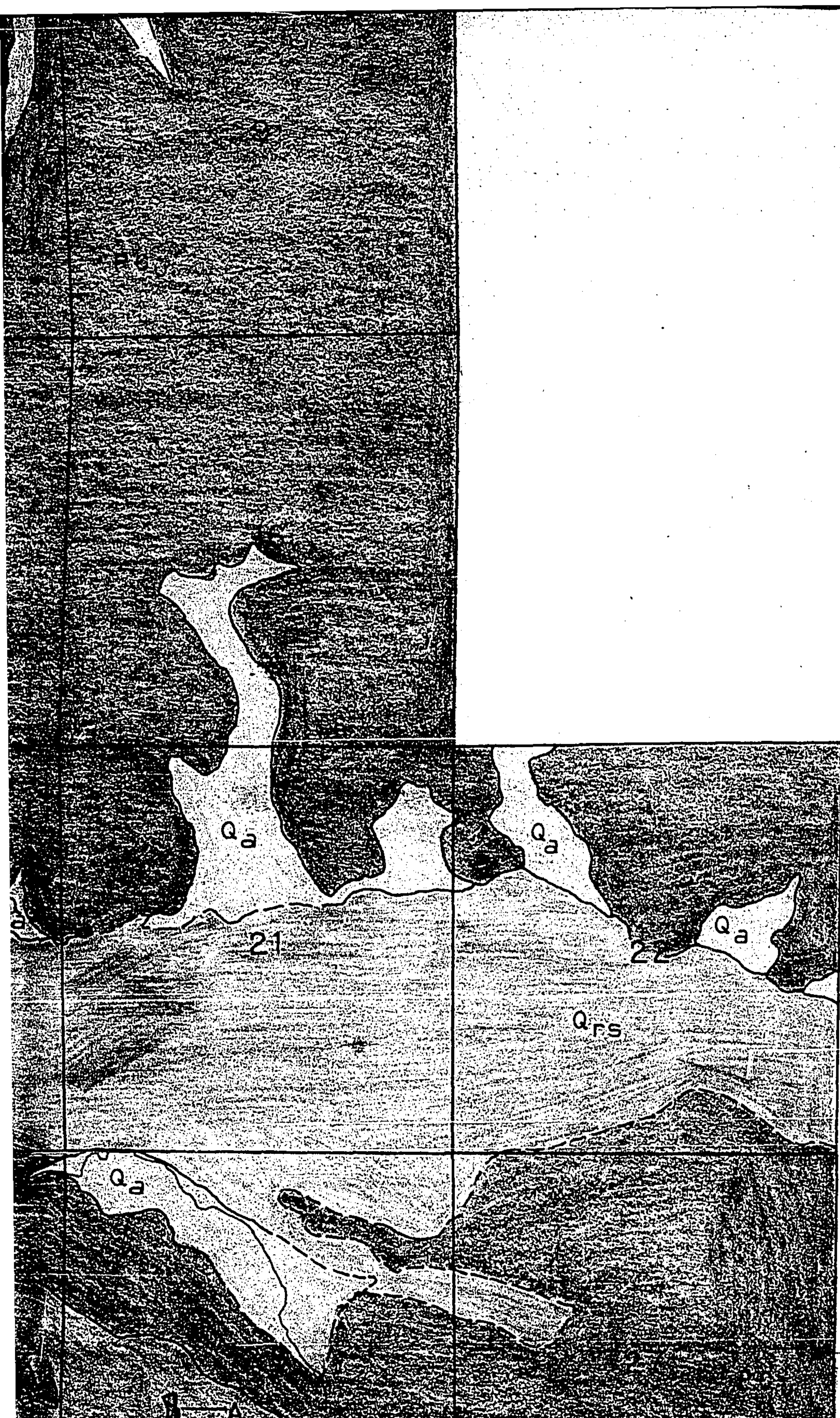
Ra
E
E
Mu
Mu
Ra
23
24
19
20
6
9
26
25
30
29
35
36
90W
89W
31
32


29
28
32
33
34

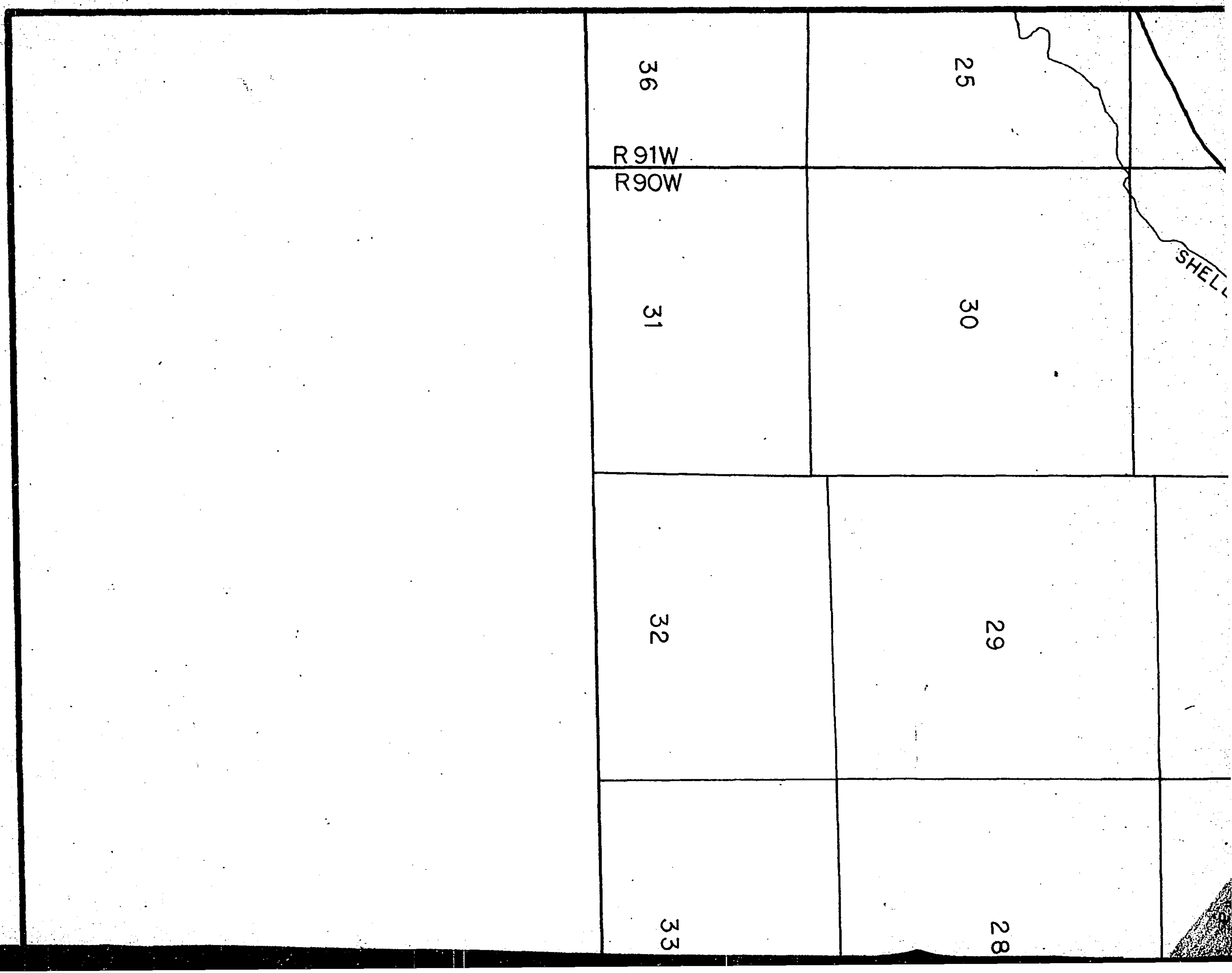


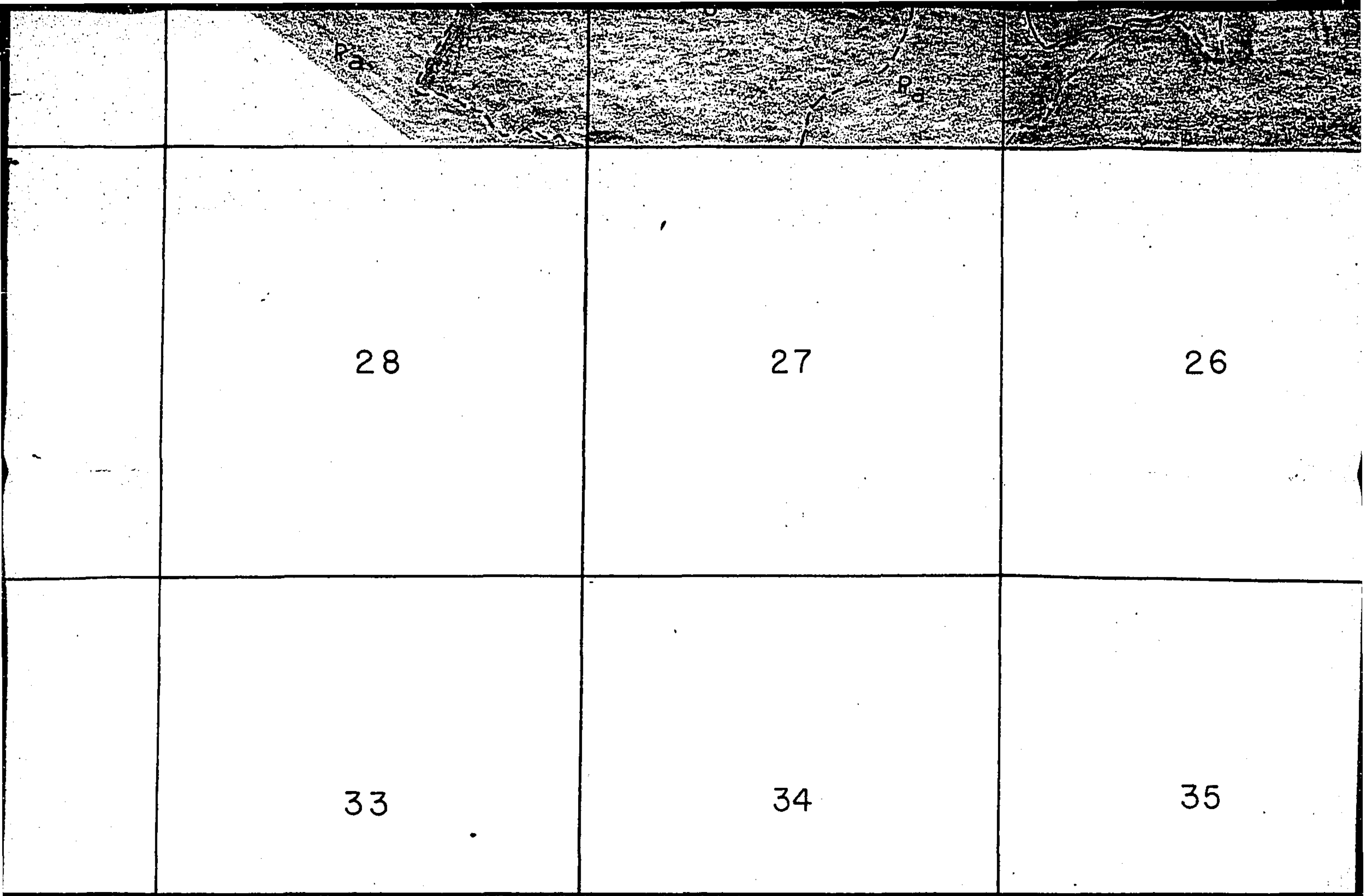
D
Qa
Qa
18
H
Qrc
Qrs
Qs
Qa
Qa
34
35
Ts
HYATTVILLE
ROAD

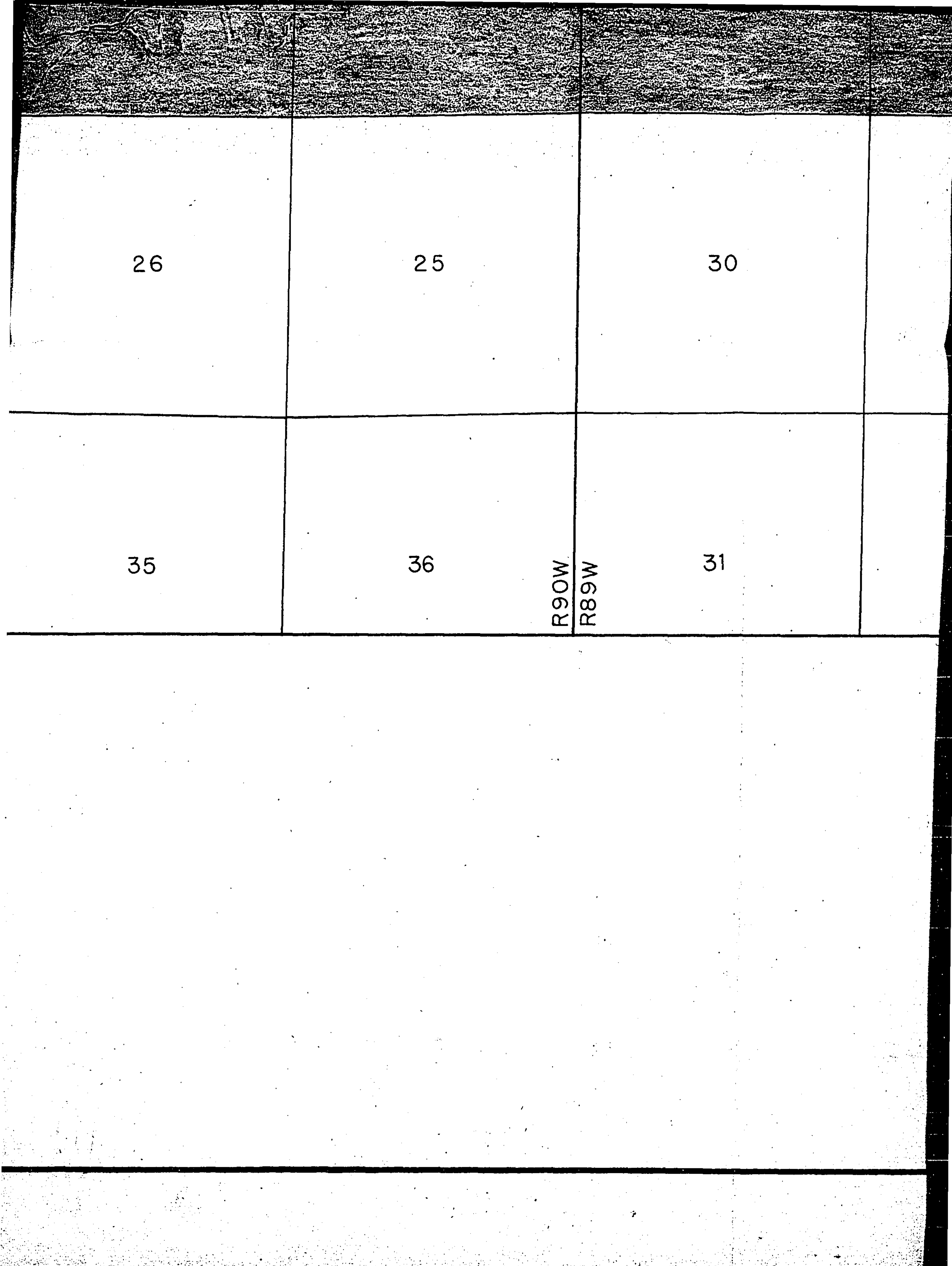
18
Qa
Qa
20
21
Qrs
Qa
Qa
Qa
Ts
HYATTVILLE ROAD

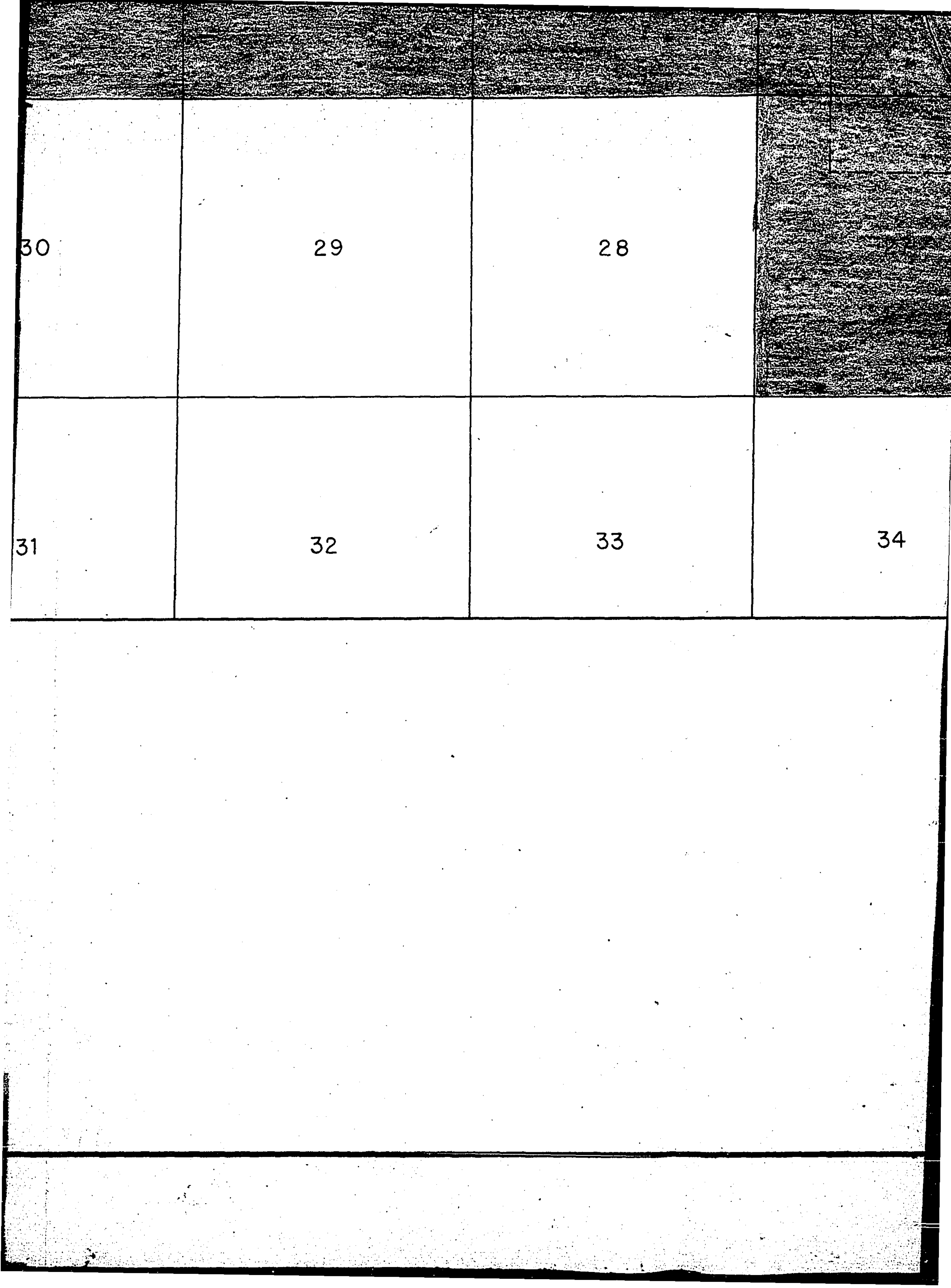


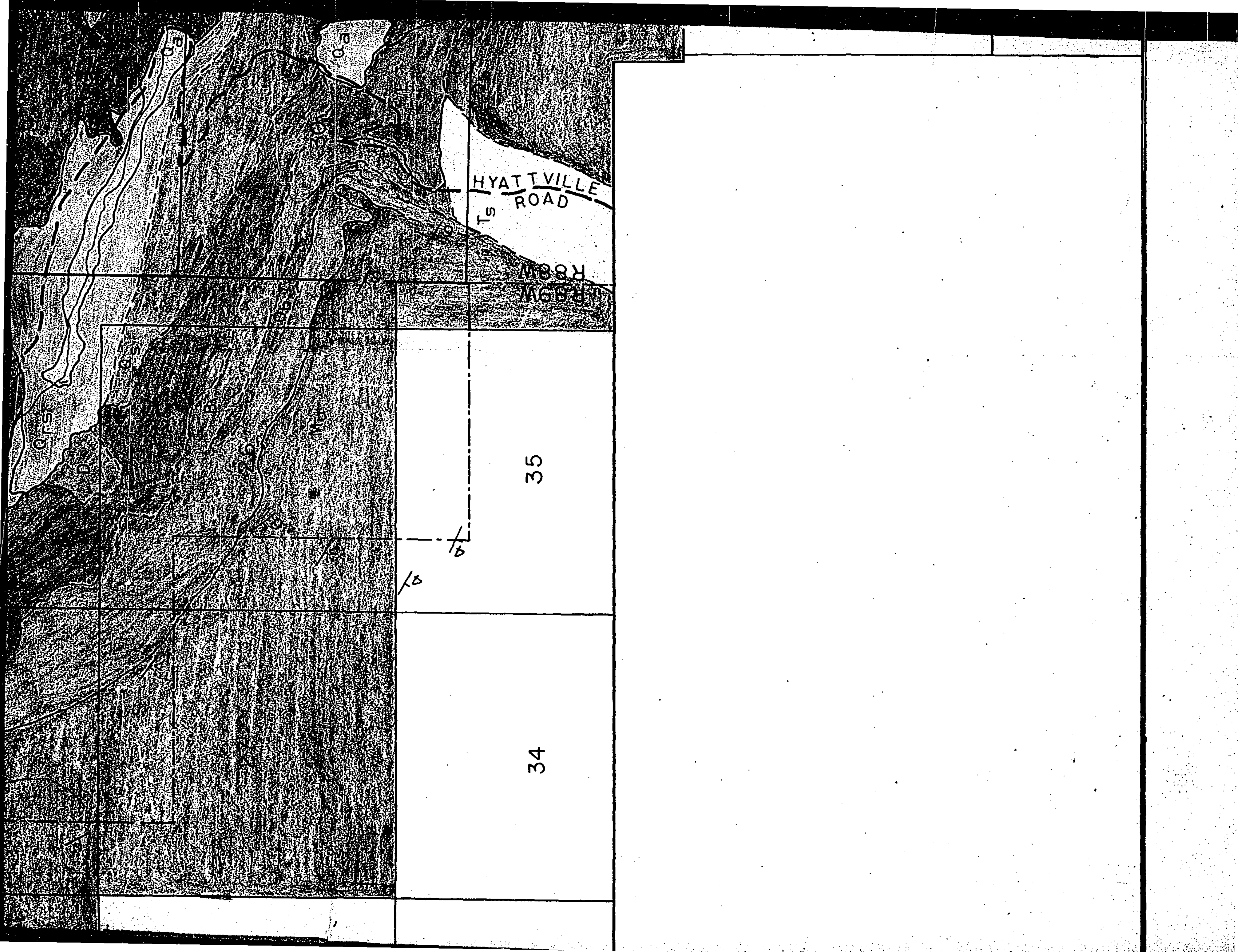
Qa
Qa
Qa
21
22
Qrs
Qa

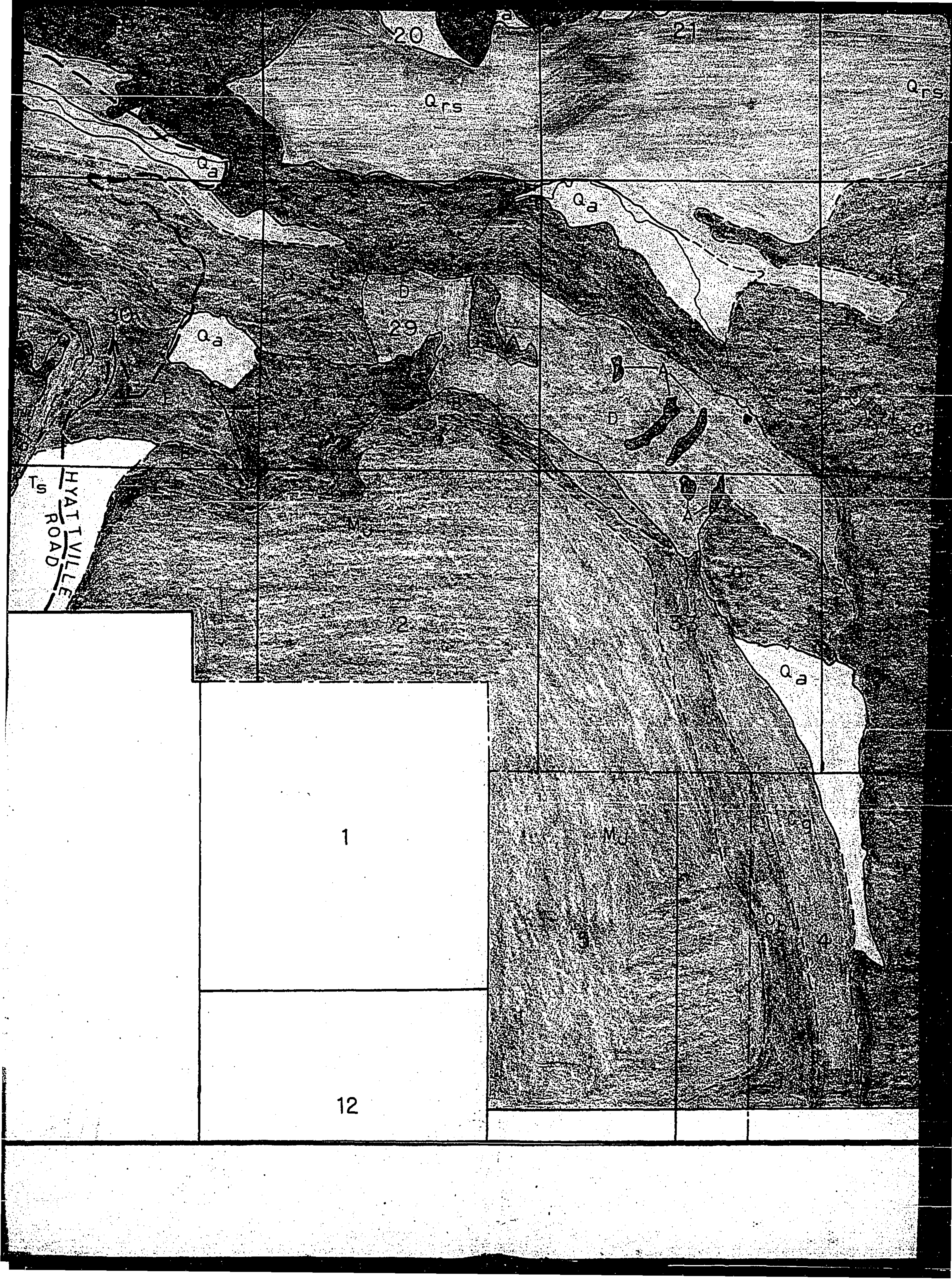

36
25
R 91W
R90W
31
30
SHEL
32
29
33
28

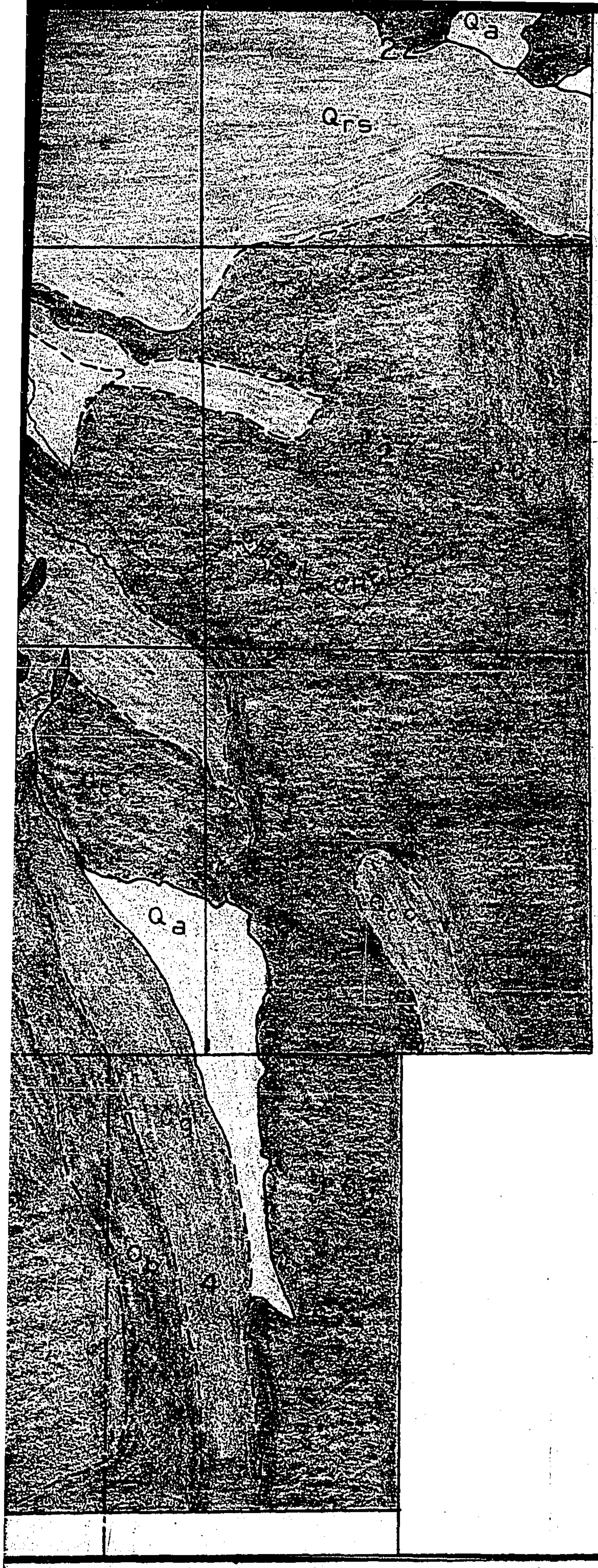

Ra
Ra
28
27
26
33
34
35

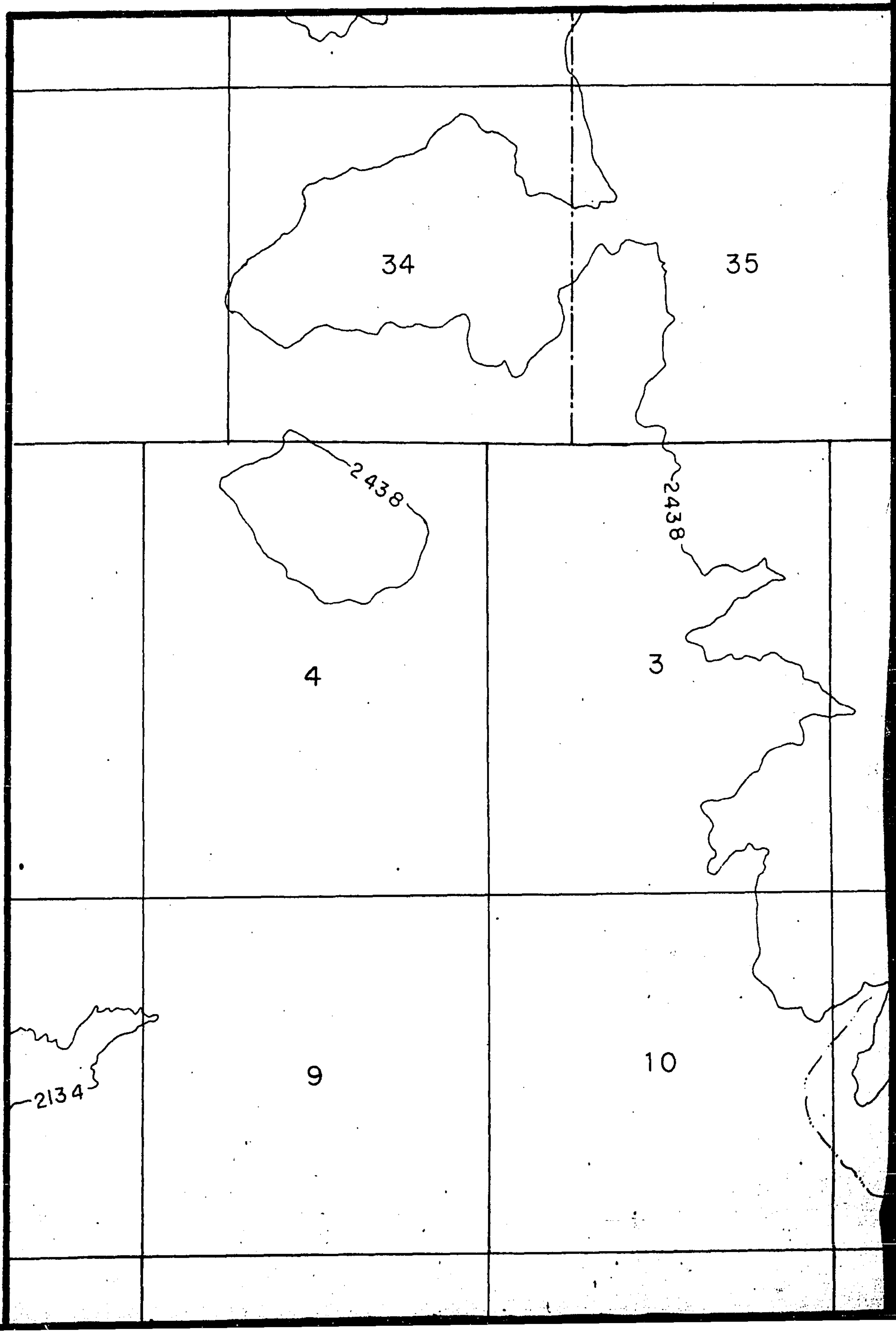

26
25
30
35
36
31
R90W
R89W

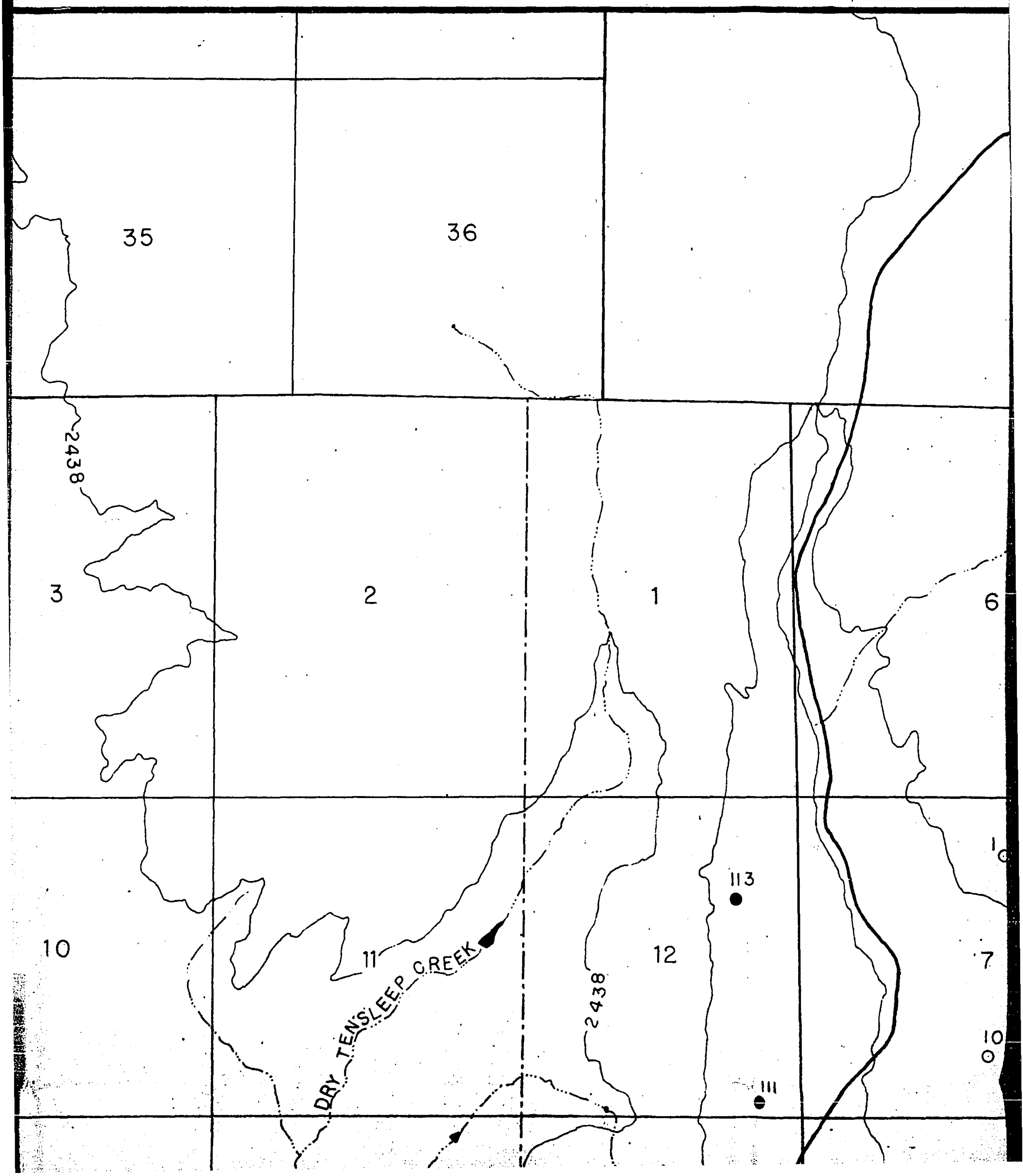

30
29
28
31
32
33
34


HYATTVILLE
ROAD
Ts
R88W
R89W
35
34

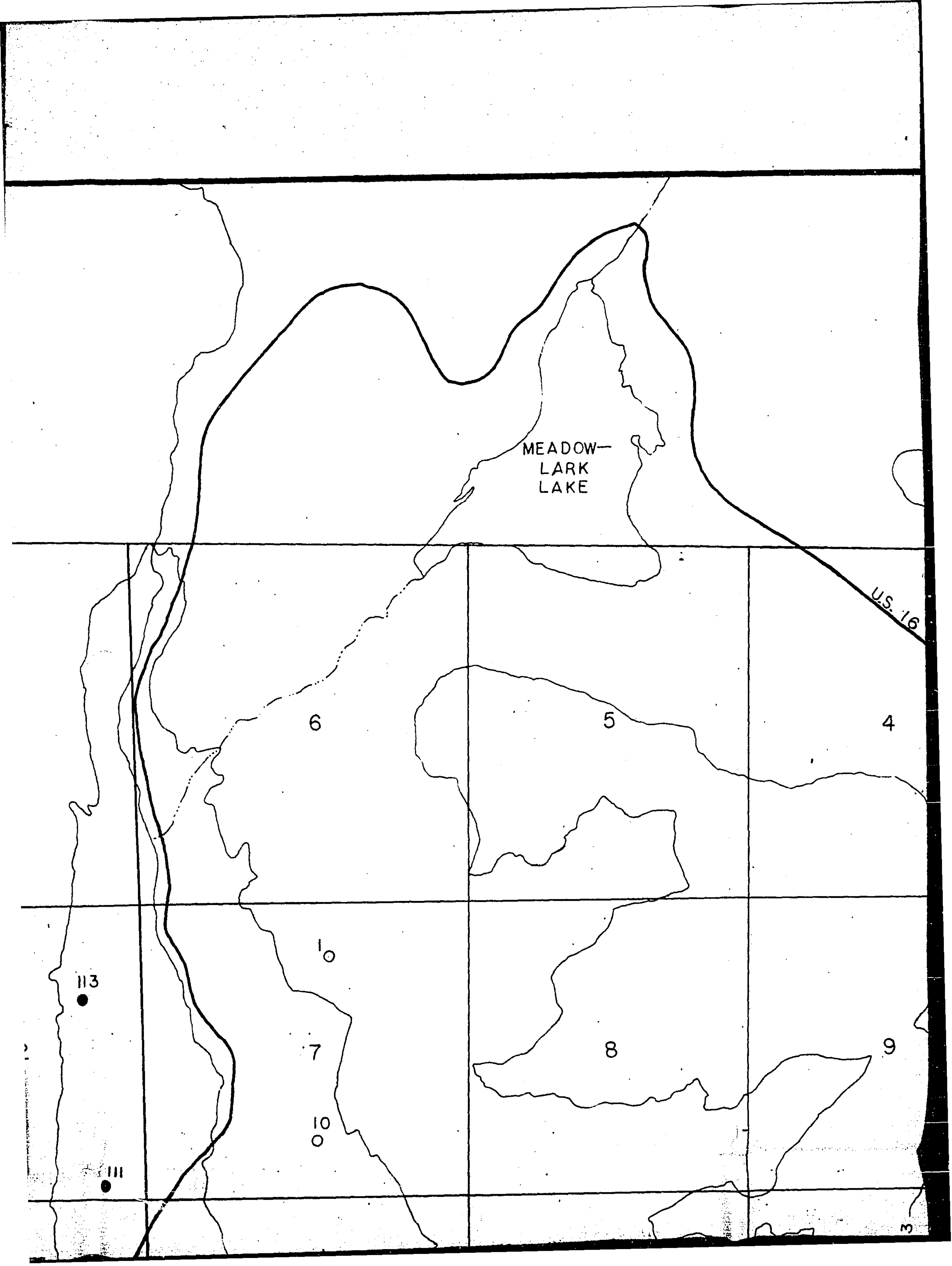

20
21
Qrs
Qrs
Qa
Qa
Qa
D
29
30
Qa
D
Ts
HYATTVILLE
ROAD
Mu
2
Qa
Mu
1
12


Qa
Qrs
Qa


34
35
2438
2438
4
3
9
10
2134



35
36
2438
3
2
1
6
1
113
10
11
DRY TENSLEEP CREEK
12
2438
7
10
111


MEADOW-
LARK
LAKE
U.S. 16
6
5
4
1
113
7
8
9
10
111

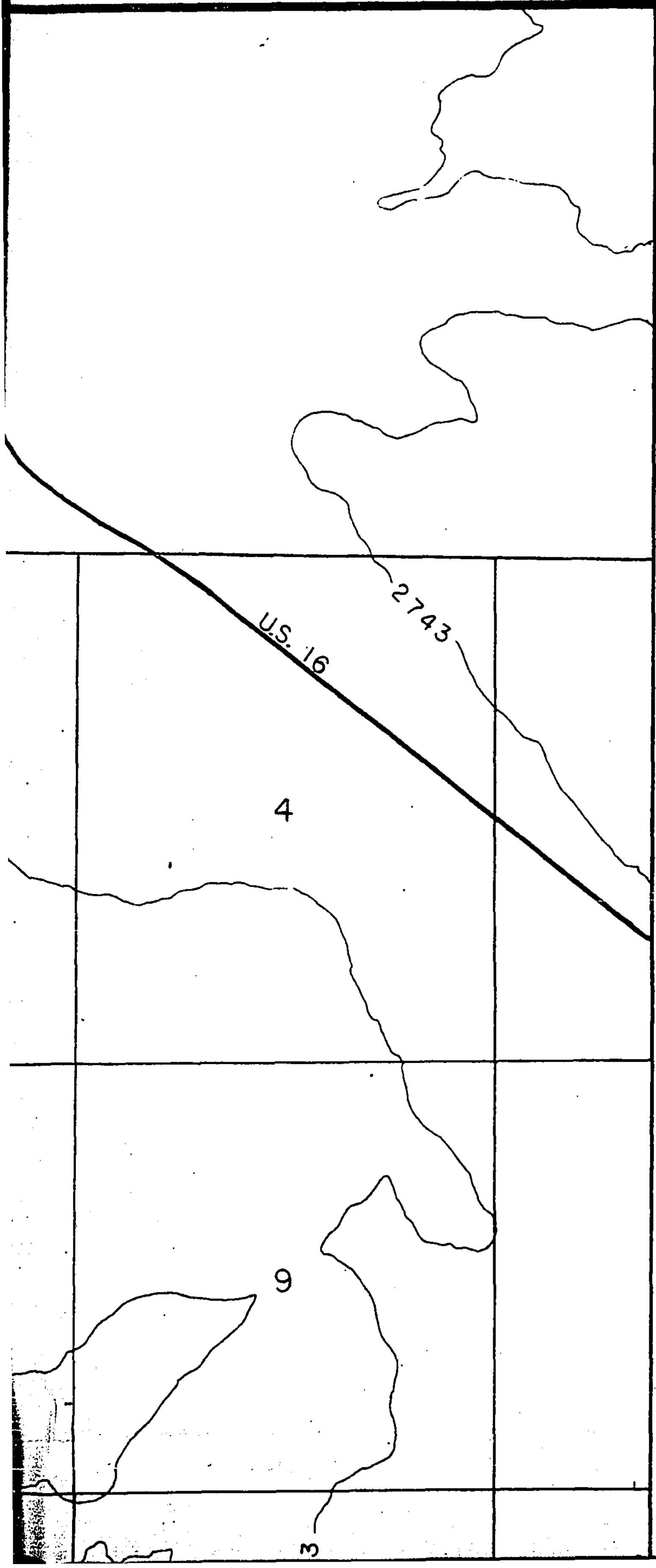


FIG
GENERAL LO
TENSLEE

LEG

● SOIL PIT
— ROAD CUT
○ LANDSLIDES
ANALYZE

SC

1 5

CONTOUR INTER

FIG. 53

GENERAL LOCATION MAP
TENSLEEP CANYON

LEGEND

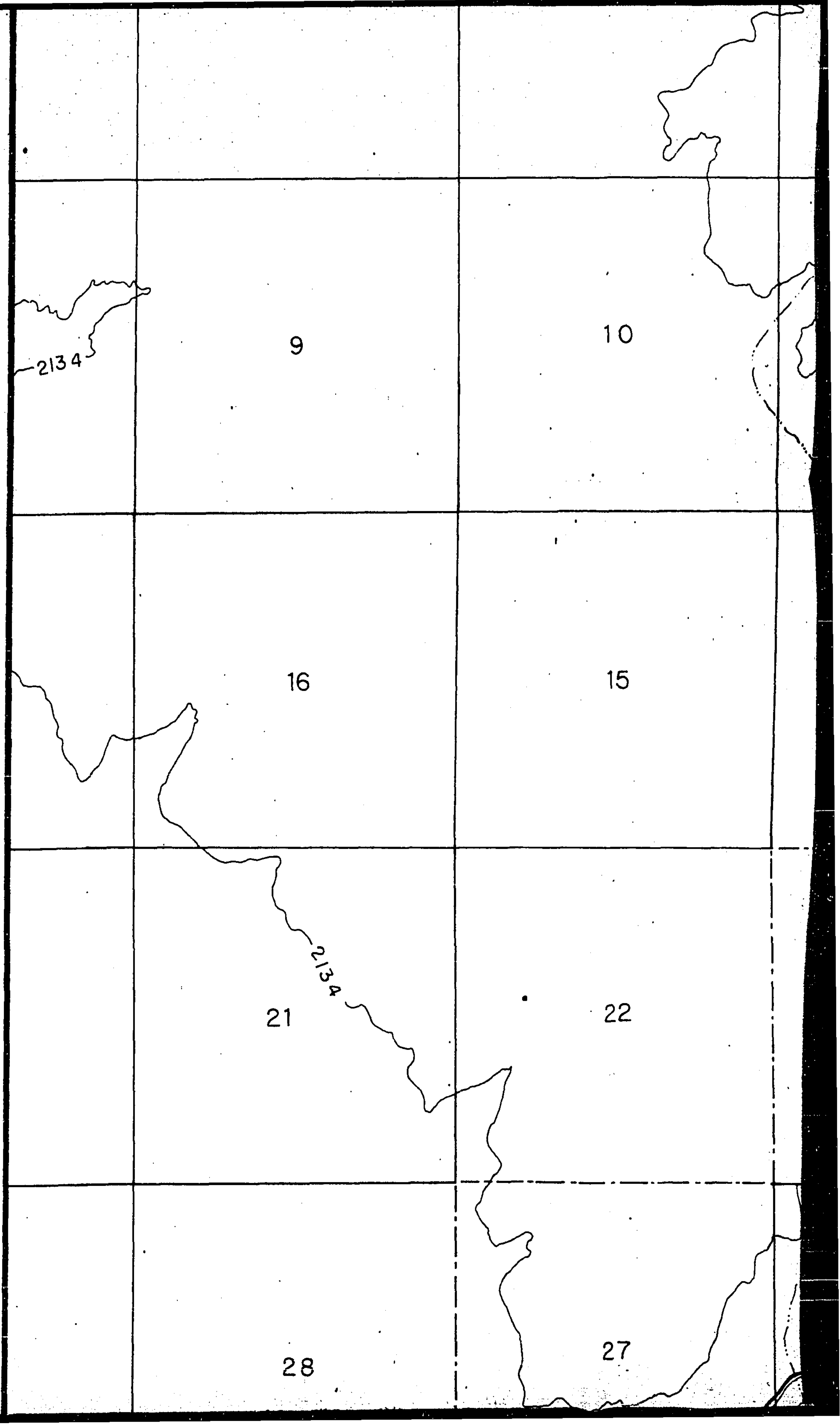
- ● SOIL PIT
- — ROAD CUT
- O LANDSLIDES STATISTICALLY ANALYZED

SCALE

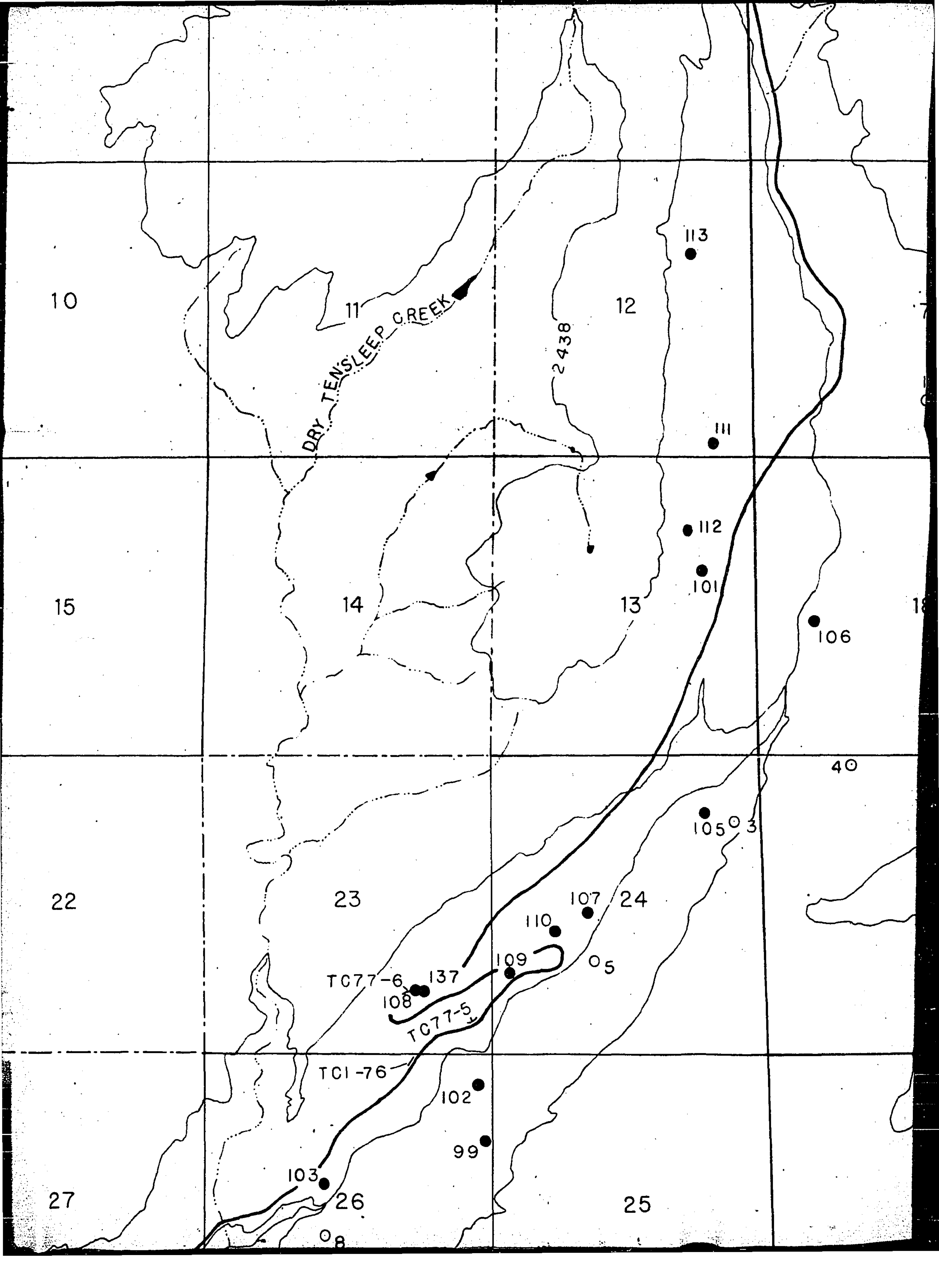
1 .5 0 1 KM.

CONTOUR INTERVAL 305 METERS

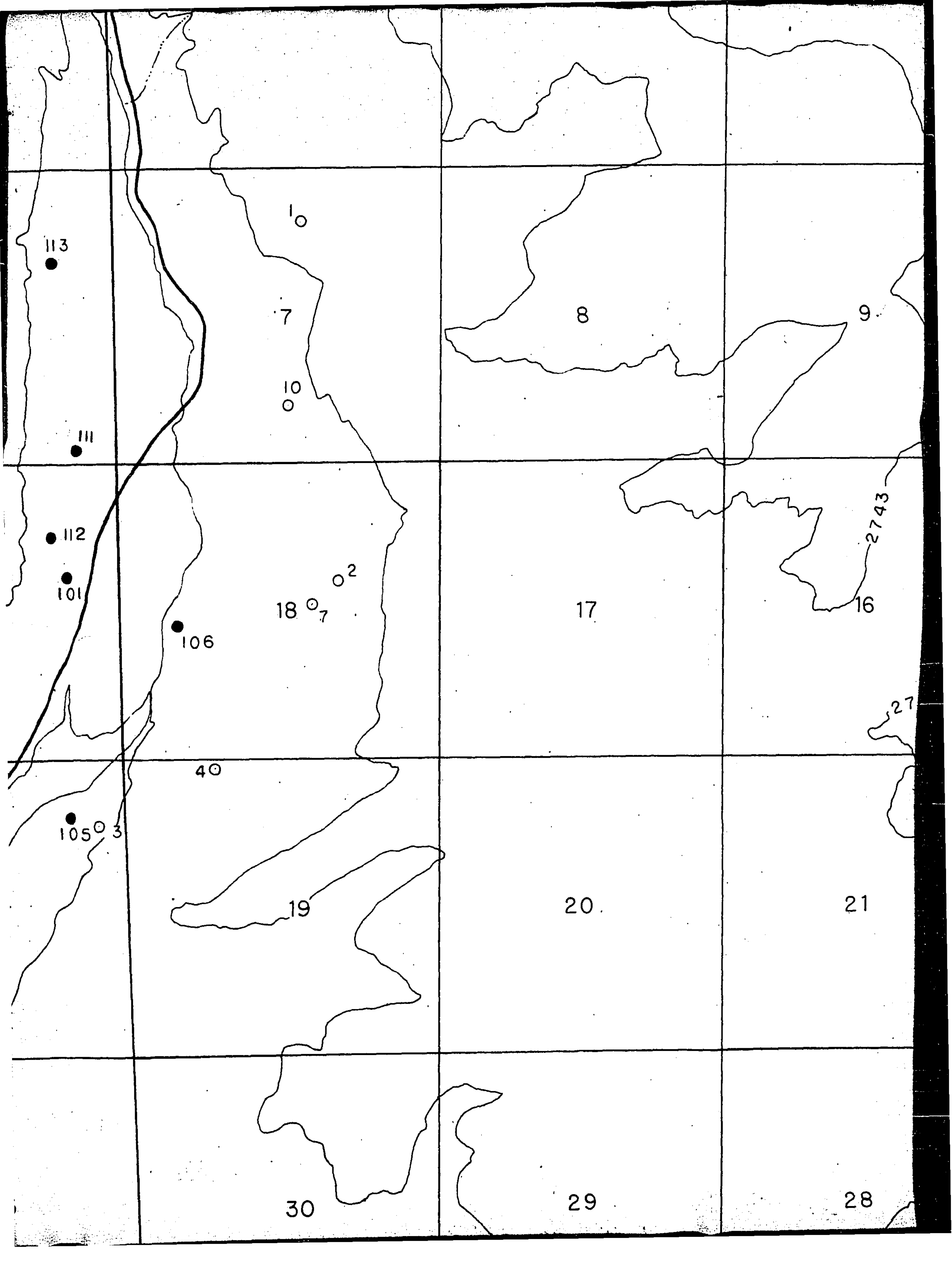
N



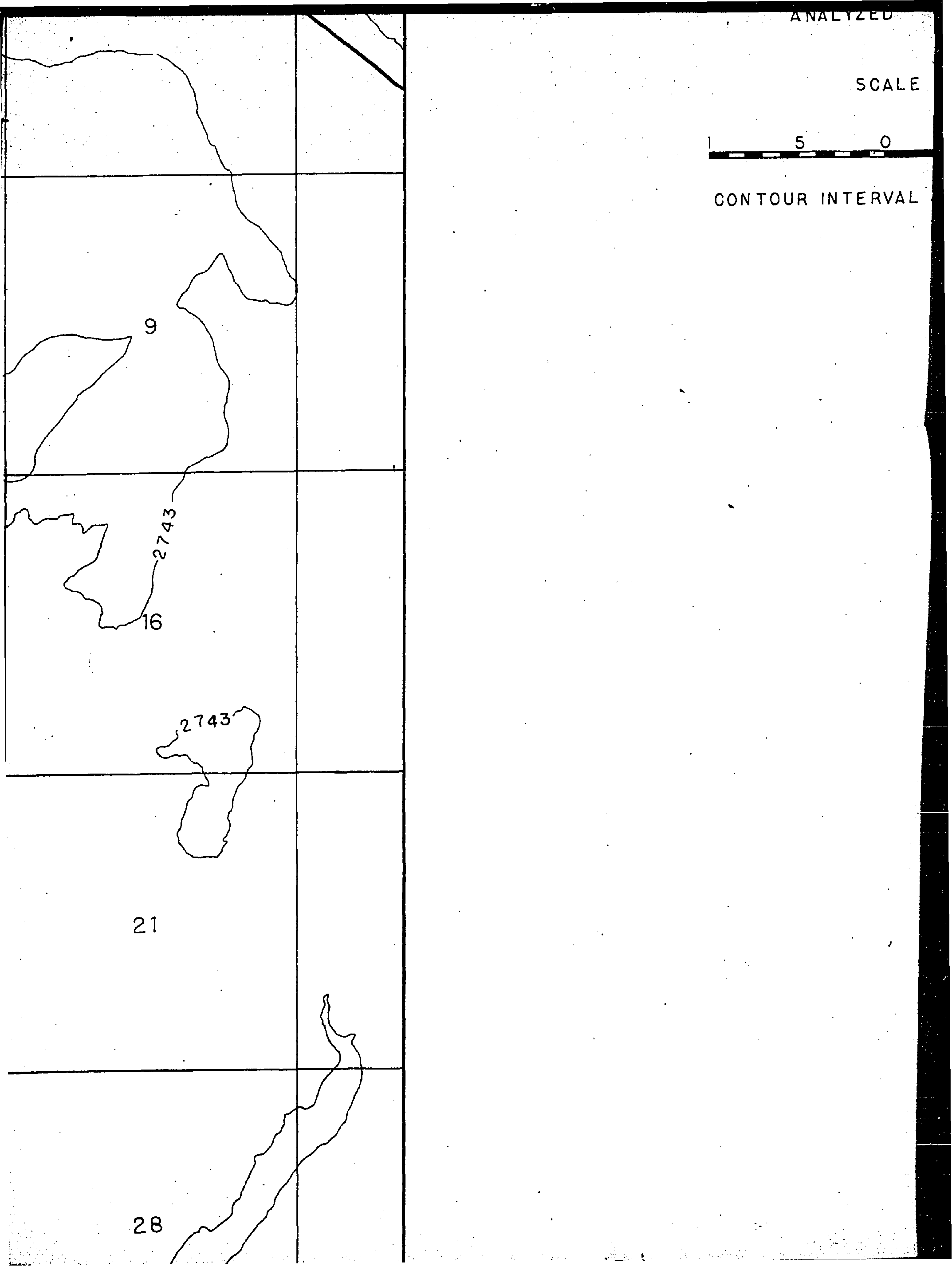
2134
9
10
16
15
2134
21
22
28
27



10
11
12
DRY TENSLEEP CREEK
2438
113
111
112
101
106
15
14
13
40
105
3
22
23
24
107
110
109
5
TC77-6
137
108
TC77-5
TC1-76
102
99
103
27
26
25
8



1
113
7
8
9
10
111
2743
112
2
101
18
7
17
16
106
27
4
105
3
19
20
21
30
29
28



ANALYZED
SCALE
1 5 0
CONTOUR INTERVAL
9
2743
16
2743
21
28

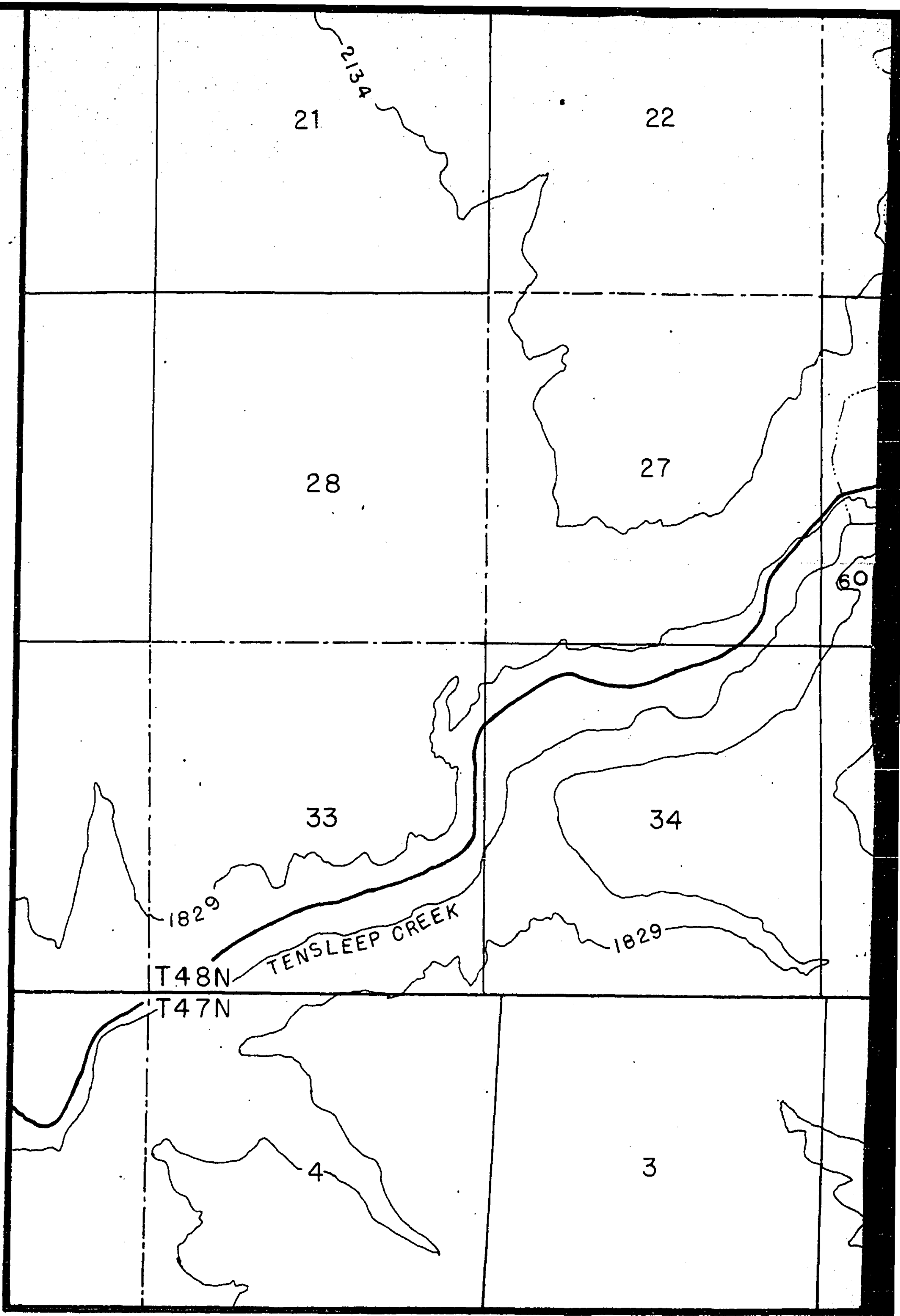
ANALYZED

SCALE

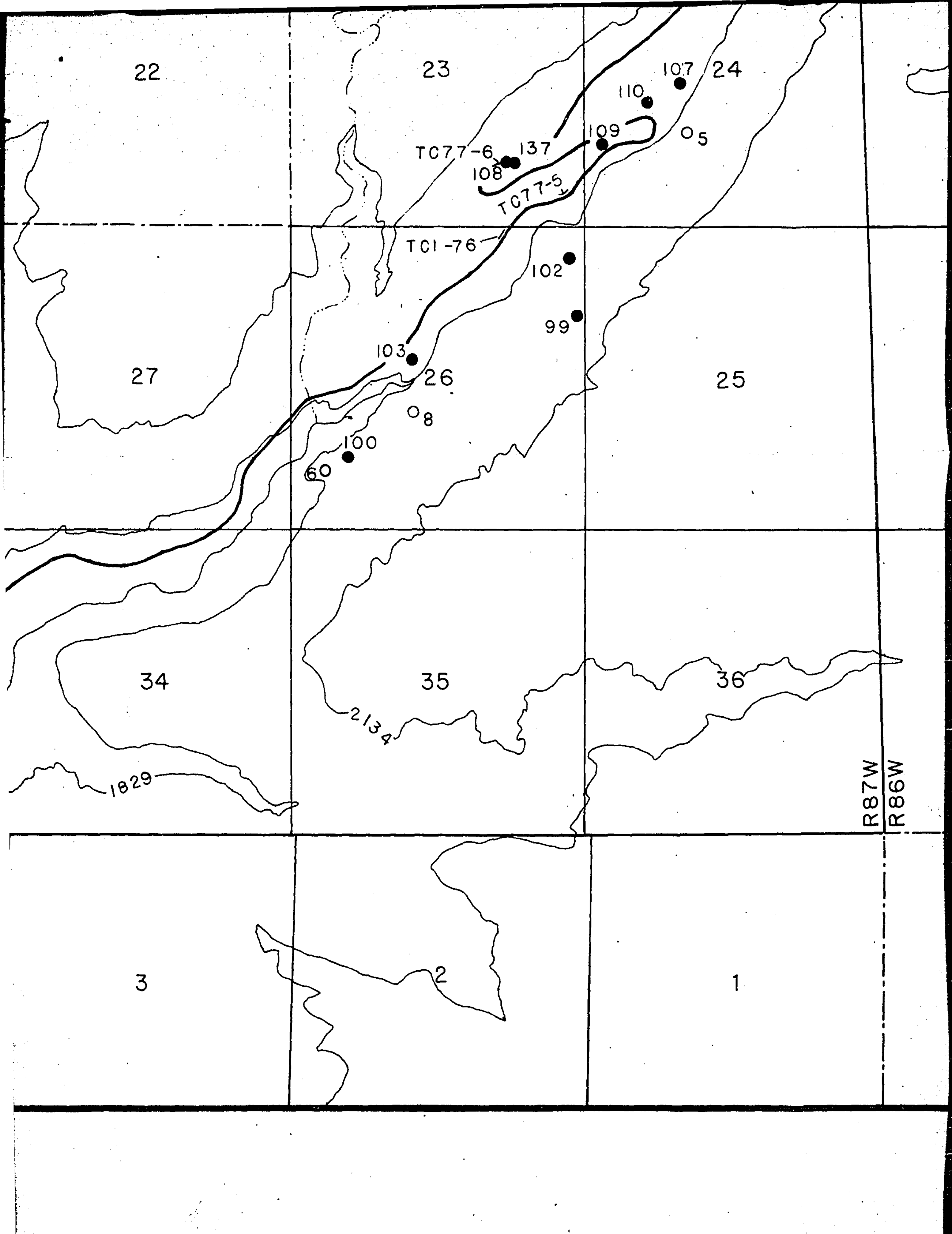
1 5 0 1 KM.

CONTOUR INTERVAL 305 METERS

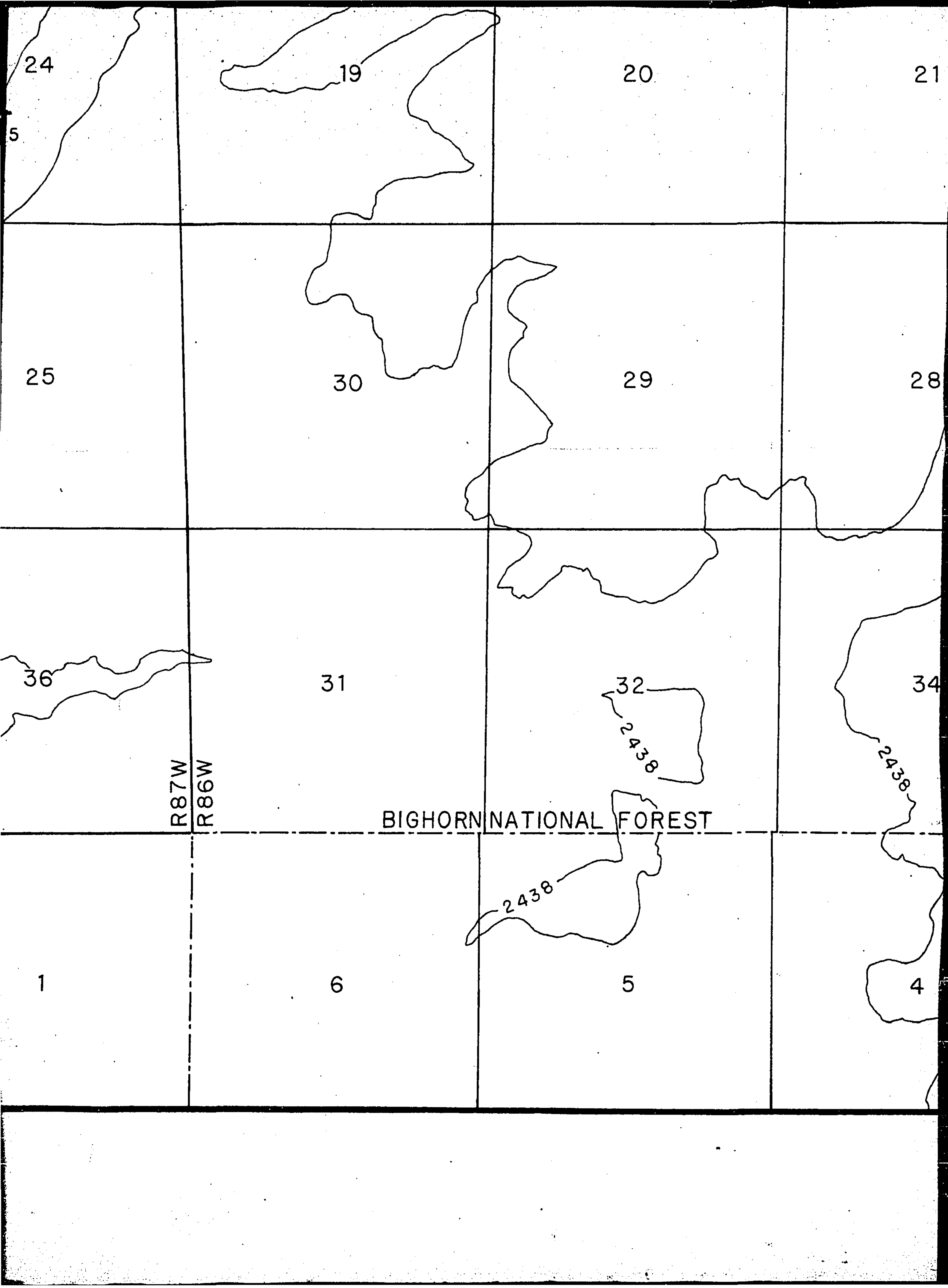
N

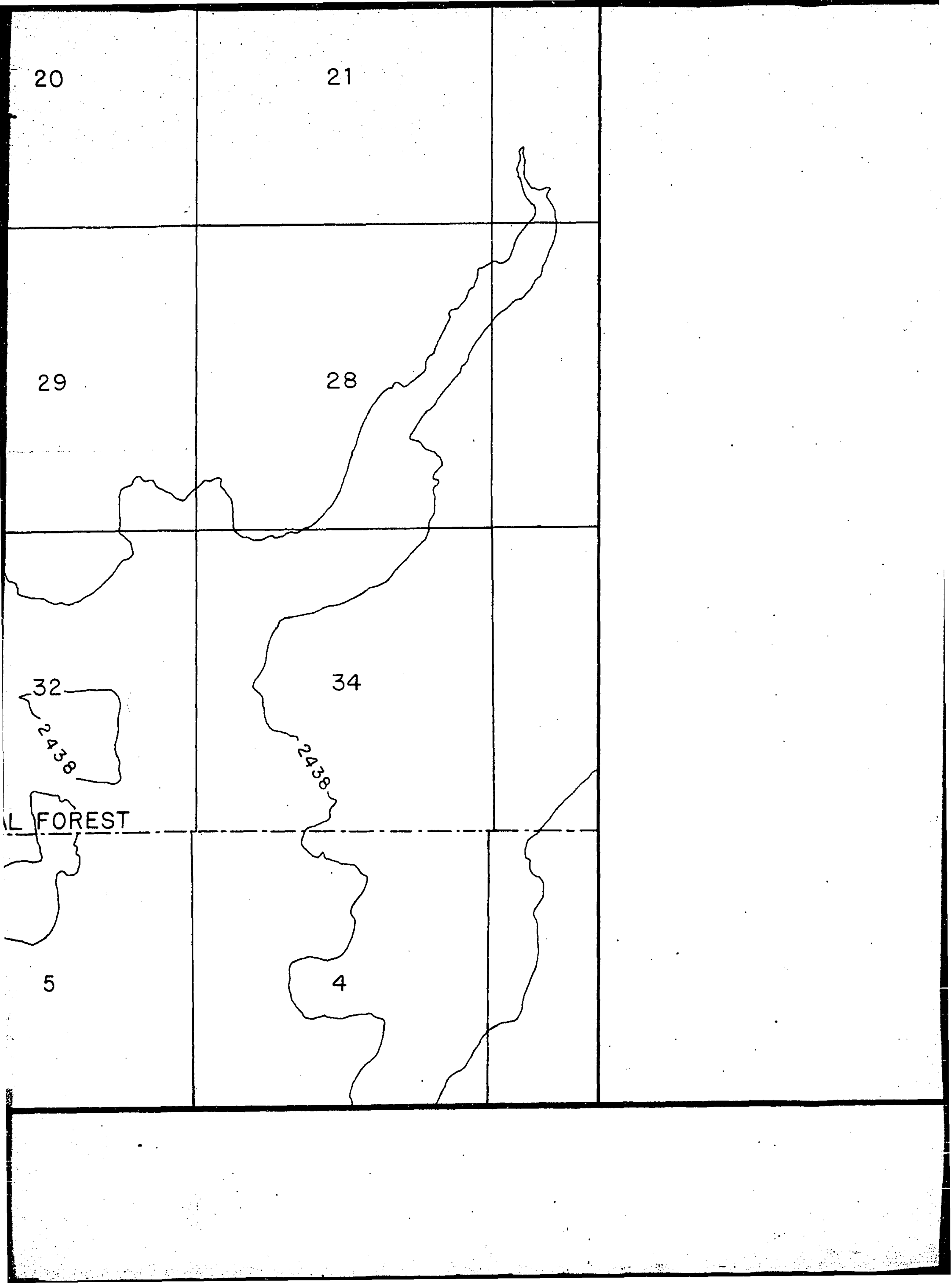


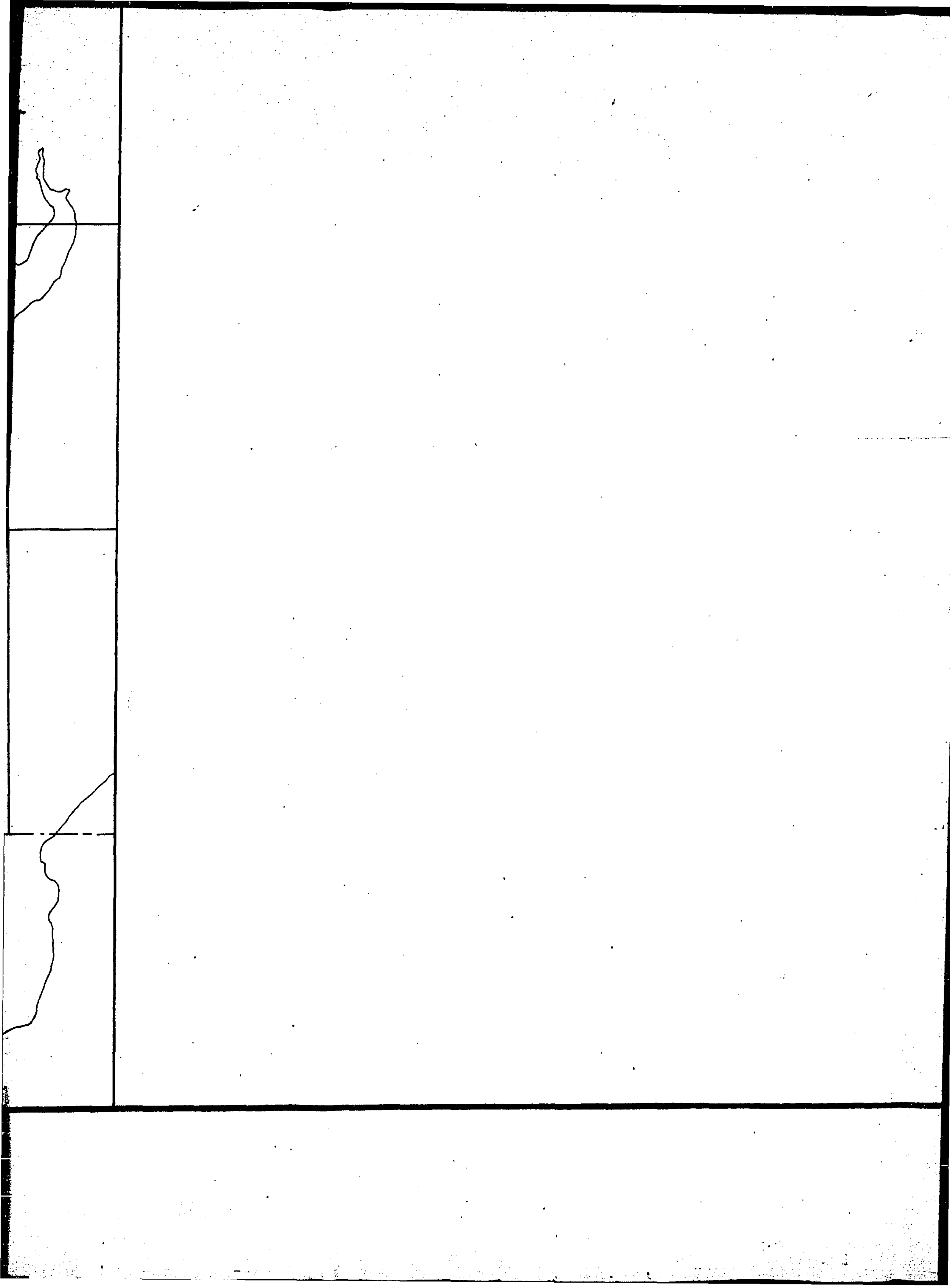
2134
21
22
28
27
60
33
34
1829
TENSLEEP CREEK
1829
T48N
T47N
4
3



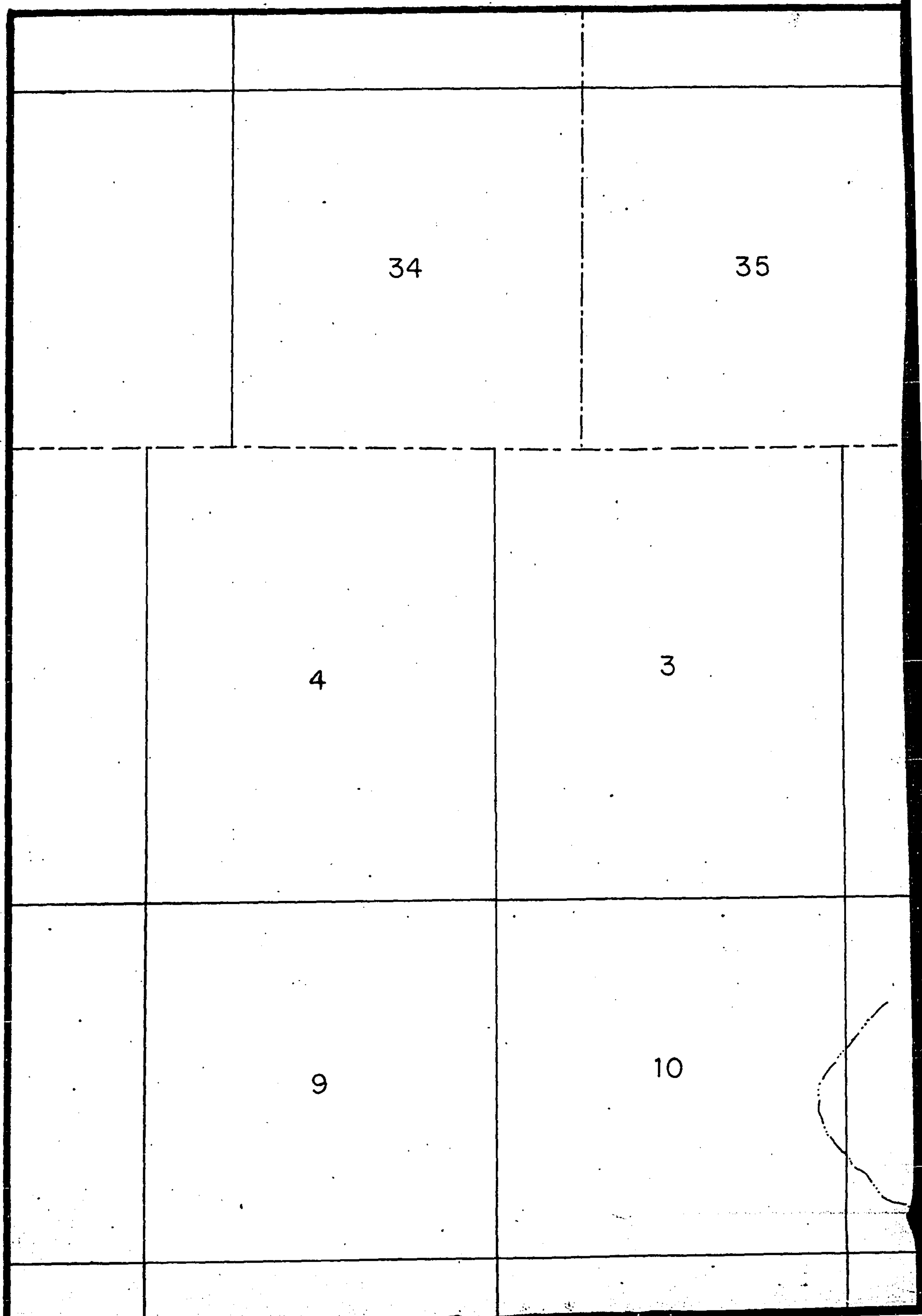
22
23
24
107
110
109
5
TC77-6
137
108
TC77-5
TC1-76
102
99
103
26
25
27
8
100
60
34
35
36
2134
1829
R87W
R86W
3
2
1

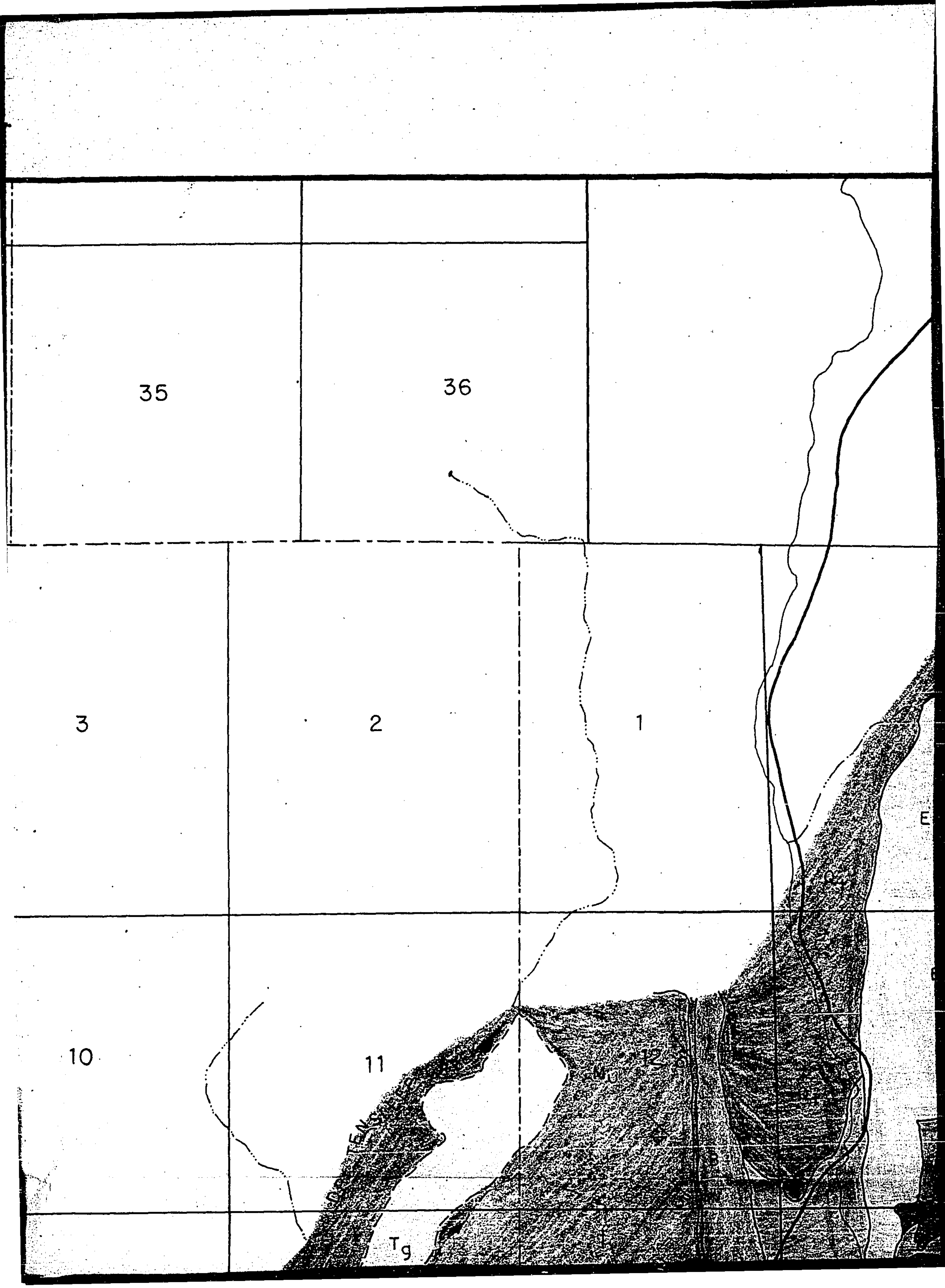

24
19
20
21
5
25
30
29
28
36
31
32
34
2438
2438
R87W
R86W
BIGHORN NATIONAL FOREST
2438
1
6
5
4


20
21
29
28
32
34
2438
2438
AL FOREST
5
4



219




35
36
3
2
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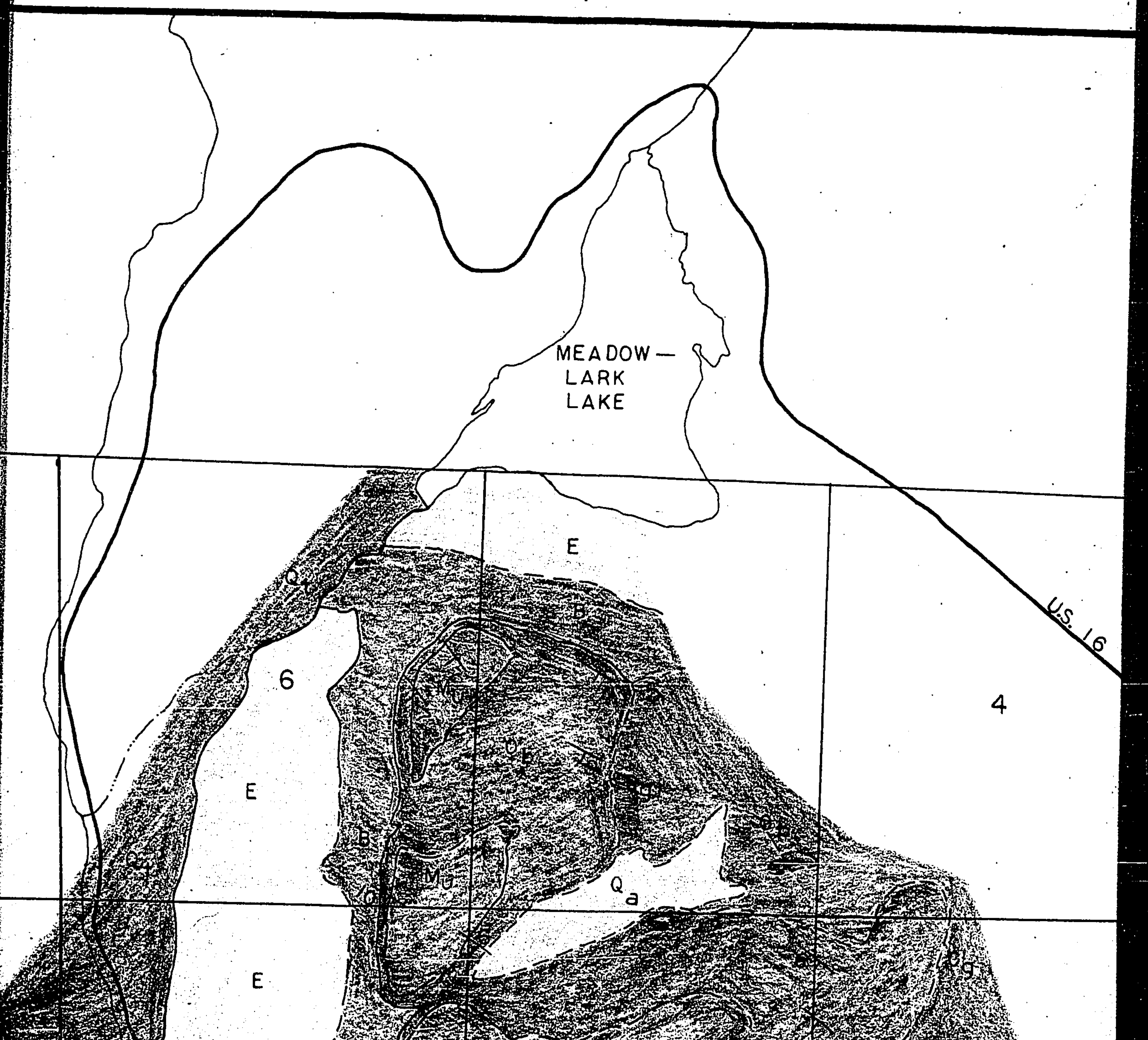
11
12
Mu
Tg


MEADOW-
LARK
LAKE
U.S. 16
E
B
6
4
E
Qa
E
7
8
Mu
D

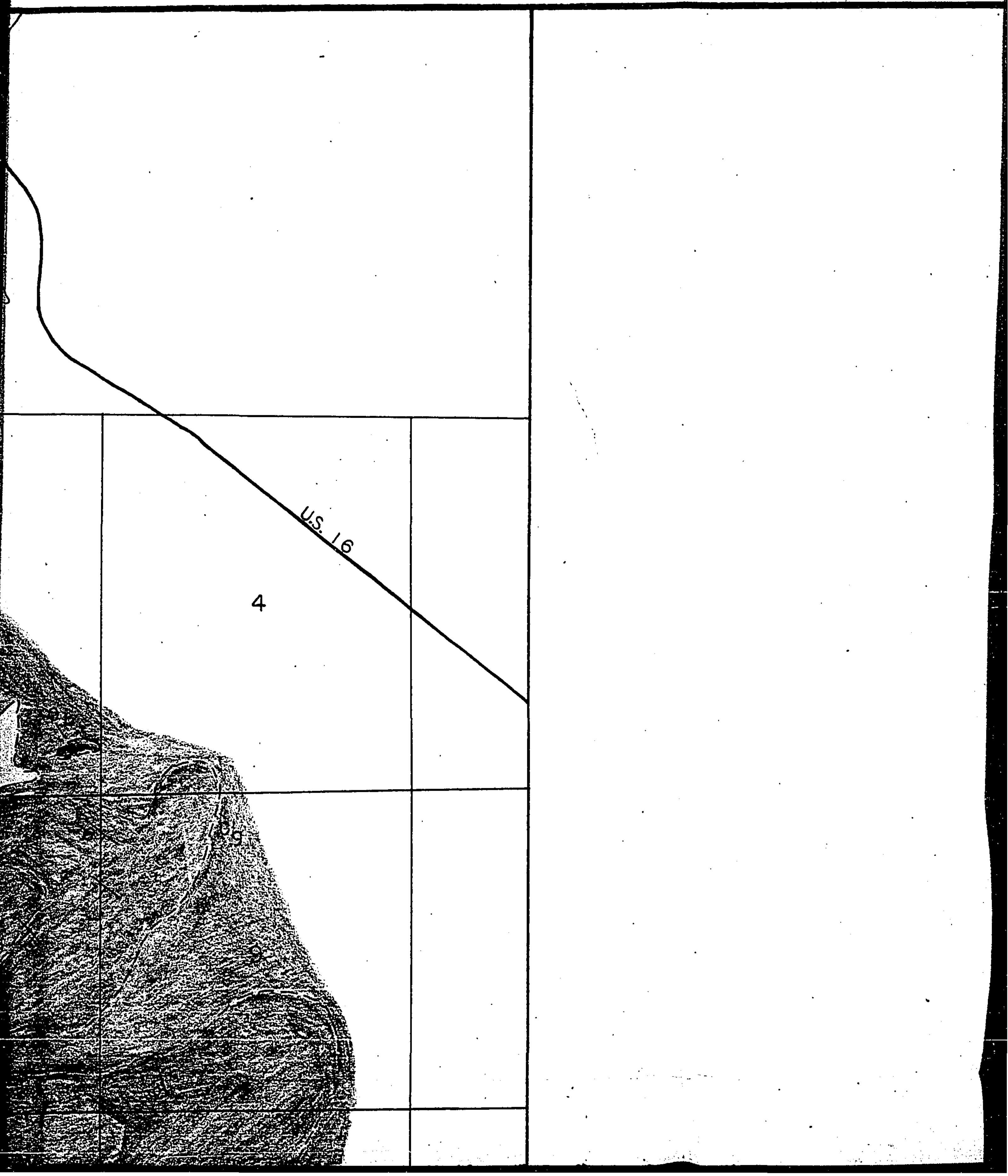
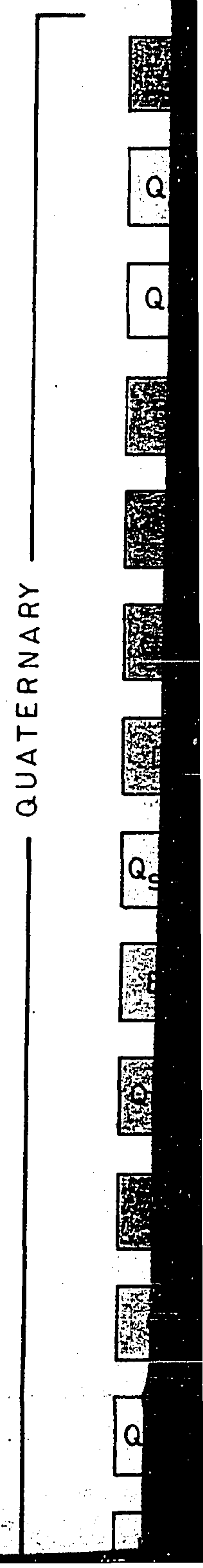

U.S. 16
4

FIG. 54
GEOLOGIC MAP
TENSLEEP CANYON

SCALE

STRIKE AND DIP



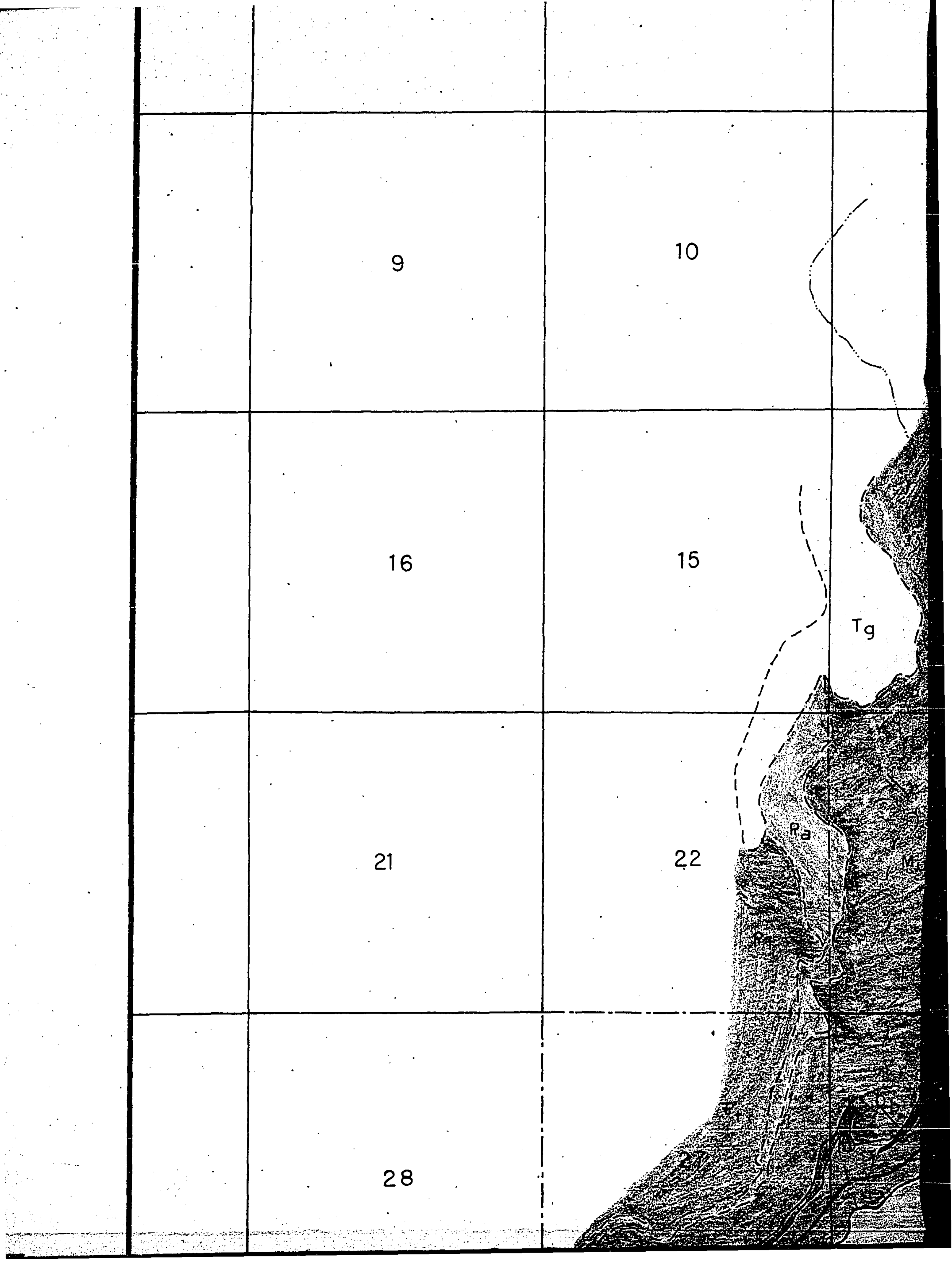
N

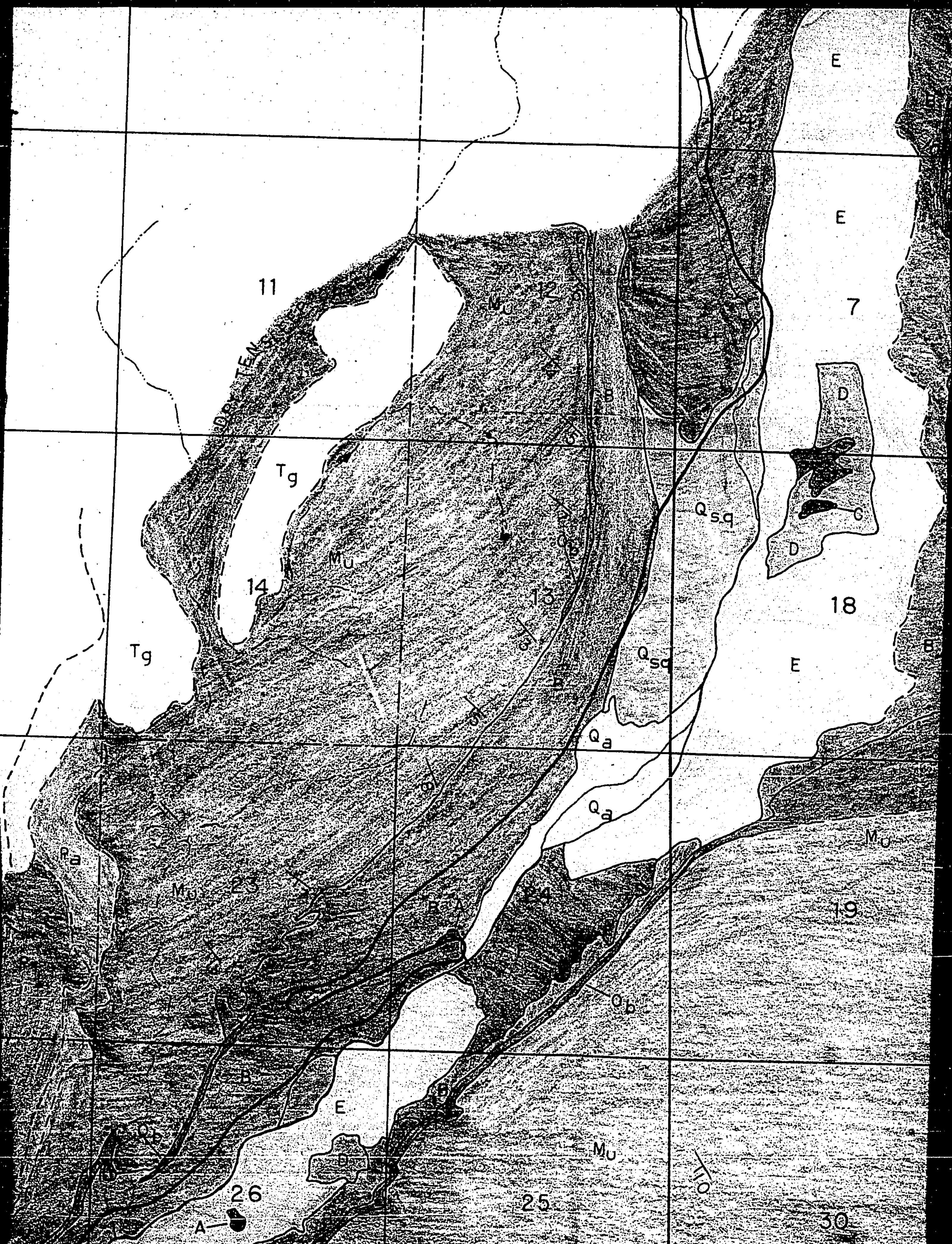
1 KM.

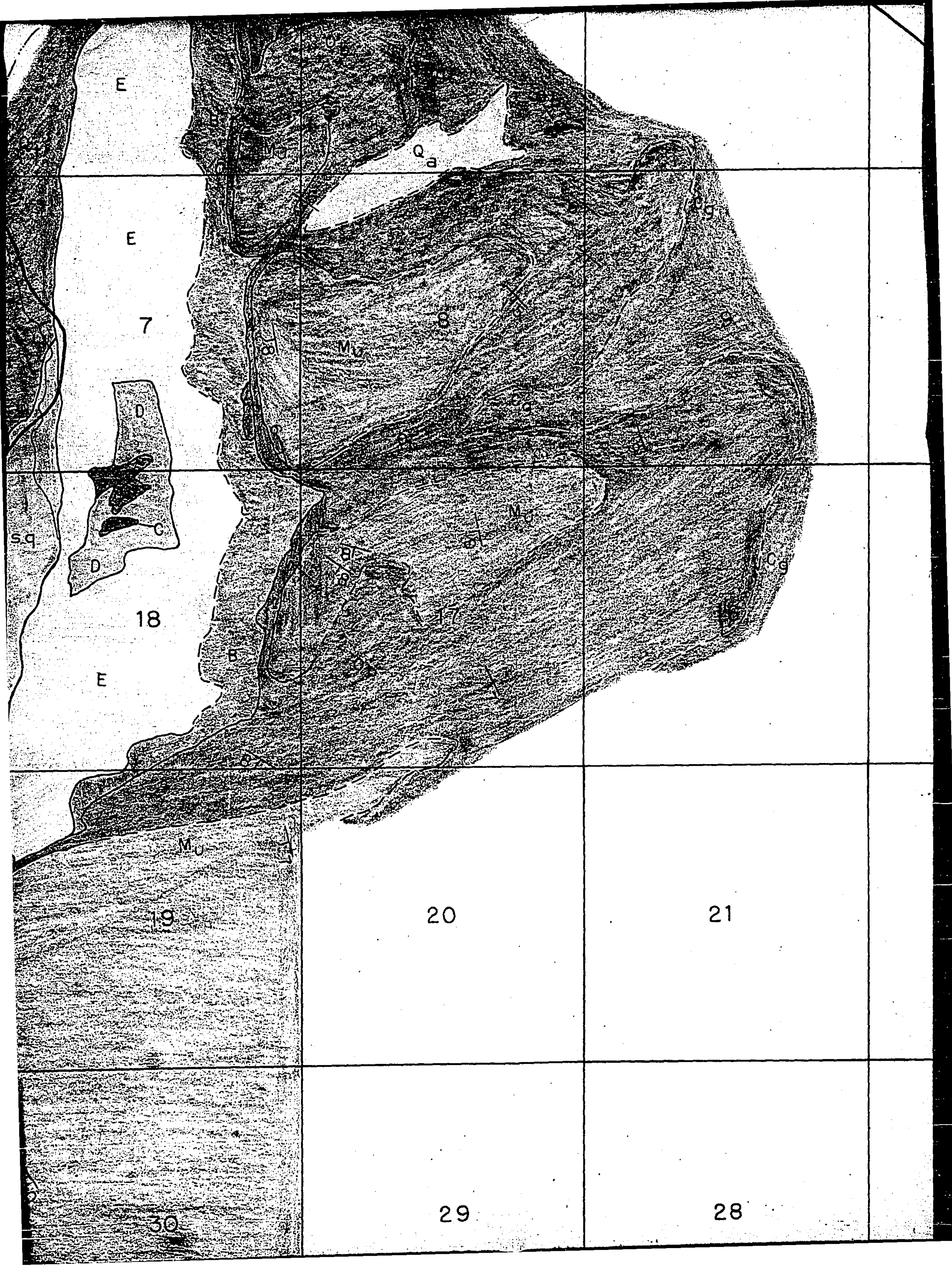
LEGEND

QUATERNARY

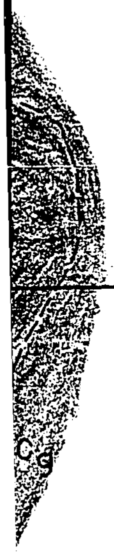
A	ACTIVE LANDSLIDE COMPLEX
Q_a	QUATERNARY ALLUVIUM
Q_c	QUATERNARY COLLUVIUM
B	QUATERNARY TALUS
	PASSIVE-1 LANDSLIDE COMPLEX
Q_t	TYRRELL MORAINE
D	PASSIVE-2 LANDSLIDE COMPLEX
Q_{sq}	SQUAW CREEK MORAINE
E	PASSIVE-3 LANDSLIDE COMPLEX
Q_{br}	BALD RIDGE MORAINE
	INACTIVE-1 LANDSLIDE COMPLEX
G	INACTIVE-2 LANDSLIDE COMPLEX
Q_b	BORROW PIT DRIFT
	INACTIVE-3 LANDSLIDE COMPLEX

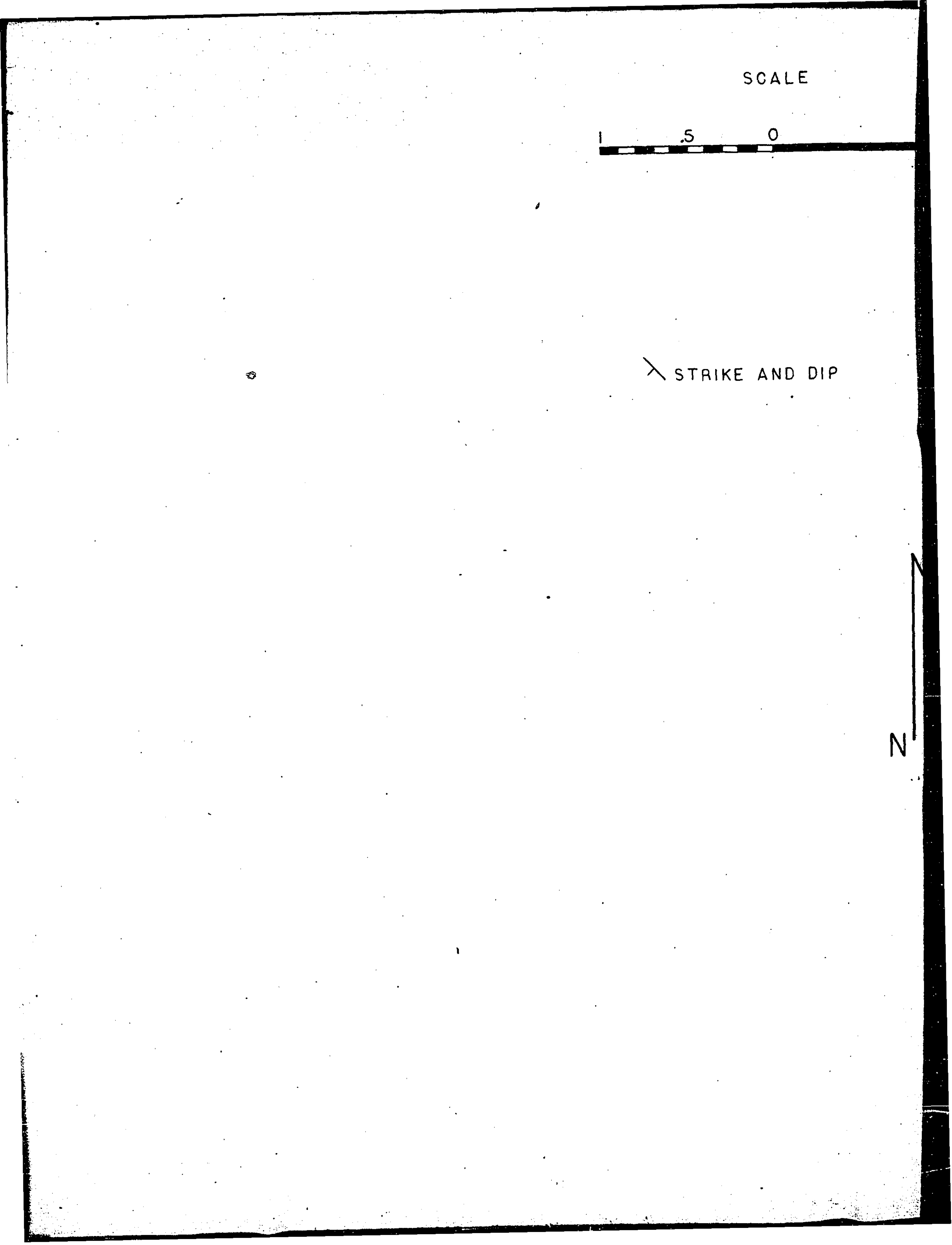

9
10
16
15
Tg
21
22
Ra
28


11
DRY TENSLEEP
Tg
Mu
14
Tg
12
13
B
Qb
Qsq
Qsq
Qa
Qa
E
7
D
D
C
18
E
B
E
Ra
Mu
23
Mu
19
B
E
D
Qb
Qb
26
A
25
Mu
30



E
Qa
E
7
Mu
D
C
D
sq
18
E
Mu
17
B
Cg
Mu
19
20
21
30
29
28




SCALE
1 .5 0
STRIKE AND DIP
N

SCALE

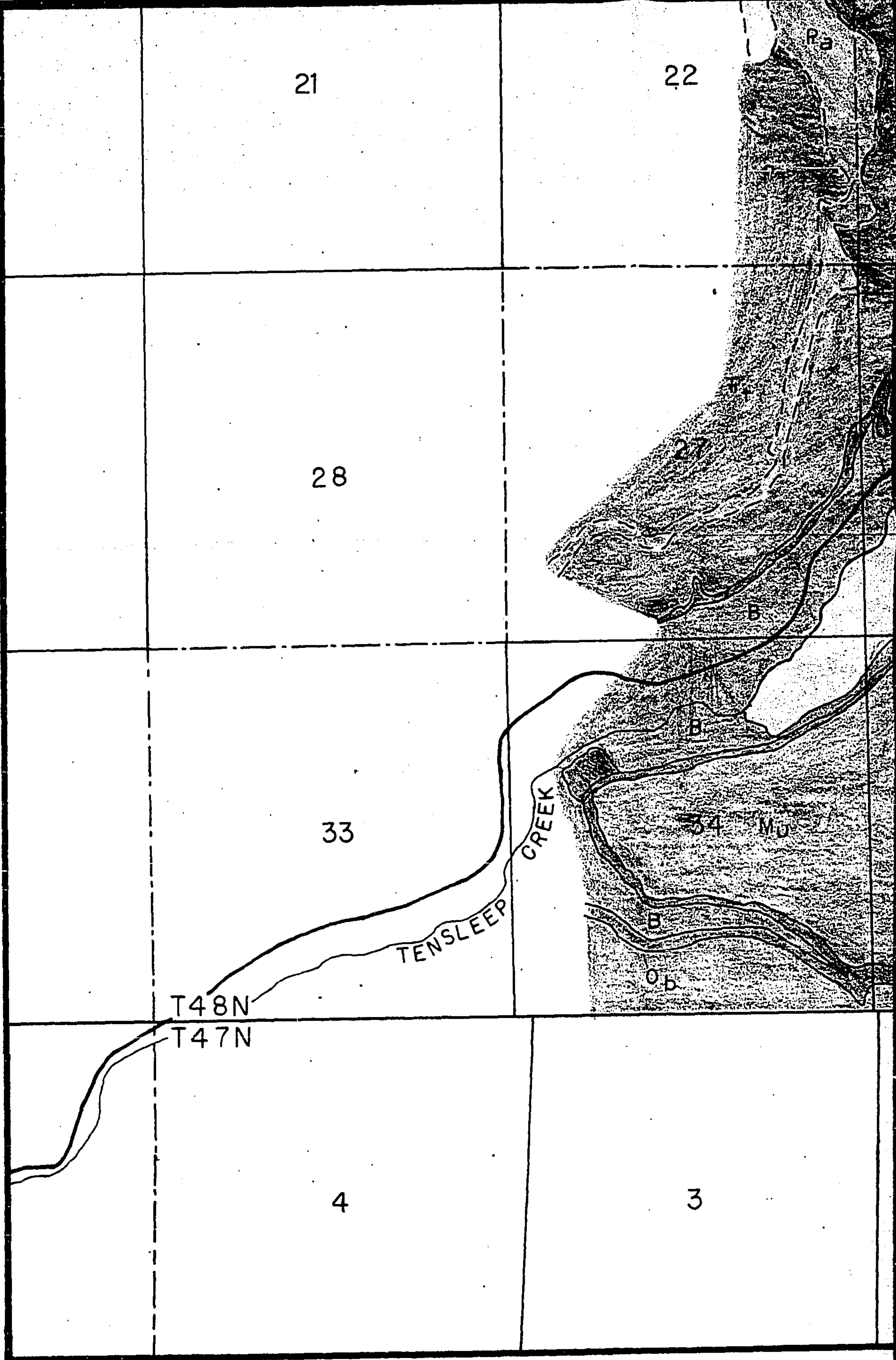
.5 0 1 KM.

STRIKE AND DIP

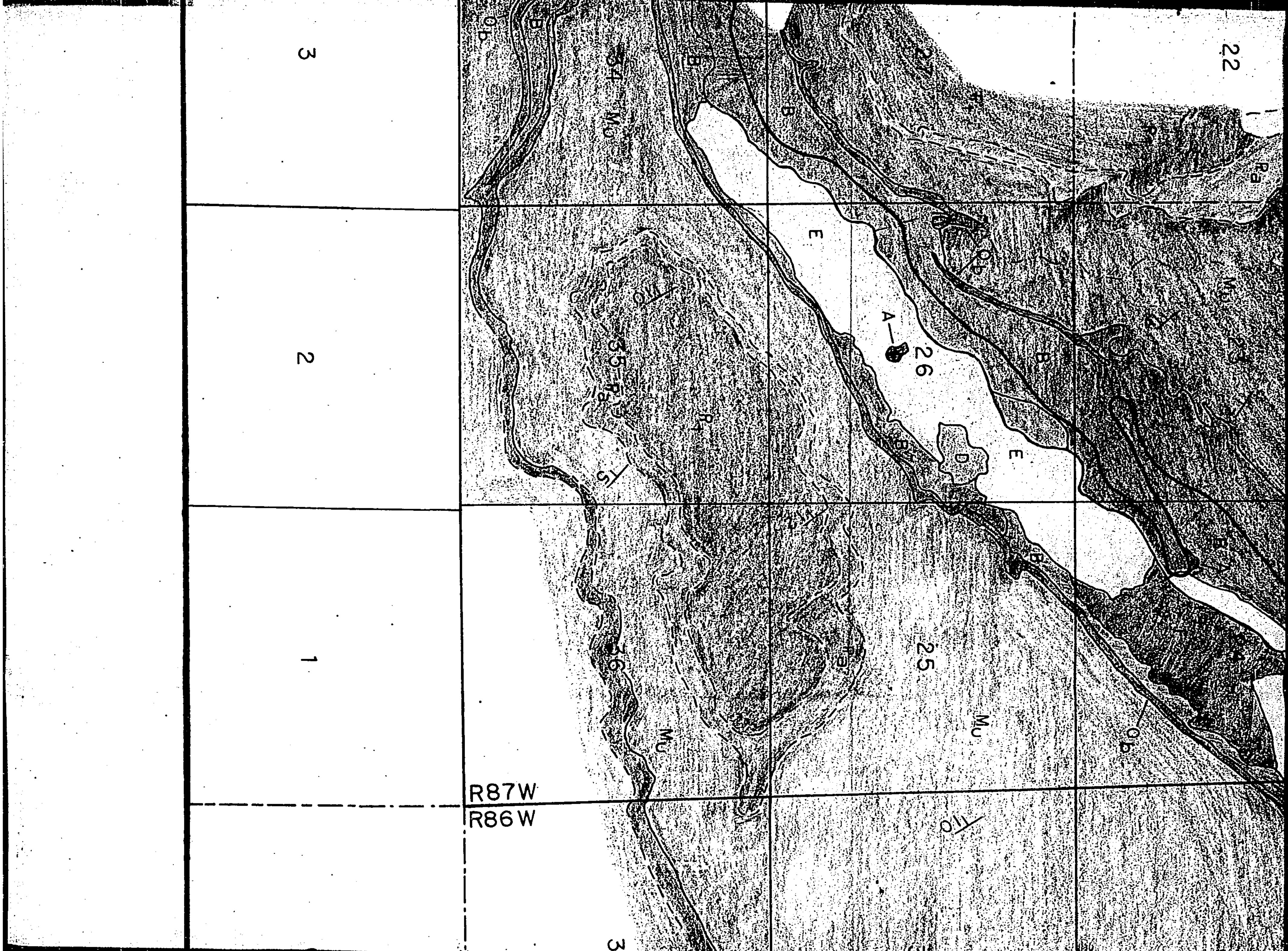
N

QUATER	D	PASSIVE-2 LANDSLIDE COM
	Q_{sq}	SQUAW CREEK MORAINE
	E	PASSIVE-3 LANDSLIDE COM
	Q_{bm}	BALD RIDGE MORAINE
	[illegible]	INACTIVE-1 LANDSLIDE CON
	G	INACTIVE-2 LANDSLIDE CO
	Q_b	BORROW PIT DRIFT
	H	INACTIVE-3 LANDSLIDE CO
TER.	T_g	TERTIARY GRAVELS
PEN.	P_t	TENSLEEP FM.
	P_a	AMSDEN FM.
ORD–MISS.	M_u	MADISON FM., JEFFERSON LEIGH & HORSESHOE MTN BIGHORN FM.
ORD.	[illegible]	STEAMBOAT ROCK MBR. B
CAMBRIAN	C_g	GALLATIN FM.
	C_{gv}	GROS VENTRE FM.
	C_f	FLATHEAD FM.
BRIAN	$P€_m$	MAFIC DIKE
	$P€_u$	XLIN. ROCKS UNDIF.

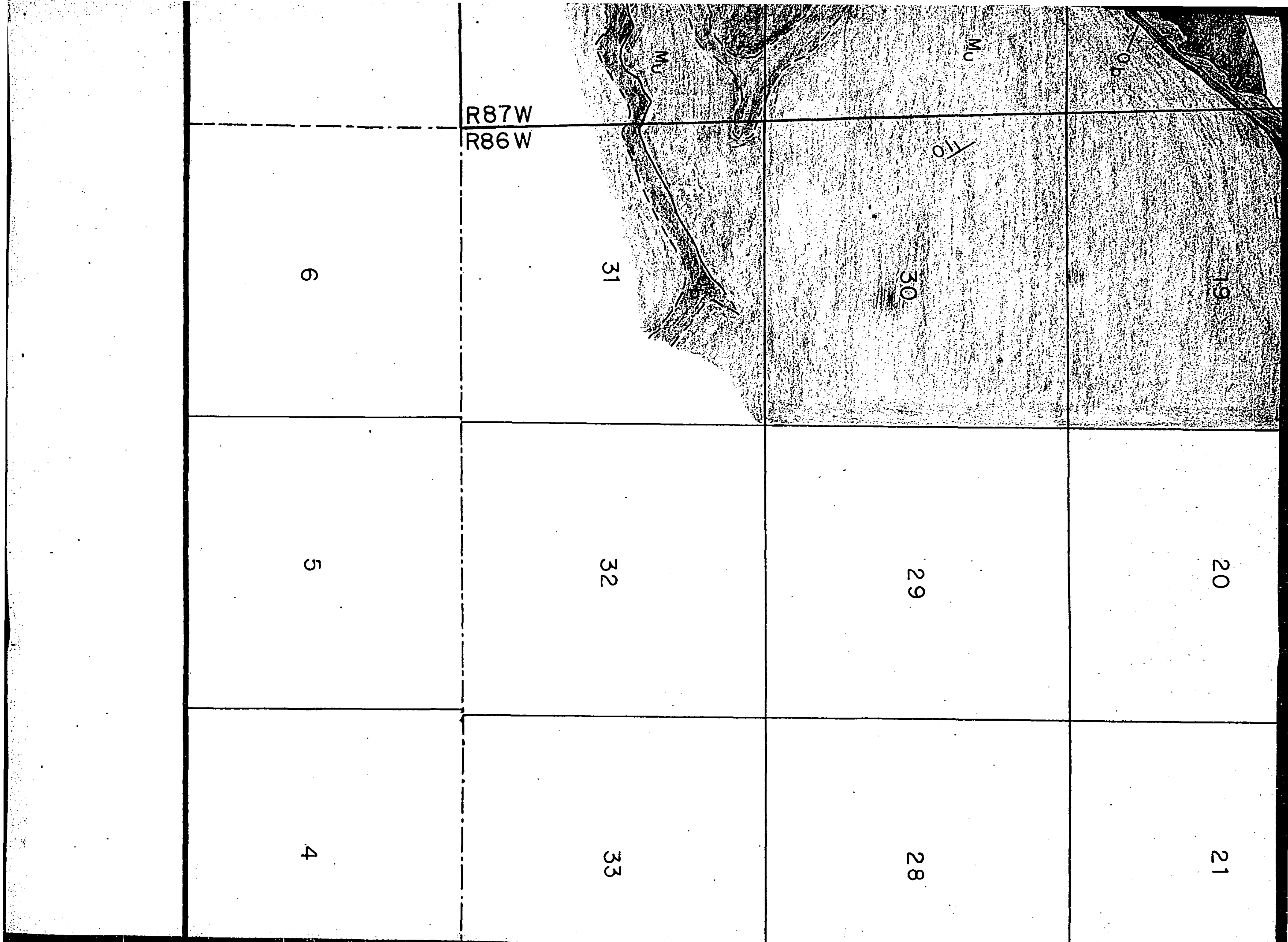
QUATER	D	PASSIVE-2 LANDSLIDE COMPLEX
	Qsq	SQUAW CREEK MORAINE
	E	PASSIVE-3 LANDSLIDE COMPLEX
	Qbr	BALD RIDGE MORAINE
	[illegible]	INACTIVE-1 LANDSLIDE COMPLEX
	G	INACTIVE-2 LANDSLIDE COMPLEX
	Qb	BORROW PIT DRIFT
	H	INACTIVE-3 LANDSLIDE COMPLEX
TER.	Tg	TERTIARY GRAVELS
PEN.	Pt	TENSLEEP FM.
	Pa	AMSDEN FM.
ORD.–MISS.	MO	MADISON FM., JEFFERSON FM., & LEIGH & HORSESHOE MTN. MBRS. BIGHORN FM.
ORD.	Ob	STEAMBOAT ROCK MBR. BIGHORN FM.
CAMBRIAN	Cg	GALLATIN FM.
	Cgv	GROS VENTRE FM.
	Cf	FLATHEAD FM.
BRIAN	P€m	MAFIC DIKE
	P€u	XLIN. ROCKS UNDIF.



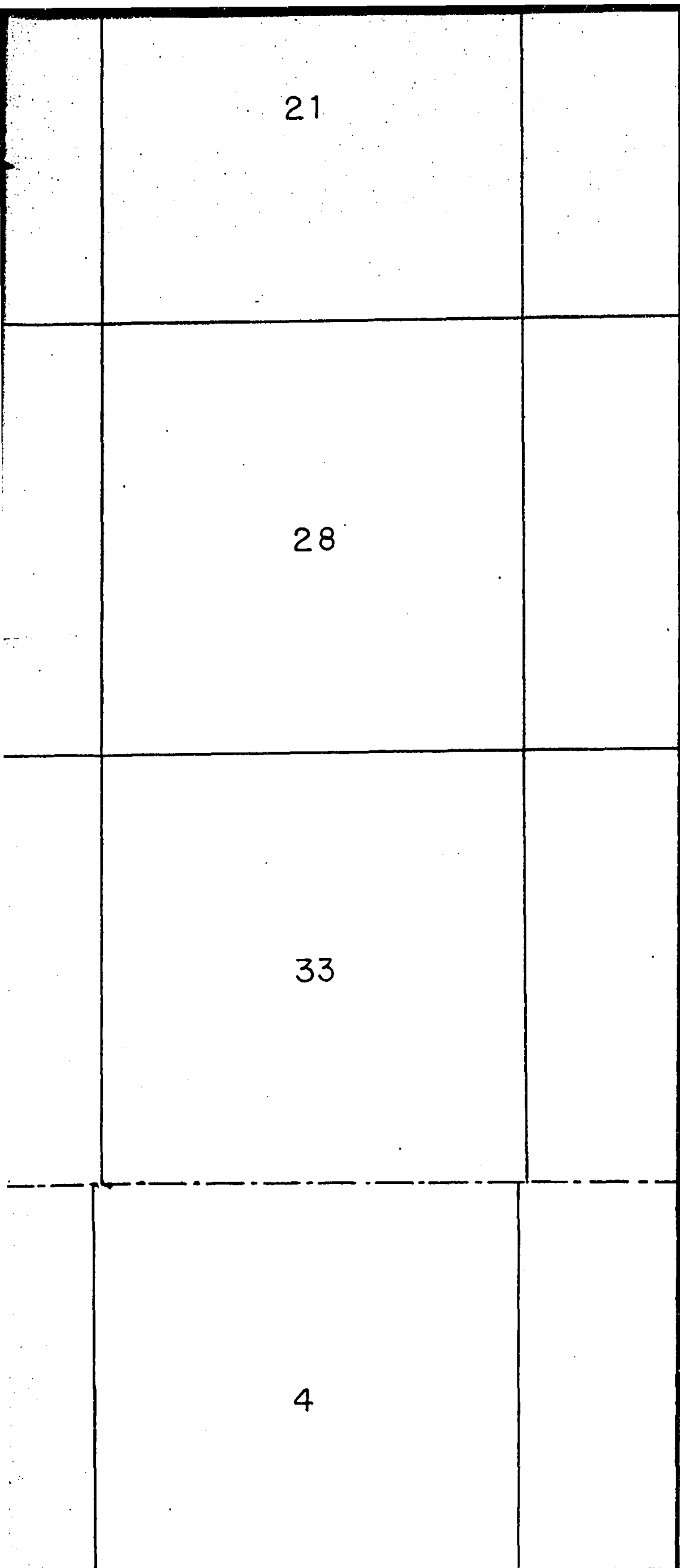
21
22
28
27
33
34
Mu
4
3
TENSLEEP CREEK
T48N
T47N
B
B
B
Ob



R87W
R86W
22
26
25
3
2
1
E
E
D



R87W
R86W
6
5
4
31
32
33
30
29
28
19
20
21
Mu


21
28
33
4

ORD.		STEAMBOAT ROCK MBR. BIGHORN
CAMBRIAN	Cg	GALLATIN FM.
	Cgv	GROS VENTRE FM.
	Cf	FLATHEAD FM.
PRECAMBRIAN	P€m	MAFIC DIKE
	P€u	XLIN. ROCKS UNDIF.

ORD.	[illegible]	STEAMBOAT ROCK MBR. BIGHORN FM.
CAMBRIAN	Cg	GALLATIN FM.
	Cgv	GROS VENTRE FM.
	Cf	FLATHEAD FM.
PRECAMBRIAN	P€m	MAFIC DIKE
	P€u	XLIN. ROCKS UNDIF.

APPENDIX C: DETAILED DESCRIPTION OF SURFICIAL SEDIMENTS

No. 1, brown colluvium

Location-roadcut No. 1

Dominant lithology
  Gravel

Specific lithologic name
  Loamy, silty, gravel

Color
  Dry
    Yellowish brown (10YR5/4)
  Wet

Texture
  Size
    Gravel.........50%
    Silt...........25%
    Loam...........25%
  Shape
    Equidimensional, very angular, low sphericity
  Sorting
    Very poorly sorted
  Fabric
    Random
  Particle surface texture, of gravel size fragments
    Smooth, nonetched

Mineralogical composition
  Gravel size fragments are from the Madison formation.
  Loam and silt are undetermined.
  Calcareous

Sedimentary structures
  Character of basal contact
    Basal contact is sharp and planar.
  Character of upper contact
    Upper contact is sharp and planar
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Massive
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
Nonindurated and a slope former

Thickness
Variable

Soil properties
Structureless
Loose
Weak
Nonsticky
Nonplactic
Will not form a ribbon

Remarks
Rock fragments range in size from fine gravel to large boulders. The large boulders are not common in this deposit.

No. 1A, washed brown colluvium

Location-roadcut No. 5

Same as brown colluvium No. 1, except material is crudely stratified.

No. 1B, very rocky brown colluvium

Location-roadcut No. 5

Same as brown colluvium No. 1, except material now contains up to 70% carbonate rock fragments.

No. 1C, brown colluvium with gray M_u boulders

Location-roadcut No. 10

Same as brown colluvium No. 1, except contains cobbles and boulders from the Madison Formation that are gray in color.

No. 1D, fine brown colluvium

Location-roadcut No. 10

Same as brown colluvium No. 1, except that rock fragments are only gravel and cobble in size.

No. 2, green colluvium

Location-roadcut No. 1

Dominant lithology
  Gravely clay

Specific lithologic name
  Gravely clay

Color
  Dry
    Olive (5Y5/3)
  Wet

Texture
  Size
    Gravel to boulders....40%
    Clay..................60%
  Shape
    Rock fragments are tabular, very angular, low sphericity
  Sorting
    Very poorly sorted
  Fabric
    In most cases the orientation is random, however, along what appear to be "shear zones" between the green colluvium and other units there appears to be a crude foliation of the platy fragments of Gallatin limestone, for raw data see remarks.
  Particle surface texture
    Rock fragments--smooth, nonetched

Mineralogical composition
  Rock fragments are from the Gallatin formation
  Clay, undetermined
  Calcareous

Sedimentary structures
  Character of basal contact
    Basal contact is sharp and planar.
  Character of upper contact
    Upper contact is sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Massive to foliated

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
Nonindurated and a slope former

Thickness
Variable

Soil properties
Structureless
Hard
Weak
Moderately sticky
Moderately plastic
Form a fair ribbon

Remarks
This material is probably from the lower part of the Gallatin formation. The matrix frequently contains 1/2" and smaller size chips of green shale. Raw data on orientation of Gallatin rock fragments, see RC1-76 for sample location. Surface of roadcut strikes N85°E, dips 82°N, apparent strike of the contact along shear zone between the green colluvium and brown colluvium is N85°E, dip 42°N.

Apparent dip of Gallatin frags. with 2 feet of contact

No.	Angle	No.	Angle
1.	31°W	26.	33°W
2.	34°W	27.	25°W
3.	44°W	28.	37°W
4.	33°W	29.	28°W
5.	6°W	30.	28°W
6.	50°W	31.	44°W
7.	47°W	32.	27°W
8.	20°W	33.	62°W
9.	43°W	34.	40°W
10.	37°W	35.	15°W
11.	17°W	36.	41°W
12.	47°W	37.	26°W
13.	38°W	38.	38°W
14.	28°W	39.	42°W
15.	41°W	40.	42°W
16.	50°W	41.	23°W
17.	26°W	42.	22°W
18.	28°W	43.	48°W
19.	57°W	44.	48°W
20.	19°W	45.	37°W
21.	49°W	46.	32°W
22.	32°W	47.	47°W
23.	73°W	48.	17°W

Apparent dip of Gallatin frags. greater than 5 feet from contact

No.	Angle	No.	Angle
1.	36°E	26.	11°E
2.	9°E	27.	58°E
3.	7°W	28.	24°W
4.	89°W	29.	34°E
5.	24°E	30.	5°E
6.	2°E	31.	5°E
7.	13°E	32.	15°E
8.	32°E	33.	78°E
9.	76°E	34.	28°W
10.	20°W	35.	77°W
11.	4°E	36.	56°W
12.	34°E	37.	40°E
13.	30°W	38.	31°W
14.	46°W	39.	10°E
15.	65°W	40.	7°E
16.	57°E	41.	13°E
17.	40°E	42.	43°W
18.	5°E	43.	29°W
19.	23°E	44.	61°W
20.	50°E	45.	41°E
21.	25°E	46.	33°W
22.	30°W	47.	27°E
23.	21°W	48.	48°E

24.	33°W	49.	36°W	24.	29°W	49.	21°E
25.	46°W	50.	34°W	25.	18°W	50.	37°W

Due to the small size of the limestone fragments, 1" to 3", it was not possible to obtain strike readings with the equipment at hand.

No. 3, green shaley colluvium

Location-roadcut No. 1

Same as green colluvium No. 2, except that it contains no rock fragments of limestone from the Gallatin Formation.

No. 3A, green bouldery colluvium

Location-roadcut No. 1

Same as green colluvium No. 2, except that it contains rock fragments of limestone from the Gallatin Formation up to 1' x 2' x 6" in size.

No. 4, mixed green and brown colluvium

Location-roadcut No. 1

This unit is a mixture of brown colluvium No. 1 and green colluvium No. 2, in roughly equal amounts. Material is mottled in appearance. Mottles consist of "pure" green and brown colluvium. Mottles are irregular in shape and from 1" to 6" in cross section.

No. 5, brown silt

Location-roadcut No. 1

Dominant lithology
  Silt

Specific lithologic name
  Brown silt

Color
  Dry
    Dark yellowish brown (10YR4/4)
  Wet

Texture
  Size
    Silt
  Shape
    Undetermined
  Sorting
    Undetermined
  Fabric
    Undetermined
  Particle surface texture
    Undetermined

Mineralogical composition
  Undetermined
  Calcareous

Sedimentary structures
  Character of basal contact
    Basal contact is sharp and planar.
  Character of upper contact
    Upper contact is sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Medium bedded complex, coarse layers preominate
  Current direction
    Unknown

Fossil content
  Occasional pulmonate gastropod observed

Degree of induration and geomorphic expression
  Nonindurated and a slope former

Thickness
  Variable

Soil properties
  Crude platy structure
  Moderate
  Friable
  Nonsticky
  Nonplastic
  Will not form a ribbon

Remarks
  Mottled in places, mottles are strong brown (7.5YR5/8), and roughly 1/16 to 1/8 inch across.

No. 5A, brown silt with pebbles

Location-roadcut No. 6

Same as brown silt No. 5, except material contains up to 5% carbonate pebbles.

No. 5B, white silt

Location-roadcut No.

Same as brown silt No. 5, except material is white (10YR8/2) (dry) in color.

No. 6, dark brown silt

Location-roadcut No. 1

Dominant lithology
  Silt

Specific lithologic name
  Dark brown silt

Color
  Dry
    Dark brown (10YR4/3)
  Wet

Texture
  Size
    Silt
  Shape
    Undetermined
  Sorting
    Undetermined
  Fabric
    Random
  Particle surface texture
    Undetermined

Mineraological composition
  Undetermined
  Calcareous

Sedimentary structures
  Character of basal contact
    Basal contact is sharp and planar
  Character of upper contact
    Upper contact is sharp and planar
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Medium bedded complex, coarse layers predominate
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
  Nonindurated and a slope former

Thickness
  Variable

Soil properties
  Crude platy structure
  Moderate
  Friable
  Nonsticky
  Nonplastic
  Will not form a ribbon

Remarks
  Occasional pulmonate gastropod observed

No. 7, gray silt

Location-roadcut No. 1

Dominant lithology
  Gray silt

Color
  Dry
    Light brownish gray (10YR6/2)
  Wet

Texture
  Size
    Silt
  Shape
    Undetermined
  Sorting
    Undetermined
  Fabric
    Undetermined
  Particle surface texture
    Undetermined

Mineralogical composition
  Undetermined
  Calcareous

Sedimentary structures
  Character of basal contact
    Basal contact is sharp and planar.
  Character of upper contact
    Upper contact is sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Medium bedded complex, coarse layers predominate
  Current direction
    Unknown

Fossil content
  Occasional pulmonate gastropod observed

Degree of induration and geomorphic expression
  Nonindurated and a slope former

Thickness
  Variable

Soil properties
- Structureless
- Moderate
- Friable
- Nonsticky
- Nonplastic
- Will not form a ribbon

Remarks

Bedding planes are accentuated by layers of iron oxide, approximately 1/16 inch thick. Silts are mottled, mottles consist of layers of Fe oxide, strong brown (7.5YR5/8) in color, no noticeable textural change. Mottles form both layers along bedding planes and irregular patches less than 1/2 inch across. They make up roughly 10% of the surface area. See photos roll 2, photos 36 and 37.

No. 8, orange gravel

Location-roadcut No. 1

Dominant lithology
Gravel

Specific lithologic name
Oligomictic, loamy, gravel

Color
Dry
Yellowish brown (10YR5/6)
Wet

Texture
Size
Gravel.......50%
Loam.........45%
Cobbles...... 5%
Shape
Equidimensional, very angular, low sphericity
Sorting
Very poorly sorted
Fabric
Random
Particle surface texture
Smooth, nonetched

Mineralogical composition
Gravel and cobbles are from the Madison formation
Loam, undetermined
Calcareous

Sedimentary structures
Character of basal contact
Basal contact is sharp and planar.
Character of upper contact
Upper contact is sharp and planar
Bedding plane structures
No bedding plane structures observed
Sedimentary unit (layer) structures
Massive
Current direction
Unknown

Fossil content
No fossils observed

Degree of induration and geomorphic expression
Nonindurated and a slope former

Thickness
Variable

Soil properties
Structureless
Loose
Weak
Nonsticky
Nonplastic
Will not form a ribbon

Remarks

No. 9, cobble size M_u fragments in a gray silt matrix (50-50)

Location-roadcut No. 1

Same as brown colluvium No. 1, except that matrix is gray in color.

No. 10, A horizon

Location-roadcut No. 1

4" to 6" thick, gravely silt (roughly 40% of A made up of gravel and cobble size fragments of Madison and Bighorn Formations), brown (10YR5/3) (dry), medium angular blocky structure, weak, friable, nonsticky, nonplastic, will not form a ribbon, highly calcareous.

No. 11, C_{Ca} horizon

Location-roadcut No. 3

C_{Ca} horizon developed in brown colluvium.

No. 11A, C_{Ca} poorly developed

Location-roadcut No. 10

A poorly developed C_{Ca} horizon developed in brown colluvium.

No. 12, red colluvium

Location-roadcut No. 5

Same as brown colluvium No. 1, except matrix is red (2.5YR5/6) (dry) in color.

No. 13, red silt

Location-roadcut No. 2

Dominant lithology
  Silt

Specific lithologic name
  Red silt

Color
  Dry
    Reddish brown (5YR5/4)
  Wet

Texture
  Size
    Silt
  Shape
    Undetermined
  Sorting
    Undetermined
  Fabric
    Undetermined
  Particle surface texture
    Undetermined

Mineralogical composition
  Undetermined
  Calcareous

Sedimentary structures
  Character of basal contact
    Basal contact is sharp and planar.
  Character of upper contact
    Upper contact is sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Massive
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
  Nonindurated and a slope former

Thickness
Variable

Soil properties
Fine to medium angular blocky structure
Hard
Friable
Nonsticky
Nonplastic
Will not form a ribbon
Peds have coating of MnO_2 (???) on them, dark reddish brown (5YR2/2)

Remarks

No. 13A, light red silt

Location-roadcut No. 2

Dominant lithology
  Silt

Specific lithologic name
  Fine sandy light red silt

Color
  Dry
    Reddish brown (2.5YR4/4)
  Wet

Texture
  Size
    Silt....................99%
    Carbonate pebbles....... 1%
  Shape
    Carbonate pebbles are spherical, well-rounded, highly spherical
  Sorting
    Undetermined
  Fabric
    Undetermined
  Particle surface texture
    Carbonate pebbles are smooth, nonetched

Mineralogical composition
  Carbonate pebbles are limestone, probably from the Madison Formation
  Calcareous

Sedimentary structures
  Character of basal contact
    Basal contact is sharp and planar.
  Character of upper contact
    Upper contact is sharp and planar
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Massive
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
  Nonindurated and a slope former

Thickness
  Variable

Soil properties
  Structureless
  Moderate
  Friable
  Nonsticky
  Nonplastic
  Will not form a ribbon

Remarks

No. 13B, red silty gravel

Location-roadcut No. 17

Dominant lithology
  Silty gravel

Specific lithologic name
  Oligomictic, muddy gravel

Color
  Fresh
    Red (2.5YR4/6), soil color chart
  Weathered
    Same as fresh

Texture
  Size
    Cobbles.........60%
    Silt...........40%
  Shape
    Cobbles are equidimensional to tabular, sub-angular to sub-rounded, low sphericity
    Silt, undetermined
  Sorting
    Very poorly sorted
  Fabric
    Random, noninterlocking
  Particle surface texture
    Cobbles are pitted and etched to a depth of 1/8"
    Silt, undetermined

Mineralogical composition
  Cobbles.........100% carbonate, probably from the Phosphoria Fm.
  Silt, undetermined
  Calcareous

Sedimentary structures
  Character of basal contact
    Basal contact is gradational over approximately 1' but appears to be planar.
  Character of upper contact
    This is the uppermost unit.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Massive
  Current direction
    Unknown

Fossil content
No fossils observed

Degree of induration and geomorphic expression
Nonindurated and a slope former

Thickness
13'

Remarks
See photo roll 8, photo 10.

No. 13C, massive sandy silt

Location-roadcut No. 17

Dominant lithology
  Silt

Specific lithologic name
  Massive sandy silt

Color
  Fresh
    Red (2.5YR4/6), soil color chart
  Weathered
    Same as fresh

Texture
  Size
    Silt...........80%
    Fine sand......20%
  Shape
    Undetermined
  Sorting
    Undetermined
  Fabric
    Undetermined
  Particle surface texture
    Undetermined

Mineralogical composition
  Undetermined
  Noncalcareous

Sedimentary structures
  Character of basal contact
    Basal contact is gradational over a distance of 4", appears to be planar.
  Character of upper contact
    Upper contact is gradational over a distance of 1', is planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Massive
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
Nonindurated and a slope former

Thickness
16'

Remarks
Material here is also moist. See photo roll 8, photo 9.

No. 13D, red silt

Location-roadcut No. 17

Dominant lithology
  Silt

Specific lithologic name
  Red silt

Color
  Fresh
    Red (2.5YR4/6), soil color chart
  Weathered
    Same as fresh

Texture
  Size
    Silt.........100%
  Shape
    Undetermined
  Sorting
    Well-sorted
  Fabric
    Undetermined
  Particle surface texture
    Undetermined

Mineralogical composition
  Undetermined
  Noncalcareous

Sedimentary structures
  Character of basal contact
    Basal contact is very sharp and planar.
  Character of upper contact
    Upper contact is very sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Massive
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
Nonindurated and a slope former

Thickness
24"

Remarks
See photo roll 8, photo 12.

No. 14, volcanic ash

Location-roadcut No. 5

Dominant lithology
  Tuff

Color
  Fresh
    Light gray (10YR7/2), soil color chart
  Weathered
    Light gray (10YR7/2), soil color chart

Texture
  Size
    Made up of fine to medium size sand particles
  Shape
    Consists of very angular glass shards with a low sphericity
  Sorting
    Individual layers are well to very well sorted
  Fabric
    No obvious particle orientation
  Particle surface texture
    Particles are smooth and glassy

Mineralogical composition
  Glass.............95%
  Mafics............trace
  Bentonite??....... 5%

Sedimentary structures
  Character of basal contact
    Basal contact is very sharp but irregular. Relief is up to 0.75 m, consists of tuff "swirled" around boulders of Bighorn and Madison limestone.
  Character of upper contact
    A gradual transition slow, but planar
  Bedding plane structures
    Bedding plane structures consist of small (50 cm) cheveron folds, fold axis is parallel to bedding planes.
  Sedimentary unit (layer) structures
    Thin bedded complex, fine layers predominate
  Current direction
    Unknown, probably from Yellowstone Park

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
  Nonindurated and a slope former

Thickness
17'

Remarks
Irregular "swirled" bottom contact and cheveron folds that the tuff was involved in a landslide movement after it was deposited.

No. 14A, ash-lithified

Location-roadcut No. 17

Dominant lithology
  Tuff

Specific lithologic name
  Tuff

Color
  Fresh
    White (5YR8/1), soil color chart
  Weathered
    Same as fresh

Texture
  Size
    Fine sand to clay
  Shape
    Undetermined
  Sorting
  Poorly sorted
  Fabric
    Random, noninterlocking
  Particle surface texture
    Undetermined

Mineralogical composition
  Volcanic glass.........?
  Clay..................?
  Noncalcareous

Sedimentary structures
  Character of basal contact
    Basal contact is very sharp and planar.
  Character of upper contact
    Upper contact is very sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Massive
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression

Upper 18" of tuff is slightly indurated, can be broken out as individual clods which can be easily broken between thumb and forefinger. Material is still a slope former. Lower 18" are well indurated, can not be broken between thumb and forefinger but can be easily be broken with a hammer. Contact between the two occurs over a distance of roughly 3".

Thickness

3'

Remarks

See photo roll 7, photos 26 and 27. In other places along the outcrop this unit appears to be cross bedded (?), grouped, small scale, planar, nonerosional, concordant, homogeneous, alpha cross stratification. Tuff is jointed, joints trend N-S and dip vertically.

No. 14B, ash-slightly lithified

Location-roadcut No. 17

Dominant lithology
  Ash

Specific lithologic name
  Ash

Color
  Fresh
    White (10YR8/2), soil color chart
  Weathered
    Same as fresh

Texture
  Size
    Medium to fine sand.........100%
  Shape
    Irregular, very angular, low sphericity
  Sorting
    Moderately well sorted
  Fabric
    Random, noninterlocking
  Particle surface texture
    Smooth and glassy

Mineralogical composition
  Volcanic glass..........97%
  Montmorillonite(?)...... 2%
  Mafics.................. 1%
  Noncalcareous

Sedimentary structures
  Character of basal contact
    Basal contact is very sharp and planar.
  Character of upper contact
    Upper contact is very sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Massive
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
Slightly lithified, can break out individual clods but they can be crushed very easily between thumb and forefinger.

Thicknes
6"-3'

Remarks
See photo roll 7, photo 29.

No. 14C, ash

Location-roadcut No. 17

Dominant lithology
  Ash

Specific lithologic name
  Ash

Color
  Fresh
    Light gray (10YR7/2), soil color chart
  Weathered
    Same as fresh

Texture
  Size
    Medium sand.........100%
  Shape
    Irregular, very angular, low sphericity
  Sorting
    Very well sorted
  Fabric
    Random, noninterlocking
  Particle surface texture
    Smooth and glassy

Mineralogical composition
  Glass...........100%
  Mafics..........trace

Sedimentary structures
  Character of basal contact
    Basal contact is gradational over a distance of approximately 2", appears to planar.
  Character of upper contact
    Upper contact is gradational over a distance of 4", appears to be planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Massive
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
Nonindurated and slope former

Thickness
5'

Remarks
Ash has a higher moisture content than surrounding material. See photo roll 8, photo 8.

No. 15, ashey silt

Location-TC76-1

Same as brown silt No. 5, except material contains approximately 20% volcanic ash and is massive.

No. 15A, ashy sand

Location-roadcut No. 17

Dominant lithology
  Ashey sand

Specific lithologic name
  Ashey sand

Color
  Fresh
    White (10YR8/2), soil color chart
  Weathered
    Same as fresh

Texture
  Size
  Medium sand..........100%
  Shape
    Sand, equidimensional to roller, sub-angular, low sphericity
    Ash, irregular, very angular, low sphericity
  Sorting
    Moderately well-sorted
  Fabric
    Random, noninterlocking
  Particle surface texture
    Sand, smooth and glassy
    Ash, smooth and glassy

Mineralogical composition
  Ash.............40%
  Quartz..........50%
  Mafics..........trace
  Rock frag.......10%
  Noncalcareous

Sedimentary structures
  Character of basal contact
    Basal contact is very sharp and planar.
  Character of upper contact
    Upper contact is very sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Massive
  Current direction
    Unknown

Fossil content
No fossils observed

Degree of induration and geomorphic expression
Nonindurated and a slope former

Thickness
5'8"

Remarks
See photo roll 8, photo 6.

No. 16, yellow silt

Location-roadcut No. 3

Dominant lithology
  Silt

Specific lithologic name
  Yellow silt

Color
  Dry
    Dark yellowish brown (10YR4/4)
  Wet

Texture
  Size
    Silt..........80%
    Fine sand.....20%
  Shape
    Undetermined
  Sorting
    Undetermined
  Fabric
    Undetermined
  Particle surface texture
    Undetermined

Mineralogical composition
  Undetermined
  Calcareous

Sedimentary structures
  Character of basal contact
    Basal contact is sharp and planar.
  Character of upper contact
    Upper contact is sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Massive
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
  Nonindurated and a slope former

Thickness
Variable

Soil properties
Medium to fine angular blocky structure
Moderate
Friable
Slightly sticky
Slightly plastic
Makes a weak ribbon
Coatings on peds, probably MnO_2, well-developed, very dark brown (10YR2/2)

Remarks

No. 17, olive sand

Location-roadcut No. 17

Dominant lithology
  Olive sand

Specific lithologic name
  Olive silty fine sand

Color
  Fresh
    Light olive brown (2.5YR5/4), soil color chart
  Weathered
    Same as fresh

Texture
  Size
    Fine sand...........80%
    Silt................20%
  Shape
    Fine sand is equidimensional to roller, sub-angular, low sphericity.
    Silt was undetermined.
  Sorting
    Moderately well sorted
  Fabric
    Random, noninterlocking
  Particle surface texture
    Undetermined

Mineralogical composition
  Undetermined
  Noncalcareous

Sedimentary structures
  Character of basal contact
    Basal contact is very sharp and planar.
  Character of upper contact
    Upper contact is very sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Massive
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
Nonindurated and a slope former

Thickness
24"

Remarks
See photo roll 8, photo 11.

No. 18, sand

Location-roadcut No. 17

Same as gravely sand No. 19A, except material contains no gravel.

No. 19, gravel

Location-roadcut No. 17

Same as conglomerate No. 25, except material is nonlithified.

No. 19A, gravely sand

Location-roadcut No. 17

Dominant lithology
  Gravely sand

Specific lithologic name
  Polymictic gravely sand

Color
  Fresh
    Very pale brown (10YR8/3), soil color chart
  Weathered
    Same as fresh

Texture
  Size
    Gravel, median size 1/4"........25%
    Fine to medium sand.............75%
  Shape
    Gravel, equidimensional to roller, sub-angular to sub-rounded, low sphericity
    Sand, equidimensional to roller, sub-angular, low sphericity
  Sorting
    Extremely poorly sorted
  Fabric
    Random, noninterlocking
  Particle surface texture
    Gravel, rock fragments are etched and pitted to a depth not greater than 1/32".
    Sand, surface texture ranges from smooth and glassy to etched and pitted, etched and pitted are most common.

Mineralogical composition
  Gravel
    Carbonate...........90%
    Igneous.............10%
  Sand
    Quartz...................75%
    Feldspar(orthoclase)......trace
    Mafics...................trace
    Rock fragments,
      mostly carbonate........25%

Sedimentary structures
  Character of basal contact
    Basal contact is very sharp and planar.
  Character of upper contact
    Upper contact is very sharp and planar.

Bedding plane structures
No bedding plane structures observed
Sedimentary unit (layer) structures
Massive
Current direction
Unknown

Fossil content
No fossils observed

Degree of induration and geomorphic expression
Nonindurated and a slope former

Thickness
2'

Remarks
See photo roll 8, photo 5.

No. 19B, sandy gravel

Location-roadcut No. 17

Same as sandy gravel No. 19B, except material is now dominantly gravel.

No. 20, interbedded green shale and sandstone

Location-roadcut No. 6

Dominant lithology
  Interbedded shale and sandstone

Specific lithologic name
  Interbedded mud-shale and quartzarenites

<u>Sandstones</u>

Color
  Fresh
    White
  Weathered
    White

Texture
  Size
    Fine sand..........100%
  Shape
    Equidimensional to roller, subangular, low sphericity
  Sorting
    Well sorted
  Fabric
    Random, noninterlocking
  Particle surface texture
    Smooth and glassy

Mineralogical composition
  Quartz...........100%
  Noncalcareous

Sedimentary structures
  Character of basal contacts of sandstone beds
    Basal contacts are very sharp and planar.
  Character of upper contacts of sandstone beds
    Upper contacts are very sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Thin bedded complex, fine layers predominate
  Current direction
    Unknown

Fossil content
  No fossils observed

Mud-shales

Color
- Fresh
  - Olive green
- Weathered
  - Dark gray

Texture
- Size
  - Clay/silt ratio roughly 1/1
- Shape
  - Undetermined
- Sorting
  - Undetermined
- Fabric
  - Mica flakes (?) parallel to shale partings observed
- Particle surface texture
  - Undetermined

Mineralogical composition
- Clay and silt...........99%
- Glauconite.............. 1%
- Noncalcareous

Sedimentary structures
- Character of basal contacts of shale beds
  - Basal contacts are very sharp and planar.
- Character of upper contacts of shale beds
  - Upper contacts are very sharp and planar.
- Bedding plane structures
  - No bedding plane structures observed
- Sedimentary unit (layer) structures
  - Thin bedded complex, fine layers predominate
- Current direction
  - Unknown

Fossil content
- No fossils observed

Degree of induration and geomorphic expression
- Unit as a whole is poorly indurated and a slope former

Thickness
- 2.5' to 8'

Remarks

Unit consists of alternating layers of sandstone and shale. Sandstone layers range in thickness from 1/8" to 1", shale layers range in thickness from 1/64" to 1/8". Alternation in thickness appears to be random. Unit is highly fractured and slightly oxidized in places.

No. 20A, interbedded green shale and sandstone-strongly oxidized

Location-roadcut No. 6

Unit 21A is the same as 21 except that they have been strongly oxidized and weathered.

No. 21, brown silt

Location-roadcut No. 2

Dominant lithology
  Brown silt

Specific lithologic name
  Fine sandy brown silt

Color
  Dry
    Yellowish brown (10YR5/4)
  Wet

Texture
  Size
    Silt.......80%
    Sand.......20%
  Shape
    Undetermined
  Sorting
    Undetermined
  Fabric
    Undetermined
  Particle surface texture
    Undetermined

Mineralogical composition
  Undetermined
  Calcareous

Sedimentary structures
  Character of basal contact
    Basal contact is sharp and planar.
  Character of upper contact
    Upper contact is sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Massive
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
  Nonindurated and a slope former

Thickness
  Variable

Soil properties
  Fine to medium angular blocky structure
  Moderate
  Friable
  Nonsticky
  Nonplastic
  Will not form a ribbon
  MnO_2(?) coatings on outside of peds, very dark brown (10YR2/2) in color

Remarks

No. 21, green sandstone

Location-roadcut No. 6

Dominant lithology
  Sandstone

Specific lithologic name
  Quartzarenite

Color
  Fresh
    Green
  Weathered
    Green with brown and buff mottles, mottles cover approximately 40% of surface

Texture
  Size
    Medium to coarse sand......100%
  Shape
    Equidimensional, rounded to well-rounded, high sphericity
  Sorting
    Moderately to poorly sorted
  Fabric
    Random, noninterlocking
  Particle surface texture
    Grains are etched and pitted

Mineralogical composition
  Quartz............97%
  Glauconite........ 3%
  Noncalcareous

Sedimentary structures
  Character of basal contact
    Basal contact is sharp and planar.
  Character of upper contact
    Upper contact is sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Medium bedded complex, coarse and fine layers in roughly equal amounts. Grouped, large scale, nonerosional, planar, concordant, heterogeneous, Beta (??) cross stratification
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
Very poorly indurated, can crumble rock in your hand, a slope former

Thickness
2" to 14"

Remarks
See photo roll 3, photo 16.

No. 21A, green shale

Location-roadcut No. 6

Dominant lithology
  Shale

Specific lithologic name
  Clay-shale

Color
  Fresh
    Olive green
  Weathered
    Dark greenish gray to purple

Texture
  Size
    Clay/silt ratio greater than 2/1
  Shape
    Undetermined
  Sorting
    Undetermined
  Fabric
    Mica flakes (?) parallel to shale partings observed
  Particle surface texture
    Undetermined

Mineralogical composition
  Undetermined
  Noncalcareous

Sedimentary structures
  Character of basal contact
    Basal contact is very sharp and planar.
  Character of upper contact
    Upper contact is a gradual transition slow.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Parallel lamination, fine layers predominate
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
  Nonindurated and a slope former

Thickness
5"

Remarks
Very good partings between layers

No. 22, brown sandstone

Location-roadcut No. 6

Dominant lithology
  Sandstone

Specific lithologic name
  Quartzarenite

Color
  Fresh
    Variable, ranges from white to buff to rusty red to light green
  Weathered
    Ranged from rusty red to buff brown

Texture
  Size
    Coarse to fine sand......100%
  Shape
    Equidimensional to roller, subangular, low sphericity
  Sorting
    Individual beds are moderately well-sorted
  Fabric
    Random, noninterlocking
  Particle surface texture
    Smooth and glassy

Mineralogical composition
  Quartz.........100%
  Clauconite.....trace

Sedimentary structures
  Character of basal contact
    Basal contact is very sharp and planar.
  Character of upper contact
    Upper contact is sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Medium bedded complex, coarse and fine layers in roughly equal amounts. Grouped, large scale, nonerosional, planar, concordant, heterogeneous, Beta (??) cross stratification
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
Moderately poorly indurated, can rub particles of rock off with your hands but cannot cumble blocks with your hands, forms a low bench

Thickness
3'

Remarks
Precise nature of the corss bedding is difficult to determine due to small size of outcrop. Color differences tend to accentuate individual layers of rock in this unit. Towards the base of this unit shaley partings 1" to 2" apart become common.

No. 22A, shattered brown sandstone

Location-roadcut No. 6

Dominant lithology
  Sandstone

Specific lithologic name
  Quartzarenite

Color
  Fresh
    Light green
  Weathered
    Buff to light pink with dark brown mottles covering approximately 25% of surface area

Texture
  Size
    Fine sand.......100%
  Shape
    Equidimensional to roller, subrounded, low sphericity
  Sorting
    Moderately sorted
  Fabric
    Random, noninterlocking
  Particle surface texture
    Grains are etched and pitted

Mineralogical composition
  Quartz..........99%
  Clauconite...... 1%
  Noncalcareous

Sedimentary structures
  Character of basal contact
    Basal contact is very sharp but somewhat undularory, amplitude is 1.5" or less, wavelength is roughly 6".
  Character of upper contact
    Upper contact is sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Medium bedded complex, coarse and fine layers in roughly equal amounts
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
Individual blocks within the shattered sandstone are moderately well indurated but the unit is still a slopw former.

Thickness
3" to 2'

Remarks
This unit consists of angular blocks of sandstone that are roughly equidimensional in shape. They range in size from 1" to 6". The blocks are moderately well-indurated but sit in a matrix of fine sand the same color as the blocks. Blocks make up approximately 80% of total, matrix approximately 20%. See photo roll 3, photos 29 and 30.

No. 22B, white sandstone

Location-roadcut No. 6

Dominant lithology
  Sandstone

Specific lithologic name
  Quartzarenite

Color
  Fresh
    White with green mottles, mottles are less than 1/64" in diameter and cover roughly 10% of the surface area.
  Weathered
    Upon weathering the mottles turn brown to orange.

Texture
  Size
    Medium to fine sand.......100%
  Shape
    Equidimensional to roller, subangular, low sphericity
  Sorting
    Moderately to poorly sorted
  Fabric
    Random, noninterlocking
  Particle surface texture
    Smooth and glassy

Mineralogical composition
  Quartz..............99%
  Glauconite.......... 1%
  Noncalcareous

Sedimentary structures
  Character of basal contact
    Basal contact is gradual transition slow.
  Character of upper contact
    Upper contact is very sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Medium bedded complex, coarse layers predominate
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
Very poorly indurated, can crumble between thumb and forefinger. Unit is a slope former.

Thickness
6"

Remarks

No. 23, red sandstone

Location-roadcut No. 6

Dominant lithology
  Sandstone

Specific lithologic name
  Quartzarenite

Color
  Fresh
    Not observed
  Weathered
    Rusty red

Texture
  Size
    Coarse sand...........100%
  Shape
    Equidimensional, well-rounded, high sphericity
  Sorting
    Well sorted
  Fabric
    Random, noninterlocking
  Particle surface texture
    Frosted

Mineralogical composition
  Quartz......................98%
  Glauconite, oxidized......... 2%
  Noncalcareous

Sedimentary structures
  Character of basal contact
    Basal contact is very sharp and planar.
  Character of upper contact
    Upper contact is very sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Medium bedded complex, coarse layers predominate
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
Very poorly indurated, can crumble fragments between thumb and fore-finger, a slope former

Remarks

No. 24, red siltstone

Location-roadcut No. 17

Dominant lithology
  Siltstone

Specific lithologic name
  Red siltstone

Color
  Fresh
    Red
  Weathered
    Red

Texture
  Size
    Clay/silt ratio is roughly 1/2
  Shape
    Undetermined
  Sorting
    Undetermined
  Fabric
    Undetermined
  Particle surface texture
    Undetermined

Mineralogical composition
  Undetermined
  Calcareous

Sedimentary structures
  Character of basal contact
    Unobserved
  Character of upper contact
    Upper contact is very sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Massive
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
  Poorly indurated and a slope former

Thickness
  Undetermined

Remarks

No. 25, conglomerate

Location-roadcut No. 17

Dominant lithology
Conglomerate

Specific lithologic name
Polymictic conglomerate

Color
Fresh
Light gray (2.5Y7/2), soil color chart
Weathered
Gray (10YR5/1), soil color chart

Texture
Size
Rock fragments-gravel to boulder size, 0.75 m maximum
Matrix-medium to coarse size sand particles
Shape
Rock fragments-subangular with a low sphericity
Matrix-subangular with a low sphericity
Sorting
Extremely poorly sorted
Fabric
Platy rock fragments (less than 50% of total rock fragments) show a crude alignment parallel to the basal contact.
Particle surface texture
Rock fragments-etched on the surface to a depth of less than 0.2 cm on the average
Matrix-surface of particles are smooth and glassy.

Mineralogical composition
Rock fragments
Carbonate rock fragments........90%
Crystalline rock fragments......10%
Matrix
Quartz..........................70%
Feldspar (ortho.)...............trace
Red silt........................ 5%
Mafics.......................... 5%
Sand size rock frag.............20%
Total
Rock fragments..................80%
Matrix..........................20%
Cementing agent is calcite.

Sedimentary structures
  Basal contact
    Very sharp and planar
  Bedding plane structures
    No bedding plane structures
  Sedimentary unit structures
    Medium to coarsely bedded complex, coarse layers preominate
  Current direction
    Unknown, probably from the east

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
  Well-indurated and a cliff former

Thickness

Remarks
  See photo roll 7, No. 25. Sample collected.

No. 25A, conglomerate

Location-roadcut No. 17

Dominant lithology
  Conglomerate

Specific lithologic name
  Polymictic conglomerate

Color
  Fresh
    Light gray
  Weathered
    Dark gray to buff

Texture
  Size
    Conglomerate ranges from granule to cobble size......60%
    Matrix is medium to coarse sand.....................40%
  Shape
    Granules and cobbles are equidimensional to roller, subrounded, low sphericity.
    Matrix grains are equidimensional to roller, subrounded, low sphericity.
  Sorting
    Extremely poorly sorted
  Fabric
    Random, noninterlocking
  Particle surface texture
    Granules and cobbles are etched to a depth of less than 1/32" on the average.
    Matrix grains have a surface texture ranging from smooth (quartz grains) to etched and pitted (rock fragments).

Mineralogical composition
  Granules and cobbles
    Granite..................15%
    Carbonate fragments.......85%
  Matrix
    Quartz...................80%
    Feldspar..................trace (orthoclase)
    Rock fragments............20%
    Mafics...................trace

Sedimentary structures
  Character of basal contact
    Basal contact is very sharp and planar.
  Character of upper contact
    Upper contact is very sharp and planar.

Bedding plane structures
No bedding plane structures observed
Sedimentary unit (layer) structures
Massive
Current direction
Unknown

Fossil content
No fossils observed

Degree of induration and geomorphic expression
Moderately well-indurated, usually is covered with colluvium

Thickness
2'8"

Remarks
See photo roll 7, photo 28. Upper 6" of conglomerate has a black colored matrix, which appears to be Mn oxide.

No. 25B, sandstone

Location-roadcut No. 17

Dominant lithology
Sandstone

Specific lithologic name

Color
Fresh
White (7.5YRN8/), soil color chart
Weathered
Reddish yellow (7.5YR7/6), soil color chart

Texture
Size
Medium sand.......100%
Shape
Equidimensional to roller, subangular to subrounded, low sphericity
Sorting
Moderately sorted
Fabric
Random, noninterlocking
Particle surface texture
Smooth and glassy

Mineralogical composition
Quartz..........50%
Mafics..........trace
Rock frags......50%

Sedimentary structures
Character of basal contact
Basal contact is very sharp and planar.
Character of upper contact
Upper contact is gradational over a distance of approximately 2", appears to be planar.
Bedding plane structures
No bedding plane structures observed
Sedimentary unit (layer) structures
Medium bedded complex, fine layers predominate
Current direction
Unknown

Fossil content
No fossils observed

Degree of induration and geomorphic expression
  Well-indurated and a ledge former

Thickness
  5"

Remarks
  See photo roll 8, photo 7.

No. 26, modern slump

Location-roadcut No. 12

Consists of unconsolidated material that has slumped down into present day roadcuts.

No. 27, talus deposits

Consists of unconsolidated material that has accumulated as talus deposits along present day roadcuts.

No. 28, Gros Ventre-Gallatin Formation

Location-roadcut No. 12

Dominant lithology
Interbedded mud-shale and pseudosparite

Limestone

Color
Fresh
Light gray to light olive green
Weathered
Gray to maroon

Texture
Size
Fine sand..........100%
Shape
Equidimensional, very angular, low sphericity
Sorting
Well sorted
Fabric
Random, interlocking
Particle surface texture
Smooth and glassy

Mineralogical composition
Calcite..............100%
Glauconite...........trace
Quartz...............trace

Sedimentary structures
Character of basal contacts of limestone beds
Basal contacts are very sharp and irregular (wavy), relief is roughly 1/4", wavelength if from 1" to 2".
Character of upper contacts of limestone beds
Upper contacts are very sharp and irregular (wavy), relief is roughly 1/4", wavelength is from 1" to 2"
Bedding plane structures
Worm tracks observed, flat pebble conglomerate
Sedimentary unit (layer) structures
Thin bedded complex, coarse layers predominate, coarse layers are roughly 10-20 times thicker than thin layers.
Current direction
Unknown

Fossil content
No fossils observed

Shales

Color
  Fresh
    Light olive green
  Weathered
    Dark olive green

Texture
  Size
    Clay/silt ratio roughly 1/1
  Shape
    Undetermined
  Sorting
    Undetermined
  Fabric
    Undetermined
  Particle surface texture
    Undetermined

Mineralogical composition
  Clay and silt...........100%
  Glauconite..............trace
  Calcareous, slightly

Sedimentary structures
  Character of basal contacts of shale beds
    Basal contacts are very sharp and irregular (wavy), relief is roughly 1/4", wavelength is from 1" to 2".
  Character of upper contacts of shale beds
    Upper contacts are very sharp and irregular (wavy), relief is roughly 1/4", wavelength is from 1" to 2".
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Parallel laminated, coarse and fine layers in roughly equal amounts
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
  Poorly indurated and a slope former

Thickness
  Unit is exposed for a thickness of 63'.

Remarks

Unit consists of alternating layers of limestone and shale. Shale beds range in thickness from 6" to 4', limestone beds range in thickness from 1" to 6". Alternation in thickness appears to be random, shale beds make up greater than 75% of the outcrop. Jointed, joints are striking NOS and dipping vertically.

No. 28A, highly fractured Gros Ventre-Gallatin Formation

Location-roadcut No. 12

Same as No. 28 except that material is highly fractured. Can still easily see the original bedding. No appreciable offset along bedding planes. Material fractured into blocks roughly 2" to 4" square.

No. 30, crystalline gravel

Location-TC76-1

Dominant lithology
  Glacial till

Specific lithologic name
  Glacial till

Color
  Fresh
    Light gray
  Weathered
    Dark gray

Texture
  Size
    Gravel to boulders............60%
    Medium to coarse sand.........40%
  Shape
    Gravel to boulders are equidimensional, subrounded to rounded, high sphericity, occasional faceted boulder observed
    Sand is equidimensional to roller, angular to subangular, low sphericity
  Sorting
    Very poorly sorted
  Fabric
    Random, noninterlocking
  Particle surface texture
    Gravel to boulders are etched and pitted, they frequently have a coating of $CaCO_3$ up to 1/4" thick on their surface.
    Sand grains appear to be "ground".

Mineralogical composition
  Gravel to boulders........100% crystalline rock fragments
  Sand
    Quartz..................70%
    Feldspar................15%
    Rock frag...............15%
  Calcareous

Sedimentary structures
  Character of basal contact
    Basal contact is sharp and planar.
  Character of upper contact
    Upper contact is sharp and planar
  Bedding plane structures
    No bedding plane structures observed

Sedimentary unit (layer) structures
Massive
Current direction
Unknown

Fossil content
No fossils observed

Degree of induration and geomorphic expression
Nonindurated and a slope former

Thickness
6'-12'

Remarks

No. 31, limestone

Location-roadcut No. 17

Dominant lithology
  Limestone

Specific lithologic name
  Micrite

Color
  Fresh
    Light gray
  Weathered
    Dark gray

Texture
  Size
    Fine to medium sand..........100%
  Shape
    Equidimensional, very angular, low sphericity
  Sorting
    Moderately well-sorted
  Fabric
    Random, interlocking
  Particle surface texture
    Smooth and glassy

Mineralogical composition
  $CaCO_3$..........100%

Sedimentary structures
  Character of basal contact
    Unobserved
  Character of upper contact
    Upper contact is very sharp and planar.
  Bedding plane structures
    No bedding plane structures observed
  Sedimentary unit (layer) structures
    Medium bedded complex, fine layers predominate
  Current direction
    Unknown

Fossil content
  No fossils observed

Degree of induration and geomorphic expression
  Well indurated and a cliff former

Remarks

APPENDIX D: SOIL TEXTURAL DATA

Soil pit No. & horizon	% sand	% silt	% clay
1A	51	43	6
1B	*[a]	*	*
1C	62	33	5
2A	67	23	10
2B	*	*	*
2C	75	15	10
3A	50	46	4
3B	*	*	*
$3C_1$	-[b]	-	-
$3C_2$	-	-	-
$3C_3$	-	-	-
4A	45	43	12
4B	44	29	27
4C	65	14	21
5A	47	41	12
5B	*	*	*
5C	60	33	17
6A	51	34	15
6B	*	*	*
6C	*	*	*
7A	46	48	15
7B	*	*	*
7C	*	*	*
7R	-	-	-
8A	51	30	20

[a] *Horizon not present.

[b] - horizon not sampled.

Soil pit No. & horizon	% sand	% silt	% clay
8B	*	*	*
8C	*	*	*
8R	-	-	-
$9A_1$	48	37	15
$9A_2$	45	40	15
9B	*	*	*
9C	67	10	23
10A	58	27	14
10B	61	10	29
$10B_{Ca}$	89	1	10
10C	*	*	*
10R	*	*	*
11A	64	21	15
11B	*	*	*
11C	69	21	10
12A	49	36	15
12B	*	*	*
12C	64	16	20
$13A_1$	51	25	24
$13A_2$	54	27	19
13B	*	*	*
13C	*	*	*
14A	56	22	22
14B	*	*	*
14C	82	8	10
15A	61	16	13
15B	*	*	*
15C	72	26	2
16A	54	28	18
16B	*	*	*
16C	66	15	19

Soil pit No. & horizon	% sand	% silt	% clay
$17A_1$	57	29	14
$17A_{2Ca}$	58	25	17
17B	*	*	*
17C	70	15	15
18A	69	15	16
18B	73	25	2
18C	72	20	8
19A	66	27	7
19B	*	*	*
19C	70	22	8
20A	55	40	5
20B	*	*	*
20C	70	26	4
21A	-	-	-
21B	-	-	-
21C	66	29	5
22A	57	24	19
22B	*	*	*
22C	59	24	17
23A	65	20	15
23B	68	11	21
23C	95	3	2
24A	54	34	12
24B	*	*	*
24C	70	22	8
$25A_1$	-	-	-
$25A_2$	62	31	17
$25B_1$	-	-	-
$25B_2$	68	15	17
25C	*	*	*

Soil pit No. & horizon	% sand	% silt	% clay
26A_1	58	29	13
26A_2	64	21	14
26B	65	23	11
26C	*	*	*
27A	54	31	14
27B	68	25	7
27C	57	34	9
28A_2	17	70	13
28B	57	32	11
28C	62	21	17
29A_2	27	36	37
29B	22	48	30
29C	61	21	18
30A_2	*	*	*
30B	-	-	-
30C	-	-	-
31A_2	-	-	-
31B	-	-	-
31C	-	-	-
32A	58	33	11
32B	77	9	18
32C	69	16	15
33A	54	29	17
33B	71	15	14
33C	87	8	5
34A_2	63	28	9
34B	53	18	29
34C	49	28	23
35A_2	49	34	17
35B	57	32	11

Soil pit No. & Horizon	% sand	% silt	% clay
35C	61	25	14
36A	58	29	13
36B	65	23	12
$36B_{Ca}$	65	23	12
36C	76	19	5
37A	51	38	11
37B	63	26	11
37C	67	27	6
38A	63	23	14
38B	68	27	5
38C	74	18	8
39A	63	25	12
39B	64	28	8
39C	80	12	8
$40A_2$	70	23	7
40B	75	18	7
40C	90	8	2
41A	*	*	*
41B	*	*	*
41C	*	*	*
42A	-	-	-
42B	-	-	-
42C	-	-	-
43A	-	-	-
43B	-	-	-
43C	-	-	-
$44A_2$	48	35	16
44B	57	28	15
44C	62	29	9
45A	-	-	-

Soil pit No. & horizon	% sand	% silt	% clay
45B	-	-	-
45C	-	-	-
$46A_2$	64	29	7
46B	75	19	6
46C	71	20	9
47A	-	-	-
47B	-	-	-
47C	-	-	-
48A	-	-	-
48B	-	-	-
48C	82	13	5
49A	60	26	14
49B	58	22	20
49C	60	27	13
50A	*	*	*
50B	*	*	*
50C	*	*	*
51A	64	29	7
51B	83	10	7
51C	85	9	6
52A	80	9	11
52B	*	*	*
$52C_{Ca}$	79	21	5
52C	74	15	11
53A	72	22	7
53B	*	*	*
$53C_{Ca}$	89	7	5
53C	90	7	3
54A	58	30	12
54B	*	*	*

Soil pit No. & horizon	% sand	% silt	% clay
$54C_{Ca}$	66	29	5
55A	80	14	6
55B	*	*	*
55C	89	10	1
56A	43	48	9
56B	*	*	*
56C	75	20	5
57A	*	*	*
57B	*	*	*
57C	*	*	*
58A	*	*	*
58B	*	*	*
58C	*	*	*
59A	87	11	2
59B	*	*	*
59C	82	16	12
60A	81	12	7
60B	*	*	*
$60C_{Ca}$	91	7	2
61A	69	20	9
61B	*	*	*
$61C_{Ca}$	77	18	6
61C	70	27	3
62A	72	19	9
62B	*	*	
$62C_{Ca}$	80	15	5
62C	64	32	4
63A	71	4	5
63B	*	*	*

Soil pit No. & horizon	% sand	% silt	% clay
63C	58	37	5
64A	70	14	16
64B	*	*	*
$64C_{Ca}$	72	22	6
64C	74	22	4
65A	56	31	13
65B	*	*	*
$65C_{Ca}$	70	22	8
65C	88	7	5
66A	46	34	20
$66B_1$	56	32	12
$66B_3$	78	15	7
$66C_{Ca}$	90	5	5
66C	80	17	3
67A	56	34	10
$67A_2$	74	21	5
67B	61	30	9
67C	75	15	10
68A	*	*	*
68B	*	*	*
68C	81	9	10
$69A_2$	71	18	11
69B	77	14	9
$69C_{Ca}$	85	11	4
70A	48	37	15
70B	62	18	20
70C	49	31	20
71A	54	31	15
71B	62	28	10
$71C_{Ca}$	70	21	9

Soil pit No. & horizon	% sand	% silt	% clay
71C	61	34	5
72A	55	38	7
72B	61	29	10
72C	86	8	6
73A	-	-	-
73B	-	-	-
73C	-	-	-
74A	86	7	7
74B	92	5	3
74C	91	6	3
$75A_2$	-	-	-
75B	-	-	-
$75C_{Ca}$	-	-	-
75C	-	-	-
76A	78	11	11
76B	79	12	9
76C	77	18	5
$77A_2$	50	40	10
77B	64	26	10
77C	68	25	7
$78A_2$	74	18	8
$78B_2$	76	14	10
$78B_3$	83	9	8
$78C_{Ca}$	85	8	7
$79A_2$	53	34	13
79B	64	19	17
79C	85	1	14
80A	57	28	15
80B	66	22	12
$80B_3$	75	15	10

Soil pig No. & horizon	% sand	% silt	% clay
$80C_{Ca}$	83	7	10
81A	76	13	11
81B	84	11	5
$81C_{Ca}$	84	11	5
82A	57	28	15
82B	69	16	15
$82B_3$	72	18	10
82C	87	10	3
83A	*	*	*
83B	*	*	*
83C	27	44	29
$84A_2$	43	41	16
84B	59	29	12
84C	*	*	*
85A	82	13	5
85B	81	4	16
85C	78	12	10
86A	75	18	7
86B	68	22	10
86C	86	10	4
87A	71	23	6
87B	75	15	10
87C	77	15	8
$88A_1$	67	16	7
$88A_2$	64	29	7
88B	77	2	21
$88C_I$	96	2	2
$88C_{II}$	88	7	5
$88C_{III}$	90	7	3
$88C_{IV}$	98	1	1

Soil pit No. & horizon	% sand	% silt	% clay
97B	*	*	*
97C	87	8	5
98A	*	*	*
98B	*	*	*
98C	81	7	12
99A	92	6	2
$99B_1$	91	6	3
$99B_2$	95	3	2
99C	88	9	3
100A	-	-	-
100B	-	-	-
100C	-	-	-
101A	-	-	-
101B	-	-	-
101C	-	-	-
102A	-	-	-
102B	-	-	-
102C	-	-	-
$102C_{Ca}$	-	-	-
103A	47	45	8
103B	56	35	9
103C	53	28	19
104A	-	-	-
104C	-	-	-
105A	67	31	2
105B	63	34	3
$105B_3$	83	14	3
105C	80	15	5
106A	-	-	-
106B	-	-	-

Soil pit No. & horizon	% sand	% silt	% clay
$106B_{Ca}$	-	-	-
106C	-	-	-
107A	63	37	0
107B	89	8	3
107C	92	5	3
108A	-	-	-
108B	-	-	-
$108C_{Ca}$	-	-	-
108C	-	-	-
109A	-	-	-
109B	-	-	-
$109C_{Ca}$	-	-	-
109C	-	-	-
110A	-	-	-
110B	-	-	-
$110C_{Ca}$	-	-	-
110C	-	-	-
111A	-	-	-
111B	-	-	-
111C	-	-	-
$112A_2$	-	-	-
112B	-	-	-
113A	-	-	-
113B	-	-	-
113C	-	-	-
114A	54	39	7
114B	68	24	8
114C	*	*	*
115A	66	24	10
115B	87	7	6

Soil pit No. & horizon	% sand	% silt	% clay
$115B_{Ca}$	88	7	5
$115C_1$	88	8	4
$115C_2$	75	12	13
116A	70	24	6
116B	85	11	4
116C	95	4	1
117A	75	20	5
117B	94	1	1
117C	89	9	2
118A	-	-	-
118B	-	-	-
118C	-	-	-
119A	-	-	-
1191A	63	28	9
$1191B_1$	85	10	5
$1191B_2$	76	18	6
$119A_I$	-	-	-
$119B_I$	-	-	-
120A	-	-	-
$120C_1$	-	-	-
$120C_{Ca}$	-	-	-
$120C_2$	-	-	-
121A	-	-	-
121C	-	-	-
122A	-	-	-
$122C_1$	-	-	-
$122C_{Ca}$	-	-	-
$122C_2$	-	-	-
123A	-	-	-
123B	-	-	-

Soil pit No. & horizon	% sand	% silt	% clay
123C	-	-	-
124C	-	-	-
125A	-	-	-
125B	-	-	-
125C	-	-	-
126A	-	-	-
126B	-	-	-
126C	-	-	-
127A	-	-	-
127B	-	-	-
127C	-	-	-
$128A_1$	77	22	1
128A	70	24	6
128C	90	9	1
$129A_1$	57	37	6
$129A_2$	69	27	4
$129B_2$	80	12	8
$129B_3$	97	1	2
129C	98	1	1
$130A_1$	65	27	8
130A	74	16	10
$130B_1$	82	13	5
$130B_3$	91	6	3
$130C_{Ca}$	81	15	4
131A	-	-	-
131B	-	-	-
131C	-	-	-
132C	3	73	24
133C	5	70	25
134C	33	23	44

Soil pit No. & horizon	% sand	% silt	% clay
135C	60	17	23
136C	21	37	42

APPENDIX E: SOIL PROFILE DESCRIPTIONS

Key for Appendix E

Depth to bedrock and depth to H_2O table are listed in meters.

Depth to soil horizon is listed in centimeters.

Texture

Texture	Term	Texture	Term
angular cobbley	ac	loam	l
angular gravelly	ag	gravelly loam	gl
gravel	g	stoney loam	stl
very coarse sand	vcos	silt	si
coarse sand	cos	silt loam	sil
sand	s	clay loam	cl
fine sand	fs	silty clay loam	sicl
very fine sand	vfs	sandy clay loam	scl
loamy coarse sand	lcos	stoney clay loam	stcl
loamy sand	ls	silty clay	sic
loamy fine sand	lfs	clay	c
sandy loam	sl		
fine sandy loam	fsl		
very fine sandy loam	vfsl		
gravelly sandy loam	gsl		

Structure

Size or class		Form or type	
very fine	vf	platy	pl
fine	f	prismatic	pr
medium	m	columnar	cpr
coarse	c	blocky	bk
very coarse	vs	angular blocky	abk
		subangular blocky	sbk
Grade or distinctness		granular	gr
structureless	0	crumb	cr
weak	1	single grain	sg
moderate	2	massive	m
strong	3		

Consistency

Dry soil		Wet soil	
loose	dl	nonsticky	wso
soft	ds	slightly sticky	wss
slightly hard	dsh	sticky	ws
hard	dh	very sticky	wvs
very hard	dvh	nonplastic	wpo
extremely hard	deh	slightly plastic	wps
		plastic	wp
		very plastic	wvp

Moist soil

loose	ml
very friable	mvfr
friable	mfr
firm	mfi
very firm	mvfi
extremely firm	mefi

Boundary

Distinctness		Topography	
abrupt	a	smooth	s
clear	c	wavy	w
gradual	g	irregular	i
diffuse	d	broken	b

Mottling

Abundance		Contrast	
few	f	faint	f
common	c	distinct	d
many	m	prominent	p

Size

fine	1
medium	2
coarse	3

Soils Data

Site No. 1 Location NW15, 53N90W		Elevation 1585	
Dominant vegetation: wild oats bunch grass	% total ground cover: 80	% good ground cover: 60	
Parent material: silty carbonate collu.	Formation name for underlying bedrock: Gallatin		
% surface covered by bedrock: 0	Landform: colluvial backfill area on landslide (slump)		
Slope angle: 2	Aspect: N10W	Erosion Class: slight	Precip.: less than 38 cm.
Drainage class: Somewhat excessively drained	Depth to H_2O table (est.)		
Depth to bedrock		seasonal	year around
rippable: 1.5+	non-rippable: 1.5+	1.5+	1.5+

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	92	10YR5/2	10YR4/3	l	med pl	l f	np ns	7+	g sm
C	92+	10YR6/1	10YR5/2	acl	mas	l f	np ns	7+	

Comments Horizons only weakly developed and are very low in organic Matter.

Soils Data

Site No. 2 Location NW15.53N90W	Elevation 1585

Dominant vegetation: wild oats, bunch grass	% total ground cover 90	% good ground cover 75

Parent material: loamy carbonate colluvium	Formation name for underlying bedrock: Gallatin
% surface covered by bedrock 0	Landform: Colluvial backfill area on landslide (slump)

Slope angle 3	Aspect N10W	Erosion Class slight	Precip. less than 39 cm.

Drainage class: ext. well

Depth to bedrock: rippable 1.5 +; non-rippable 1.5 +

Depth to H_2O table (est.): seasonal 1.5+; year around 1.5+

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	46	10YR5/2	10YR4/3	l	pl	lo f	ns np	7+	g sm
C	46 +	10YR6/1	10YR5/2	ags	mas	lo f	ns np	7+	

Comments Horizons only weakly developed and are very low in organic matter.

Soils Data				
Site No. 3 Location NW15,53N90W			Elevation 1695	
Dominant vegetation saw grass		% total ground cover 60		% good ground cover 40
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin		
% surface covered by bedrock 0		Landform colluvial backfill area on landslide (slump)		
Slope angle 4	Aspect N15W	Erosion Class moderate		Precip. less than 38 cm.
Drainage class exc. well		Depth to H_2O table (est.)		
Depth to bedrock		seasonal		year around
rippable 1.5 +	non-rippable 1.5+	1.5 +		1.5+

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	10.4	10YR3/3	10YR2/2	l	m2pl	lo mfi	wso wpo	es	gs
C_1	137.2	10YR5/2	10YR4/3	l	m1pl	lo mfi	wso wpo	es	gs
C_2	167.6	10YR6/3	10YR5/4	vfs	m	lo mfi	wso wpo	es	gs
C_3	167.6+	10YR5/2	10YR4/3	agsil	m	lo mfi	wso wpo	es	

Comments A horizon contains some organic matter, profile only poorly differentiated. The structure in the C_1 is due to bedding planes. This appears to be a depression filling on an old rotational slump.

Soils Data

Site No. 4 Location NW31, 53N89W		Elevation 2621	
Dominant vegetation: sage, grass, and forbs		% total ground cover: 80	% good ground cover: 60
Parent material: weathered limestone		Formation name for underlying bedrock: Madison	
% surface covered by bedrock: 0		Landform: sideslope	
Slope angle: 5	Aspect: N12E	Erosion Class: moderate	Precip. greater than 50 cm.
Drainage class: well		Depth to H_2O table (est.)	
Depth to bedrock: rippable 1.5 +	non-rippable 1.5 +	seasonal 1.5 +	year around 1.5 +

Profile description

Horizon	Depth	Color dry / moist	Texture	Structure	Consistency dry / wet	pH	Boundary
A	15.4	2.5YR2/4 / 2.5YR2/2	sil	m3abk	dsh wss / mfr wps	7-	cs
B	61.4	2.5YR5/4 / 2.5YR3/4	sil	m3abk	dsh ws / mfr ws	7-	cs
C	61.4+	7.5YR5/6 / 7.5YR4/2	acsi	m	dsh wss / mfr wps	7+	

Comments Clay skins ?? present in the A horizon as well as a fair amount of organic matter. Clay skins present in the B horizon.

Soils Data

Site No. 5 Location SW30,53N89W		Elevation 2670	
Dominant vegetation grass, sage, and forbs		% total ground cover 80	% good ground cover 50
Parent material weathered carbonate bedrock		Formation name for underlying bedrock Madison	
% surface covered by bedrock 20		Landform sideslope	
Slope angle 15	Aspect N90E	Erosion Class moderate	Precip. greater than 50 cm.
Drainage class well		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	30.7	2.5YR2/4	2.5YR2/2	sil	m2abk	dsh mfr	wss wpo	7-	cs
C	30.7+	7.5YR5/6	7.5YR4/2	acsi	m	dsh mfr	wss wpo	7+	

Comments Clay skins ?? and large amount of organic matter present in the A horizon. As moved up the hill from pit no. 4 appear to have lost the B horizon.

Soils Data

Site No. 6 Location SW30,53N89W		Elevation 2804	
Dominant vegetation grass, sage, and forbs	% total ground cover 30		% good ground cover 15
Parent material weathered carbonate bedrock	Formation name for underlying bedrock Madison		
% surface covered by bedrock 50	Landform ridgecrest		
Slope angle 5	Aspect S15W	Erosion Class moderate	Precip. greater than 50 cm.
Drainage class well	Depth to H_2O table (est.)		
Depth to bedrock	seasonal	year around	
rippable 1.5 + / non-rippable 1.5 +	1.5 +	1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	15.4	2.5YR2/4	2.5YR2/2	sil	m2abk	dsh mfr	wss wps	7-	as
B	15.4+								

Comments Poorly developed clay skins?? present on the peds in the A horizon. Much organic matter also present.

Soils Data

Site No. 7 Location NE35.53N89W		Elevation 2731	
Dominant vegetation grass, sage, and forbs	% total ground cover 70	% good ground cover 50	
Parent material weathered carbonate bedrock	Formation name for underlying bedrock Madison		
% surface covered by bedrock 20	Landform sideslope		
Slope angle 15	Aspect S20W	Erosion Class moderate	Precip. greater than 50 cm.
Drainage class well		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.2	non-rippable 1.5+		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	20.5	2.5YR5/4	2.5YR4/6	sil	m2abk	dsh mfr	wso wpo	7-	as
R	20.5+							7+	

Comments Poorly developed clay skins ??? present in A horizon. Good deal of organic matter, appears to be 10% by volume.

Soils Data

Site No. 8 Location SW18.53N90W		Elevation 2560	
Dominant vegetation grass, and sage		% total ground cover 60	% good ground cover 40
Parent material weathered Amsden silts and carbonates		Formation name for underlying bedrock Amsden	
% surface covered by bedrock 20		Landform ridge crest	
Slope angle 10	Aspect S45W	Erosion Class slight	Precip. greater than 50 cm.
Drainage class moderately well		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 0.3	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	15.4	2.5YR2/4	2.5YR2/2	sil	m2abk	dsh mfr	wso spo	7-	as
R	15.4+	10R4/8						7-	

Comments Poorly developed clay skins ??? on peds in A horizon.

Soils Data

Site No. 9 Location SW18,53N90W	Elevation 2560
Dominant vegetation: grass, sage, and forbs	% total ground cover 70 / % good ground cover 50
Parent material: weathered Amsden silts and carbonates	Formation name for underlying bedrock: Amsden
% surface covered by bedrock: 0	Landform: ridgecrest
Slope angle 10 / Aspect S45W	Erosion Class: slight / Precip. greater than 50 cm.
Drainage class: moderately well	Depth to H_2O table (est.) seasonal: 1.5 + / year around: 1.5 +
Depth to bedrock rippable: 1.5 + / non-rippable: 1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A_1	10.2	7.5YR3/2	7.5YR3/2	sil	m2abk	dh mfi	ws wp	7-	cs
A_2	30.7	2.5YR2/4	2.5YR2/2	sil	m2abk	dh mfi	ws wp	7-	cs
C	30.7+	10R4/8	10R3/6	si	m	dh mfi	ws wp	7-	

Comments No clay skins present. Up to 10% organic matter (est.) in the A horizon.

Soils Data

Site No. 10 Location SW18, 54N88W		Elevation 2719	
Dominant vegetation alpine fir, sage, grass, and forbs	% total ground cover 90		% good ground cover 75
Parent material weathered carbonate bedrock	Formation name for underlying bedrock Madison		
% surface covered by bedrock 0	Landform sideslope		
Slope angle 9	Aspect S10E	Erosion Class slight	Precip. greater than 50 cm.
Drainage class moderately well		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A_1	41	10YR2/2	10YR2/2	sil	c2gr	dsh mfr	wss wps	7-	cs
B_1	56.3	5YR3/2	5YR3/2	cl	m2abk	dsh mfi	ws wp	7-	cs
B_{2Cs}	87	7.5YR4/4	7.5YR3/2	cl	m2abk	dsh mfi	ws wp	7+	cs
R	87+	7.5R7/6						7+	

Comments A horizon, weakly developed clay skins ??? and high content of undecayed organic matter (est. 10%). B_1 horizon, well developed clay slins (5YR3/2), mottles are present (c2f), they are 2.5YR3/4 in color. B_{2Ca} horizon, well-developed clay skins (5YR4/2), common distinct veinlets of $CaCO_3$ running through B_{2Ca}, they are 10YR8/2.

Soils Data

Site No. 11 Location NW25,53N89W			Elevation 2743
Dominant vegetation grass, sage, and forbs	% total ground cover 80		% good ground cover 60
Parent material weathered carbonate bedrock	Formation name for underlying bedrock Madison		
% surface covered by bedrock 10	Landform sideslope		
Slope angle 21	Aspect N89E	Erosion Class class 1	Precip. greater than 50 cm, est.
Drainage class somewhat excessively drained	Depth to H_2O table (est.) seasonal 1.5 +		year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	46	7.5YR3/2	7.5YR3/2	sil	m2abk	ds mfvr	wso wpo	7-	cs
C	61	5YR4/3	5YR3/3	agl	m	ds mfvr	wso wpo	7+	as
R	61+	7.5YR7/6						7+	

Comments A horizon, clay skins ??? (5YR3/2), carbonate pebbles present, less than 10% (est.). C horizon, pea size carbonate pebbles present, 30% by volume (est.).

Soils Data

Site No. 12 Location NW31.53N89W		Elevation 2621	
Dominant vegetation grass, sage, and forbs		% total ground cover 90	% good ground cover 70
Parent material weathered carbonate bedrock		Formation name for underlying bedrock Madison	
% surface covered by bedrock 0		Landform toeslope	
Slope angle 19	Aspect N89E	Erosion Class class 1	Precip. greater than 50 cm.
Drainage class somewhat excessively drained		Depth to H_2O table (est.)	
Depth to bedrock rippable	non-rippable	seasonal	year around
1.5 +	1.5 +	1.5 +	1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	60.9	10YR3/3	10YR2/2	sil	m1abk	sa mfvr	wso wpo	7-	cs
C	73.7	7.5YR4/4	7.5YR3/2	sil	m	sa mfvr	wso wpo	7+	as
R	73.7+	7.5YR7/6						7+	

Comments A horizon, well-developed clay skins??? (7.5YR3/2).
C horizon, contains 10% (est.) angular carbonate rock fragments.

Soils Data

Site No. 13 Location SW30, 53N88W		Elevation 2694	
Dominant vegetation: grass, sage, and forbs		% total ground cover 90	% good ground cover 70
Parent material: weathered carbonate bedrock		Formation name for underlying bedrock: Madison	
% surface covered by bedrock 20		Landform: sideslope	
Slope angle 35	Aspect N89E	Erosion Class: class 1	Precip. greater than 50 cm.
Drainage class: somewhat excessively drained		Depth to H_2O table (est.)	
Depth to bedrock		seasonal	year around
rippable	non-rippable	1.5+	1.5 +
0.61	1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A_1	46	10YR3/3	10YR3/2	sil	m1abk	ds mfvr	wso wpo	7-	gs
A_2	121.9+	10YR3/3	10YR3/2	agsil	m1abk	sa mfvr	wso wpo	7+	

Comments A_1 horizon, clay skins??? present (10YR3/2). A_2 horizon, same as A_1 except contains 20% (est.) angular carbonate rock fragments. Soil pit discontinued at 121.9 cm.

Soils Data

Site No. 14 Location SE25.53N89W		Elevation 2767
Dominant vegetation grass, sage, and forbs	% total ground cover 80	% good ground cover 60
Parent material weathered carbonate bedrock	Formation name for underlying bedrock Madison	
% surface covered by bedrock 20	Landform sideslope	
Slope angle 5 / Aspect N90E	Erosion Class class 1	Precip. greater than 50 cm.
Drainage class somewhat excessively drained	Depth to H_2O table (est.) seasonal 1.5 + / year around 1.5 +	
Depth to bedrock rippable 45.7 / non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	10.2	10YR3/3	10YR3/2	sil	m1abk	ds mfvr	wso wpo	7-	cs
C	45.7	5YR4/4	5YR3/3	acsil	m	ds mfvr	wso wpo	7+	as
R	45.7+	7.5YR7/6						7+	

Comments

Soils Data

Site No. 15 Location NE35,53N89W		Elevation 2773	
Dominant vegetation grass, sage, and forbs	% total ground cover 80	% good ground cover 60	
Parent material weathered carbonate bedrock	Formation name for underlying bedrock Madison		
% surface covered by bedrock 10	Landform ridgecrest		
Slope angle 22	Aspect S40W	Erosion Class class 1	Precip. greater than 50 cm.
Drainage class well drained	Depth to H_2O table (est.)		
Depth to bedrock rippable 1.5 +	Depth to bedrock non-rippable 1.5 +	seasonal 1.5 +	year around 1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	12.8	10YR3/4	10YR2/2	sil	m2gr	ds mfvr	wso wpo	7-	cs
C	101.6	10YR4/4	10YR3/3	acsl	m	ds mfvr	wso wpo	7+	

Comments A horizon, poorly developed clay skins??? (10YR3/2), also contains 10-15% angular pebble size carbonate fragments. C horizon, contains 50% (est.) angular cobble and gravel size carbonate rock fragments.

Soils Data

Site No. 16 Location SE26.53N89W		Elevation 2743	
Dominant vegetation grass, sage, and forbs	% total ground cover 90	% good ground cover 75	
Parent material weathered carbonate bedrock	Formation name for underlying bedrock Madison		
% surface covered by bedrock 0	Landform sideslope		
Slope angle 18	Aspect N80W	Erosion Class class 1	Precip. greater than 50 cm.
Drainage class well drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +	
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	30.7	10YR4/3	10YR3/3	sil	m2gr	ds mfvr	wso wpo	7-	ca
C	101.6+	7.5YR4/4	7.5YR3/2	acsl	m	ds mfvr	wso wpo	7+	

Comments A horizon, clay skins ??? (10YR3/3), less than 10% angular pebble size carbonate rock fragments. C horizon contains 10% (est.) angular pebble size carbonate rock fragments.

Soils Data

Site No. 17 Location NE35.53N89W	Elevation 2707
Dominant vegetation grass, sage, and forbs	% total ground cover 85 / % good ground cover 60
Parent material weathered carbonate bedrock	Formation name for underlying bedrock Madison
% surface covered by bedrock 20	Landform sideslope
Slope angle 25 / Aspect S45E	Erosion Class class 1 / Precip. greater than 50 cm.
Drainage class well drained	Depth to H_2O table (est.) seasonal 1.5 + / year around 1.5 +
Depth to bedrock: rippable 1.5 + / non-rippable 1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A_1	30.7	5YR3/4	5YR2/2	sil	m2abk	ds mfvr	wso wpo	7-	gs
A_{2Ca}	61.4	5YR3/4	5YR2/2	agsil	m2abk	ds mfvr	wso wpo	7+	cs
C	61.4+	5YR4/3	5YR3/3	agsil	m	ds mfvr	wso wpo	7+	

Comments A_1 horizon, clay skins??? (5YR3/2) present. A_{2Ca} same as A_1 but contains 15% (est.) angular pebble size carbonate rock fragments.

Soils Data

Site No. 18 Location NW19,53N89W		Elevation 2755	
Dominant vegetation: grass, sage, and forbs	% total ground cover 100		% good ground cover 80
Parent material: weathered granite bedrock	Formation name for underlying bedrock: granite		
% surface covered by bedrock 0	Landform sideslope		
Slope angle 5	Aspect SOE	Erosion Class: class 1	Precip. greater than 50 cm.
Drainage class: moderately well drained	Depth to H_2O table (est.)		
Depth to bedrock: rippable 1.5 +, non-rippable 1.5 +	seasonal 1.5 +	year around 1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	35.8	5YR3/2	5YR2/2	sil	m1abk	ds mfvr	wso wpo	7-	cs
B	61.4	2.5Y6/6	2.5Y5/6	sic	m2abk	dsh mfr	ws wp	7-	cs
C	61.4+	2.5Y6/6	2.5Y5/6	sc	m	dsh mfr	ws wp	7-	

Comments A horizon, clay skins??? (5YR3/1). B horizon, well-developed clay skins (5Y6/2), mottles present, (f2d), contains less than 5% (est.) highly weathered, acid crystaline, pebble size, rock fragments. C horizon, contains 5% (est.) highly weathered, acid crystaline, pebble size, rock fragments. They appear to be a mica schist.

Soils Data

Site No. 19 Location NW10,53N90W			Elevation 1585
Dominant vegetation wild oats, sage and cactus	% total ground cover 60		% good ground cover 60
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin		
% surface covered by bedrock 0	Landform colluvial backfill area on landslide (slump)		
Slope angle 4 / Aspect SOW	Erosion Class class 1		Precip. less than 30 cm.
Drainage class well drained	Depth to H_2O table (est.) seasonal 1.5 +		year around 1.5 +
Depth to bedrock rippable 1.5 + / non-rippable 1.5 +			

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	5	10YR5/3	10YR4/3	agl	figr	dl mvfr	wso wpo	7+	cs
C	101.6+	10YR7/4	10YR6/4	agsil	m	dl mvfr	wso wpo	7+	

Comments A horizon, organic matter less than 1% (est.), contains 15% (est.) angular gravel size carbonate rock fragments, appear to be from the Madison formation. A horizon reacts violently with HCl. C horizon, contains 15% (est.) angular gravel size carbonate rock fragments, appear to be from the Madison formation. C hroizon reacts violently with HCl.

Soils Data

Site No. 20 Location NW10, 53N90W		Elevation 1585
Dominant vegetation: wild oats, sage, and cactus	% total ground cover 50	% good ground cover 50
Parent material: loamy carbonate colluvium	Formation name for underlying bedrock: Gallatin	
% surface covered by bedrock: 0	Landform: colluvial backfill area on landslide (slump)	
Slope angle 8 / Aspect S0E	Erosion Class: class 1	Precip. less than 38 cm.
Drainage class: well drained	Depth to H_2O table (est.) seasonal: 1.5 +	year around: 1.5 +
Depth to bedrock rippable: 1.5+ / non-rippable: 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	5	10YR5/3	10YR4/3	agl	m1gr	dl mvfr	wso wpo	7+	cs
C	101.6+	10YR6/4	10YR5/4	agsil	m	dl mvfr	wso wpo	7+	

Comments Profile in general is poorly developed. A horizon, contains 10% (est.) angular gravel size carbonate rock fragments, appear to be from the Madison Formation. A horizon reacts violently with HCl. C horizon, contains 20% (est.) angular gravel size carbonate rock fragments, appear to be from the Madison Formation. C horizon reacts violently with HCl.

Soils Data

Site No. 21 Location NW15,53N90W | Elevation 1539

Dominant vegetation: grass, sage, and juniper | % total ground cover: 70 | % good ground cover: 70

Parent material: carbonate colluvium forming landslide debris | Formation name for underlying bedrock: Gallatin

% surface covered by bedrock: 0 | Landform: sideslope-landslide (slump)

Slope angle: 55 | Aspect: NOE | Erosion Class: class 1 | Precip. less than 38 cm.

Drainage class: somewhat excessively drained

Depth to H_2O table (est.): seasonal 1.5 +; year around 1.5 +

Depth to bedrock: rippable 1.5 +; non-rippable 1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments: Material churned by mass movement, no discernible soil profile present. Consists of 50% (est.) angular gravel to boulder size carbonate rock fragments from the Madison Formation set in a silty matrix. Matrix is 10YR5/2, m, dl, mvfr, wso, wpo, and reacts violently with HCl.

Soils Data

Site No. 22 Location NW15,53N90W | Elevation 1585

Dominant vegetation: grass, sage, and juniper | % total ground cover 50 | % good ground cover 50

Parent material: loamy, carbonate colluvium | Formation name for underlying bedrock: Gallatin

% surface covered by bedrock: 0 | Landform: colluvial backfill area on landslide (slump)

Slope angle: 1 | Aspect: SOW | Erosion Class: class 1 | Precip.: less than 38 cm.

Drainage class: well-drained

Depth to bedrock: rippable 1.5 +; non-rippable 1.5 +

Depth to H_2O table (est.): seasonal 1.5 +; year around 1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	5	5YR6/1	5YR5/2	sil	m1gr	dl mvfr	wso wpo	7+	cs
C	101.6+	5YR6/1	5YR5/2	sil	m1pl?	dl mvfr	wso wpo	7+	

Comments: Profile very poorly differentiated. A horizon has 1% organic matter (est.), C horizon has none. Structure in C horizon appears to be due to depositional bedding.

Soils Data

Site No. 23 Location ~~44,39,15~~ 107,29,10		Elevation 2746	
Dominant vegetation grass, and forbs	% total ground cover 80		% good ground cover 60
Parent material weathered acid crystaline bed rock	Formation name for underlying bedrock granite		
% surface covered by bedrock 0	Landform sideslope		
Slope angle 14	Aspect SOE	Erosion Class class 1	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 0.9	year around 1.5 +
Depth to bedrock rippable 0.7	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	7.6	7.5YR4/2	7.5YR3/2	l	flgr	ds mvfr	wso wpo	7-	cs
B	15.2	7.5YR5/4	7.5Yr4/2	sil	m1abk	dsh mfr	wss wps	7-	cs
C	71.2	2.5YR6/8	2.5YR5/6	gsl	m	ds mvfr	wso wps	7-	gi
R	71.2+	10R5/8							

Comments B horizon, poorly developed clay skins (7.5YR4/4), contains 2% (est.) angular gravel fragments of deeply weathered igneous rock. Depth to C horizon is variable, consists of deeply weathered pink granite.

Soils Data

Site No. 24 Location ~~44,40,00~~ 107,32,30		Elevation 2830	
Dominant vegetation grass, sage, and forbs	% total ground cover 80	% good ground cover 60	
Parent material weathered carbonate bedrock	Formation name for underlying bedrock Bighorn		
% surface covered by bedrock 20	Landform sideslope		
Slope angle 8	Aspect SOW	Erosion Class class 1	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5+
Depth to bedrock rippable 1.5+	non-rippable 1.5+		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	10.2	7.5YR3/2	7.5YR3/2	sil	m2gr	dsh mfr	ws wp	7-	cs
C	101.2+	10YR8/6	10YR7/6	acsil	m	ds mvfr	wso wps	7+	

Comments A horizon, poorly developed clay skins (5YR2/2)???, angular carbonate pebbles make up less than 1% (est.) of total. C horizon, 50% (est.) angular cobble size dolomite fragments.

Soils Data

Site No. 25 Location 44,40,00 107,32,30		Elevation 2896	
Dominant vegetation grass, and forbs	% total ground cover 95	% good ground cover 80	
Parent material weathered carbonate bedrock	Formation name for underlying Madison		
% surface covered by bedrock 0	Landform ridgecrest-saddle		
Slope angle 3	Aspect N40E	Erosion Class class 2	Precip. greater than 50 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +	
Depth to bedrock rippable 1.5+	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A_1	7.6	7.5YR3/2	7.5YR2/2	sil	m1gr	ds mvfr	wso wpo	6.5	cs
A	45.7	7.5YR3/2	7.5YR2/2	sic	m2gr	dsh mfr	wss wps	7.0	cw
B_1	55.9	10YR6/6	10YR5/6	sic	m2abk	dsh mfr	wss wps	7.0	cw
B_2	101.6+	10YR6/6	10YR5/6	aesic	m2abk	dsh mfr	wss wps	7.5	

Comments A horizon, clay skins??? (10YR3/2) present but not well developed. B_1 horizon, well-developed clay skins (10YR5/4). B_2 horizon, clay skins extremely well developed (10YR5/4), contains 60% (est.) angular cobble size carbonate rock fragments from the Madison Formation

Soils Data				
Site No. 26 Location 44,40,00 107,32,3			Elevation 2932	
Dominant vegetation grass, and forbs		% total ground cover 95		% good ground cove.
Parent material weathered carbonate bedrock		Formation name for underlying bedrock Madison		
% surface covered by bedrock 0		Landform sideslope		
Slope angle 7	Aspect N90E	Erosion Class class 1	Precip. greater than 50 cm.	
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +	
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +			

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A_1	20.5	7.5YR3/2	7.5YR2/2	sil	m1gr	ds mvfr	wso wpo	5.0	gs
A_2	41.0	7.5YR3/2	7.5YR2/2	sil	m1gr	ds mvfr	wso wpo	5.0	gs
B	56.3	7.5YR4/4	7.5YR3/2	sic	f1abk	ds mvfr	wso wpo	7.0	as
R	56.3+	5YR4/3						7+	

Comments A_1 horizon, poorly developed clay skins??? (5YR2/2). A_2 horizon, well developed clay skins??? (5YR3/2). B horizon, well developed clay skins (5YR4/3), 10% (est.) angular gravel size fragments of carbonate rock from the Madison Formation. A lithologic discontinuity is present, A and B horizons appear to be alluvial in origin.

Soils Data

Site No. 27 Location 107,32,32 44,39,30 | Elevation 2951

Dominant vegetation: grass, sage, and forbs | % total ground cover 85 | % good ground cover 70

Parent material: weathered carbonate bedrock | Formation name for underlying bedrock: Madison

% surface covered by bedrock: 20 | Landform: sideslope

Slope angle: 16 | Aspect: S60W | Erosion Class: class 2 | Precip.: greater than 50 cm.

Drainage class: well-drained

Depth to bedrock: rippable 1.5 +; non-rippable 1.5 +

Depth to H_2O table (est.): seasonal 1.5 +; year around 1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	15.4	5YR3/4	5YR3/2	sil	m1gr	ds mvfr	wso wpo	6.0	cs
B	30.7	10YR3/4	10YR3/3	agsic	f1abk	ds mvfr	wso wpo	7.0	cs
C	101.6+	10YR7/6	10YR6/6	agsil	m	ds mvfr	wso wpo	7.5	

Comments B horizon, weakly developed clay skins (7.5Yr4/2), 25% (est.) angular gravel size fragments of carbonate rock from the Madison Formation. C horizon, 60% (est.) angular gravel size fragments of carbonate rock from the Madison Formation.

Soils Data

Site No. 28 Location ~~44,40,30~~ 107,33,45		Elevation 2890	
Dominant vegetation subalpine fir	% total ground cover 100		% good ground cover 50
Parent material weathered carbonate bed rock	Formation name for underlying bedrock Madison		
% surface covered by bedrock 0	Landform sideslope		
Slope angle 8	Aspect S70W	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class moderately well	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +	
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_1	-3.8				m	ds mvfr	wsp wpo		cs
O_2	0				m	ds mvfr	wsp wpo		cs
A_2	7.7	5YR3/3	5YR3/2	si	m2pl	ds mvfr	wso wpo	4.0	gs
B	23	5YR3/2	5YR3/2	sic	m2abk	ds mvfr	wso wpo	6.5	cs
C	25.6	7.5YR4/4	7.5YR3/2	sic	m	ds mvfr	wso wpo	6.5	cw
R	25.6+	5YR4/3						7+	

Comments B horizon, well-developed clay skins (5YR3/2).

Soils Data

Site No. 29 Location 44,40,15 / 107,33,45		Elevation 2914	
Dominant vegetation subalpine fir		% total ground cover 95	% good ground cover 90
Parent material weathered carbonate bedrock		Formation name for underlying bedrock Madison	
% surface covered by bedrock 0		Landform sideslope	
Slope angle 24	Aspect N10E	Erosion Class class 1	Precip. greater than 50 cm.
Drainage class moderately well		Depth to H_2O table (est.)	
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +	seasonal 1.5 +	year around 1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_1	-1.3					ds mvfr	wso wpo		cs
A_2	1.3	5YR3/1	5YR3/1	sic	m2pl	ds mvfr	wso wpo	5.0	cs
B	15.4	5YR3/4	5YR3/3	sic	m2abk	ds mvfr	wso wpo	4.0	cs
C	101.6+	5YR4/3	5YR3/3	ac	m	ds mvfr	wso wpo	7+	

Comments B horizon, well-developed clay skins (5YR4/3). C horizon made up of 95% (est.) angular gravel to cobble size fragments of carbonate rock from the Madison Formation, very little matrix.

Soils Data

Site No. 30 Location ~~44,38,30~~ 107,34,00		Elevation 2560	
Dominant vegetation Dou glas fir		% total ground cover 85	% good ground cover 80
Parent material weathered carbonate bed rock		Formation name for underlying bedrock Bighorn	
% surface covered by bedrock 0		Landform floodplain	
Slope angle 5	Aspect N90E	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class imperfectly drained		Depth to H_2O table (est.) seasonal 0.3	year around 0.9
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
0_1	-2.6					ds mvfr	wso wpo		cs
0_2	0					ds mvfr	wso wpo		cs
B	30.7	7.5YR4/4	7.5YR3/2	c	m3abk	dh mfi	ws wp	4.5	cs
IA_1	41.0	7.5YR2/0	7.5YR2/0	c	m2abk	dh mfi	ws wp	6.0	cs
IIB	70.0+	2.5Y6/4	2.5Y5/4	c	m2abk	dh mfi	ws wp	6.5	

Comments B horizon, moderately well-developed clay skins (7.5YR4/2). Water table was encountered at 70.0 cm.

Soils Data

Site No. 31 Location ~~44,38,30~~ 107,34,00		Elevation 2560	
Dominant vegetation Douglas fir	% total ground cover 95	% good ground cover 95	
Parent material weathered carbonate bed rock	Formation name for underlying bedrock Bighorn		
% surface covered by bedrock 0	Landform sideslope		
Slope angle 40	Aspect N10E	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 0.6 year around 1.5 +		
Depth to bedrock rippable 1.5 + non-rippable 1.5 +			

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_1	-5					ds mvfr	wso wpo		cs
O_2	-2.5					ds mvfr	wso wpo		cs
A_2	30.7	5YR3/3	5YR3/2	sil	m1pl	ds mvfr	wso wpo	5.0	cs
B	51.2	10YR5/6	10YR4/4	sic	m2abk	dsh mfr	wss wps	7.0	cs
C	101.6+	10YR5/1	10YR4/1	acs	m	ds mvfr	wso wpo	7+	

Comments B horizon contains 5% (est.) angular gravel size fragments of deeply weathered carbonate rock from the Bighorn and Madison Formations. C horizon contains 60% (est.) angular gravel and cobble size fragments of carbonate rock from the Bighorn and Madison Formations.

Soils Data

Site No. 32 Location 44,40,45 107,33,45		Elevation 2868	
Dominant vegetation grass, and forbs		% total ground cover 90	% good ground cover 90
Parent material weathered carbonate bedrock		Formation name for underlying bedrock Madison	
% surface covered by bedrock 0		Landform ridgecrest	
Slope angle 3	Aspect N40E	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	30.7	7.5YR3/2	7.5YR3/2	acsil	m2gr	ds mvfr	wso wpo	5.0	cs
B	51.2	10YR3/4	10YR3/3	acsic	f2abk	ds mvfr	wso wpo	7.0	cs
C	101.6+	10YR6/6	10YR5/6	acsi	m	ds mvfr	wso wpo	7.5	

Comments A horizon, poorly developed clay skins??? (5YR3/2), contains 40% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation. B horizon, moderately well-developed clay skins (10YR3/3), contains 50% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation. C horizon, contains 70% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation

Soils Data

Site No. 33 Location 107,33,50 / 44,40,35		Elevation 2834	
Dominant vegetation grass and forbs		% total ground cover 60	% good ground cover 60
Parent material weathered carbonate bedrock		Formation name for underlying bedrock Madison	
% surface covered by bedrock 20		Landform sideslope	
Slope angle 8	Aspect N45W	Erosion Class class 4	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	32.3	5YR3/2	5YR2/2	acsi	migr	ds mvfr	wso wpo	6.5	ci
B	41.0	5YR2/2	5YR2/2	acsic	m1abk	ds mvfr	wso wpo	7.0	cs
C	101.6+	10YR7/4	10YR6/4	acsil	m	ds mvfr	wso wpo	8.0	

Comments A horizon, poorly developed clay skins??? (5YR2/2), contains 20% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison formation. B horizon, contains moderately well-developed clay skins (5YR3/2), contains 50% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation. C horizon, contains 70% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation.

Soils Data

Site No. 34 Location 44,40,45 107,32,57		Elevation 2865
Dominant vegetation subalpine fir	% total ground cover 70	% good ground cover 70
Parent material weathered carbonate bed rock	Formation name for underlying bedrock Madison	
% surface covered by bedrock 0	Landform sideslope	
Slope angle 10 / Aspect S20E	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 + / year around 1.5 +	
Depth to bedrock: rippable 1.5 + / non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_1	-2.6					ds mvfr	wso wpo		cs
O_2	0					ds mvfr	wso wps		cs
A_2	7.7	5YR4/4	5YR3/3	sil	m2pl	dsh mfr	wss wps	5.0	gs
B	25.6	5YR4/4	5YR3/3	sil	m2abk	dsh mfr	wss wps	5.0	cs
C	101.6+	7.5YR6/6	7.5YR5/6	acsil	m	dsh mfr	wss wps	7.0	

Comments A horizon, poorly developed clay skins (5YR3/3)???. B horizon, clay skins present (5YR4/3). C horizon, contains 40% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation. C horizon has a pH of 7.0 and a depth of 27.9 cm and a pH of 8.0 at a depth of 40.6 cm.

Soils Data

Site No. 35 Location ~~44,40,45~~ 107,32,57		Elevation 2850	
Dominant vegetation subalpine fir	% total ground cover 70		% good ground cover 70
Parent material weathered carbonate bed rock	Formation name for underlying bedrock Madison		
% surface covered by bedrock 0	Landform sideslope		
Slope angle 10	Aspect S20E	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained	Depth to H_2O table (est.)		
Depth to bedrock	seasonal	year around	
rippable 1.5 +	non-rippable 1.5 +	1.5 +	1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_1	-2.6					ds mvfr	wso wpo		cs
O_2	0					ds mvfr	wso wpo		cs
A_2	7.7	5YR4/4	5YR3/3	sil	m1pl	ds mvfr	wso wps	5.0	gs
B	25.6	5YR4/4	5YR3/3	sil	m1abk	ds mvfr	wso wps	5.0	cs
C	41.0	7.5YR6/6	7.5YR5/6	acsil	m	ds mvfr	wso wps	7.5	as
R	41.0+	5YR4/3						7+	

Comments B horizon, clay skins present (5YR3/2). C horizon, contains 70% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation

Soils Data

Site No. 36 Location ~~44,41,00~~ 107,34,50		Elevation 2859	
Dominant vegetation grass, and forbs	% total ground cover 90	% good ground cover 80	
Parent material weathered carbonate bed rock	Formation name for underlying bedrock Madison		
% surface covered by bedrock 0	Landform ridgecrest		
Slope angle 5	Aspect N30W	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +	
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	20.5	10YR2/2	10YR2/2	si	m1gr	ds mvfr	wso wps	5.5	cs
B	35.9	7.5YR4/4	7.5YR3/2	sil	m1abk	ds mvfr	wso wpo	6.0	cs
B_{Ca}	58.9	10YR5/8	10YR5/4	acsil	m2abk	dsh mfr	wss wps	8.0	cs
C	101.6+	5YR6/4	5YR5/4	acsil	m	ds mvfr	wso wpo	8.5	

Comments A horizon, poorly developed clay skins??? (10YR2/1). B horizon, well-developed clay skins (%YR3/3). B_{Ca} horizon, well-developed clay skins (7.5YR4/4), contains 40% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation. C horizon, contains 80% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation.

Soils Data

Site No. 37 Location 44.41.00-107.34.50		Elevation 2859
Dominant vegetation: scattered firs, grass, and sage	% total ground cover 90	% good ground cover 80
Parent material: weathered carbonate bed rock	Formation name for underlying bedrock: Madison	
% surface covered by bedrock: 0	Landform: ridgecrest	
Slope angle 5 / Aspect N30W	Erosion Class: class 0	Precip. greater than 50 cm.
Drainage class: well-drained	Depth to H_2O table (est.) seasonal: 1.5 +	year around: 1.5 +
Depth to bedrock rippable: 1.5 +	non-rippable: 1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	12.8	5YR3/3	5YR3/2	si	m1gr	ds mvfr	wso wps	5.0	as
B	20.5	5YR4/4	5YR3/3	sic	m1abk	ds mvfr	wso wps	5.0	cs
C	101.6+	7.5YR5/4	7.5YR4/4	acsil	m	ds mvfr	wso wps	8.5	

Comments A horizon, clay skins??? (5YR3/2. B horizon, well-developed clay skins (5YR3/3). C horizon, contains 60% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation.

Soils Data

Site No. 38 Location 44.41.00-107.34.56		Elevation 2886	
Dominant vegetation grass, sage, and forbs	% total ground cover 90		% good ground cover 90
Parent material weathered carbonate bed rock	Formation name for underlying bedrock Madison		
% surface covered by bedrock 0	Landform ridgecrest		
Slope angle 10	Aspect S70E	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal	year around
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +	1.5 +	1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_2	-1.3					ds mvfr	wso wpo		as
A	35.8	5YR3/4	5YR3/3	si	m1gr	ds mvfr	wso wps	5.0	gs
B	74.2	5YR4/6	5YR3/4	acsic	m1abk	ds mvfr	wso wps	5.5	as
C	101.6+	10YR5/6	10YR4/4	acsi	m	ds mvfr	wso wso	7.0	

Comments A horizon, poorly developed clay skins ??? (5YR3/2). B horizon, poorly developed clay skins (5YR3/3), contains less than 5% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation. C horizon, contains 60% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation.

Soils Data

Site No. 39 Location 44.40.57-107.34.58		Elevation 2850	
Dominant vegetation: grass, sage, and forbs	% total ground cover 90		% good ground cover 75
Parent material: weathered carbonate bed rock	Formation name for underlying bedrock Madison		
% surface covered by bedrock 5	Landform sideslope		
Slope angle 18	Aspect S45W	Erosion Class class 1	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	25.6	5YR4/3	5YR3/3	si	m1gr	ds mvfr	wso wpo	6.0	gs
B	43.5	5YR4/4	5YR3/3	acsic	m1abk	ds mvfr	wso wpo	6.5	as
C	101.6+	10YR5/4	10YR4/3	acsi	m	ds mvfr	wso wpo	8.5	

Comments A horizon, poorly developed clay skins ??? (5YR3/2). B horizon, poorly developed clay skins (5YR3/3), contains 40% (est.) angular gravel size fragments of carbonate rock fragments from the Madison Formation. C horizon, contains 60% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation.

Soils Data

Site No. 40 Location SW19,53N89W		Elevation 2591
Dominant vegetation Douglas fir	% total ground cover 100	% good ground cover 100
Parent material glacial till	Formation name for underlying bedrock Shell Creek Moraine	
% surface covered by bedrock 0	Landform lateral moraine	
Slope angle 55 / Aspect N10E	Erosion Class class 1	Precip. greater than 50ccm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 + / non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_2	-7.7					ds mvfr	wso wpo		as
O_1	-2.6					ds mvfr	wso wpo		as
A_2	10.2	7.5YR4/4	7.5YR3/2	bl	c1pl	ds mvfr	wso wpo	7-	gs
B	33.3	5YR4/6	5YR3/4	bl	c1abk	ds mvfr	wso wpo	7-	cs
C	101.6+	7.5YR4/4	7.5YR3/2	bl	m	ds mvfr	wso wpo	7-	

Comments A horizon contains 40% (est.) rounded and faceted, gravel to boulder size fragments of acid crystaline Precambrian rock. B horizon, poorly developed clay skins (5YR3/2), contains 40% (est.) rounded and faceted, gravel to boulder size fragments of acid crystaline Precambrian rock. C horizon contains 70% (est.) rounded and faceted, gravel to boulder size fragments of acid crystaline Precambrian rock.

Soils Data

Site No. 41 Location 44.40.55-107.36.15		Elevation 2949	
Dominant vegetation grass, sage, and forbs		% total ground cover 90	% good ground cover 70
Parent material weathered carbonate bedrock		Formation name for underlying bedrock Madison	
% surface covered by bedrock 40		Landform ridgecrest	
Slope angle 5	Aspect N45E	Erosion Class class 1	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 0.6 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments Solution cavity due to widening along joint trend (N30W), no profile taken.

Soils Data

Site No. 42 Location 44.40.55-107.36.15		Elevation 2911	
Dominant vegetation grass, and forbs		% total ground cover 100%	% good ground cover 90
Parent material weathered carbonate bedrock		Formation name for underlying bedrock Madison	
% surface covered by bedrock 10		Landform ridgecrest	
Slope angle 3	Aspect NOE	Erosion Class class 1	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Hori-zon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	20.5	7.5YR4/2	7.5YR3/2	si	m1gr	ds mvfr	wso wpo	7-	gs
B	25.6	7.5YR3/2	7.5YR3/2	sic	m1abk	ds mvfr	wso wpo	7-	cs
C	101.6+	5YR5/3	5YR4/3	acsic	m	ds mvfr	wso wpo	7+	

Comments B horizon, clay skins (7.5YR4/2), contains less than 5% (est.) angular gravel size fragments of carbonate rock fragments from the Madison Formation. C horizon contains 70% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation. Site no. 42 is located 30 feet west from a sink hole. Site no. 43 is located in the sink hole.

Soils Data

Site No. 43 Location 44.40.55-107.36.15		Elevation 2911
Dominant vegetation grass and forbs	% total ground cover 100	% good ground cover 90
Parent material weathered carbonate bed rock	Formation name for underlying bedrock Madison	
% surface covered by bedrock 0	Landform sink hole	
Slope angle 0 / Aspect NOE	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class moderately well	Depth to H_2O table (est.)	
Depth to bedrock: rippable 1.5 + / non-rippable 1.5 +	seasonal 1.5 +	year around 1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	5	7.5YR3/2	7.5YR3/2	si	m1gr	ds mvfr	wso wpo	7-	cs
B	15.4	5YR2/2	5YR2/2	si	m1abk	ds mvfr	wso wpo	7-	cs
C	101.6+	7.5YR3/2	7.5YR3/2	si	m	ds mvfr	wso wpo	7-	

Comments Soil pit dug in sink hole.

Soils Data

Site No. 44 Location 44.41.15-107.37.15	Elevation 2890
Dominant vegetation subalpine	% total ground cover 95 / % good ground cover 85
Parent material weathered carbonate bed rock	Formation name for underlying bedrock Madison
% surface covered by bedrock 0	Landform sideslope
Slope angle 18 / Aspect N60W	Erosion Class class 0 / Precip. greater than 50 cm.
Drainage class imperfectly drained	Depth to H_2O table (est.) seasonal 0.6 / year around 1.5 +
Depth to bedrock rippable 1.5 + / non-rippable 1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_2	-5					ds mvfr	wso wpo	7-	cs
O_1	-2.6					ds mvfr	wso wpo	7-	cs
A_2	10.1	5YR3/4	5YR3/3	sic	m1pl	ds mvfr	wso wpo	7-	gs
B	40.6	5YR4/4	5YR3/3	acsic	m1abk	ds mvfr	wso wpo	7-	cs
C	101.6+	10YR5/4	10YR4/4	acsi	m	ds mvfr	wso wpo	7+	

Comments A horizon, mottles present (c2d, 5YR3/2). B horizon, mottles present (c2d, 5YR2/2), contains 20% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation. C horizon, contains 40% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation. Soil is frozen at a depth of 35.6 cm.

Soils Data

Site No. 45 Location SW32.55N89W | Elevation 2880

Dominant vegetation grass, and forbs | % total ground cover 90 | % good ground cover 70

Parent material weathered carbonate bed rock | Formation name for underlying bedrock Madison

% surface covered by bedrock 0 | Landform ridgecrest

Slope angle 18 | Aspect N60W | Erosion Class class 0 | Precip. greater than 50 cm.

Drainage class well-drained

Depth to bedrock: rippable 1.5 +, non-rippable 1.5 +

Depth to H_2O table (est.): seasonal 1.5 +, year around 1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	23	5YR3/2	5YR3/2	sic	m1gr	ds mvfr	wso wpo	7-	gs
B	32.3	7.5YR4/4	7.5YR3/2	sic	m1abk	ds mvfr	wso wpo	7-	cs
C	101.6+	10YR5/4	10YR4/4	acsic	m	ds mvfr	wso wpo	7+	

Comments A horizon, poorly developed clay skins ??? (5YR2/2). B horizon, clay skins well-developed (7.5YR3/2). C horizon, highly calcareous, contains 30% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation.

Soils Data

Site No. 46 Location 44.41.20-107.38.5		Elevation 2896
Dominant vegetation subalpine fir	% total ground cover 100	% good ground cover 80
Parent material weathered carbonate bed rock	Formation name for underlying bedrock Madison	
% surface covered by bedrock 0	Landform ridgecrest	
Slope angle 7 / Aspect S20E	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 + / non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_2	-5					ds mvfr	wso wpo	7-	cs
O_1	-2.6					ds mvfr	wso wpo	7-	cs
A_2	15.4	5YR3/3	5YR3/2	si	f1pl	ds mvfr	wso wpo	7-	cs
B	28	5YR4/4	5YR4/3	sic	m1abk	ds mvfr	wso wpo	7-	cs
C	101.6+	10YR6/4	10YR5/3	acsi	m	ds mvfr	wso wpo	7+	

Comments B horizon, well-developed clay skins (5YR3/3). C horizon, contains 30% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation.

Soils Data

Site No. 47 Location 44.35.15-107.43.00		Elevation 2417
Dominant vegetation: grass, sage, and forbs	% total ground cover 70	% good ground cover 50
Parent material: weathered carbonate bed rock	Formation name for underlying bedrock: Madison	
% surface covered by bedrock: 15	Landform: sideslope	
Slope angle 3	Aspect N75W	Erosion Class: class 1
	Precip. less than 50 cm.	
Drainage class: somewhat excessively drained	Depth to H_2O table (est.)	
Depth to bedrock rippable 1.5 +	seasonal 1.5 +	year around 1.5 +
Depth to bedrock non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A_1	10.1	5YR3/2	5YR2/2	acsi	m1gr	ds mvfr	wso wpo	7-	gs
A_{Ca}	18	5YR3/2	5YR2/2	acsi	m1gr	ds mvfr	wso wpo	7+	gs
B_{Ca}	41	5YR4/3	5YR3/3	acsi	m1abk	ds mvfr	wso wpo	7+	cs
C_{Ca}	101.6+	5YR6/4	5YR5/4	acsil	m	ds mvfr	wso wpo	7+	

Comments A_1 and A_{Ca} horizons contain 15% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation. B_{Ca} horizon, highly calcareous, contains 15% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation. C_{Ca} horizon, highly calcareous, contains 30% (est.) angular gravel and cobble size fragments of carbonate rock from the Madison Formation.

Soils Data

Site No. 48 Location 44.36.15-107.41.00		Elevation 2509	
Dominant vegetation grass, and sage	% total ground cover 90		% good ground cover 90
Parent material deeply weathered sandstone	Formation name for underlying bedrock Amsden		
% surface covered by bedrock 0	Landform ridgecrest		
Slope angle 8	Aspect S10E	Erosion Class class 0	Precip. less than 50 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +	
Depth to bedrock rippable 0.4	non-rippable 1.5 +		

Profile description

Hori-zon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	12.8	5YR3/2	5YR2/2	sl	m1gr	ds mvfr	wso wpo	7-	gs
B	40.6	5YR3/3	5YR3/2	sil	m1abk	ds mvfr	wso wpo	7-	as
C	101.6+	5YR4/6	5YR4/4	sl	m	ds mvfr	wso wpo	7-	

Comments B horizon, poorly developed clay skins (5YR3/1). C horizon consists of deeply weathered sandstone.

Soils Data

Site No. 49 Location 44,38,00-107,40,50		Elevation 2535	
Dominant vegetation grass, sage, and forbs	% total ground cover 90	% good ground cover 80	
Parent material weathered siltstone	Formation name for underlying bedrock Amsden		
% surface covered by bedrock 0	Landform ridgecrest		
Slope angle 2	Aspect N70W	Erosion Class class 0	Precip. less than 50 cm.
Drainage class moderately well-drained	Depth to H_2O table (est.) seasonal q.5 +	year around 1.5 +	
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A_1	10.2	2.5YR2/2	2.5YR2/2	si	m1gr	ds mvfr	wso wpo	7-	cs
A	15.4	2.5YR4/6	2.5YR3/4	si	m2abk	dsh mfr	wss wps	7-	cs
B	46	2.5YR3/4	2.5YR3/2	sic	m2abk	dsh mfr	wss wps	7-	cs
C	101.6+	2.5YR4/6	2.5YR4/4	sic	m	dsh mfr	wss wps	7-	

Comments B horizon, clay skins present (2.5YR3/2).

Soils Data									
Site No. 50 Location 44.35.00-107.34.10						Elevation			
Dominant vegetation				% total ground cover			% good ground cover		
Parent material				Formation name for underlying bedrock					
% surface covered by bedrock				Landform					
Slope angle		Aspect		Erosion Class			Precip.		
Drainage class				Depth to H_2O table (est.) seasonal year around					
Depth to bedrock rippable non-rippable									

Profile description

Hori-zon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments Copeman's Tomb turnout, about 3.2 kilometers from Shell Falls. Slump block exposed in roadcut, composed of Gallatin Formation, interbedded glauconitic shales and sandstones. Grab samples taken from shales and sandstone.

Soils Data

Site No. 51 Location 44.34.30-107.40.00		Elevation 1676
Dominant vegetation: bunch grass, juniper, and cacti	% total ground cover 50	% good ground cover 30
Parent material: loamy carbonate colluvium	Formation name for underlying bedrock: Gallatin	
% surface covered by bedrock: 0	Landform: ridgrcrest on slumpblock	
Slope angle 0; Aspect 0	Erosion Class: class 4	Precip. less than 39 cm.
Drainage class: somewhat excessively drained	Depth to H_2O table (est.) seasonal: 1.5 +	year around: 1.5 +
Depth to bedrock rippable: 1.5 +	non-rippable: 1.5 +	

Profile description

Hori-zon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	17.8	10YR5/3	10YR4/3	acsi	m1gr	ds mvfr	wso wpo	7+	cs
B	25.0	10YR5/4	10YR4/3	acsi	m1abk	ds mvfr	wso wpo	7+	cs
C	101.6+	10YR8/4	10YR8/4	acsi	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous all the way to the surface. B horizon, contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formation. C horizon, contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous.

Soils Data

Site No. 52 Location 44.39.50-107.39.55		Elevation 1585	
Dominant vegetation grass, sage, and prickly pear	% total ground cover 60	% good ground cover 45	
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform sideslope on a slumpblock	
Slope angle 40	Aspect S80W	Erosion Class class 3	Precip. less than 38 cm.
Drainage class somewhat excessively drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	41	10YR6/3	10YR5/3	acsil	m-f1abk	ds mvfr	wso wpo	7+	cs
C_{Ca}	82	10YR7/6	10YR7/6	acsil	m	ds mvfr	wso wpo	7+	cs
C	101.6+	10YR7/8	10YR7/6	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 30% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous all the way to the surface. C_{Ca} horizon, contains 60% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous, lighter color is due to a build up of $CaCO_3$. C horizon, contains 60% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous.

Soils Data

Site No. 53 Location 44.34.52-107.39.54		Elevation 1582	
Dominant vegetation grass, sage, and junipers	% total ground cover 50		% good ground cover 35
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin		
% surface covered by bedrock 0	Landform sideslope on a slumpblock		
Slope angle 40	Aspect S80W	Erosion Class class 3	Precip. less than 38 cm.
Drainage class somewhat excessively drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	17.8	10YR6/3	10YR5/3	acsil	m1abk	ds mvfr	wso wpo	7+	cs
C_{Ca}	34.4	7.5YR8/6	7.5YR8/6	acsil	m	ds mvfr	wso wpo	7+	cs
C	101.6+	10YR8/6	10YR7/6	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. C_{Ca} horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous, lighter color is due to a build up of $CaCO_3$. C horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous.

Soils Data

Site No. 54 Location 44.34.52-107.39.52		Elevation 1615	
Dominant vegetation junipers, and Douglas fir		% total ground cover 50	% good ground cover 35
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform sideslope on a slumpblock	
Slope angle 28	Aspect N60W	Erosion Class class 3	Precip. less than 38 cm.
Drainage class somewhat excessively drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	48.6	10YR4/3	10YR3/3	acsi	micr	ds mvfr	wso wpo	7+	s
C_{Ca}	101.6+	10YR8/2	10YR8/2	acsi	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous all the way to the surface. C_{Ca} horizon, contains 60% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous, lighter color is due to a build up of $CaCO_3$.

Soils Data

Site No. 55 Location 44.34.47-107.39.50		Elevation 1670	
Dominant vegetation juniper, Doug. fir and Limber pine		% total ground cover 50	% good ground cover 35
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform ridgecrest on a slumpblock	
Slope angle 10	Aspect N60W	Erosion Class class 1	Precip. 38 cm.
Drainage class somewhat excessively drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	30.5	10YR4/2	10YR3/2	acsil	m-f1cr	ds mvfr	wso wpo	7+	gs
B	45.3	10YR5/3	10YR4/3	acsil	m1abk	ds mvfr	wso wpo	7+	gs
C	101.6+	10YR6/4	10YR5/4	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous all the way to the surface. C horizon, contains 70% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. Profile is only poorly developed.

Soils Data

Site No. 56 Location 44.34.47-107.39.51		Elevation 1670
Dominant vegetation sawgrass	% total ground cover 90	% good ground cover 90
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0	Landform colluvial backfill are on landslide (slump)	
Slope angle 3 / Aspect NOE	Erosion Class class 0	Precip. less than 38 cm.
Drainage class somewhat excessively drained	Depth to H_2O table (est.) seasonal 1.5 + / year around 1.5 +	
Depth to bedrock rippable 1.5 + / non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	20.5	10YR3/2	10YR2/2	si	m-f1cr	ds mvfr	wso wpo	7+	as
C	101.6+	10YR4/2	10YR3/2	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon is highly calcareous all the way to the surface. C horizon, contains 15% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formation, highly calcareous.

Soils Data			
Site No. 57 Location 44.34.45-107.40.15		Elevation 1561	
Dominant vegetation	% total ground cover		% good ground cover
Parent material	Formation name for underlying bedrock		
% surface covered by bedrock	Landform		
Slope angle / Aspect	Erosion Class	Precip.	
Drainage class	Depth to H_2O table (est.) seasonal / year around		
Depth to bedrock rippable / non-rippable			

Profile description

Hori-zon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments Granite outcrop above road level (H14), landslides have moved directly onto granite. Precambrian surface appears to be highly irregular in general.

Soils Data

Site No. 58 Location			Elevation
Dominant vegetation		% total ground cover	% good ground cover
Parent material		Formation name for underlying bedrock	
% surface covered by bedrock		Landform	
Slope angle	Aspect	Erosion Class	Precip.
Drainage class		Depth to H_2O table (est.) seasonal year around	
Depth to bedrock rippable non-rippable			

Profile description

Hori-zon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments

Soils Data

Site No. 59 Location 44.35.00-107.39.49		Elevation 1707	
Dominant vegetation grass, and sage		% total ground cover 70	% good ground cover 50
Parent material weathered shale and limestone		Formation name for underlying bedrock Gros Ventre, and Gallatin	
% surface covered by bedrock 0		Landform sideslope on landslide	
Slope angle 13	Aspect N30E	Erosion Class class 4	Precip. 38 cm.
Drainage class somewhat excessively drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	12.8	10YR6/3	10YR5/3	acsil	m1cr	ds mvfr	wso wpo	7+	gs
C	101.6+	10YR7/3	10YR6/3	acsl	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 70% (est.) angular gravel to cobble size fragments of carbonate rock from the Gallatin, and Bighorn Formations, highly calcareous all the way to the surface. C horizon, contains 50% (est.) angular gravel to cobble size fragments of carbonate rock from the Gallatin, and Bighorn Formations, also contains 10% (est.) green shale chips, highly calcareous. Extremely poor profile development.

Soils Data

Site No. 60 Location 44.34.55-107.39.52		Elevation 1609	
Dominant vegetation grass, sage, and juniper	% total ground cover 30		% good ground cover 10
Parent material weathered carbonate bed rock	Formation name for underlying bedrock Gallatin		
% surface covered by bedrock 0	Landform sideslope on landslide (slump)		
Slope angle 75 / Aspect N90E	Erosion Class class 0		Precip. 38 cm.
Drainage class somewhat excessively drained	Depth to H_2O table (est.) seasonal 1.5 +		year around 1.5 +
Depth to bedrock rippable 0.4 / non-rippable 1.5 +			

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	23	10YR7/4	10YR6/4	acsil	micr	ds mvfr	wso wpo	7+	s
C_{Ca}	43.5	2.5Y8/2	2.5Y8/4	acsil	m	dsh mvfr	wso wpo	7+	as
R	43.5+	5YR4/3						7+	

Comments A horizon, contains 30% (est.) angular gravel to cobble size fragments of carbonate rock from the Gallatin, and Bighorn Formations, highly calcareous all the way to the surface. C_{Ca} horizon, contains 30% (est.) angular gravel to cobble size fragments of carbonate rock from the Gallatin, and Bighorn Formations, highly calcareous, lighter color is due to a build up of $CaCO_3$. R horizon is highly calcareous.

Soils Data

Site No. 61 Location 44.34.54-107.34.51		Elevation 1634	
Dominant vegetation grass, sage, juniper, Doug. fir		% total ground cover 50	% good ground cover 30
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform sideslope on landslide (slump)	
Slope angle 30	Aspect N90W	Erosion Class class 4	Precip. 38 cm.
Drainage class somewhat excessively drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	17.8	10YR6/3	10YR5/3	acsil	m1cr	ds mvfr	wso wpo	7+	as
C_{Ca}	69.0	10YR8/3	10YR8/3	acsil	m	dh mfi	wso wpo	7+	as
C	101.6+	10YR8/6	10YR7/6	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous all the way to the surface. C_{Ca} horizon, contains 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous, lighter color is due to a build up of $CaCO_3$. C horizon, contains 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous.

Soils Data

Site No. 62 Location 44.35.06-107.39.47	Elevation 1707
Dominant vegetation grass, and sage	% total ground cover 70 / % good ground cover 50
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin
% surface covered by bedrock 0	Landform ridgecrest on landslide (slump)
Slope angle 10 / Aspect N90W	Erosion Class class 4 / Precip. 38 cm.
Drainage class somewhat excessively drained	Depth to H_2O table (est.) seasonal 1.5 + / year around 1.5 +
Depth to bedrock rippable 1.5 + / non-rippable 1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	18	10YR5/3	10YR4/3	acsil	micr	ds mvfr	wso wpo	7+	as
C_{Ca}	35.8	10YR8/2	10YR8/2	acsil	m	ds mvfr	wso wpo	7+	cs
C	101.6+	10YR6/4	10YR5/4	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 60% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous all the way to the surface. C_{Ca} horizon, contains 70% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous, lighter color is due to a build up of $CaCO_3$. C horizon, contains 70% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous.

Soils Data

Site No. 63 Location 44.34.57-107.39.45		Elevation 1817
Dominant vegetation Douglas fir	% total ground cover 70	% good ground cover 50
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0	Landform sideslope on landslide (slump)	
Slope angle 60	Aspect N40W	Erosion Class class 0
Precip. 38 cm.		
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_2	-7.7					ds mvfr	wso wpo	7-	cs
O_1	-2.6					ds mvfr	wso wpo	7-	as
A	25.6	10YR3/3	10YR3/2	acsil	m2pl	dsh mfr	wss wps	7+	gs
C	101.6+	10YR4/3	10YR3/3	acsil	m	dsh mfr	wss wps	7+	

Comments A horizon, contains 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, slightly calcareous. C horizon, contains 60% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, calcareous. No noticeable C_{Ca} horizon has developed.

Soils Data

Site No. 64 Location 44.34.10-107.39.40		Elevation 1707	
Dominant vegetation grass, sage, and juniper		% total ground cover 70	% good ground cover 50
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform sideslope on landslide (slump)	
Slope angle 65	Aspect N30W	Erosion Class class 5	Precip. 38 cm.
Drainage class somewhat excessively drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	43	10YR5/3	10YR4/3	acsil	m1cr	ds mvfr	wso wpo	7+	gs
C_{Ca}	84.5	10YR6/3	10YR6/2	acsil	m	ds mvfr	wso wpo	7+	as
C	101.6+	10YR6/4	10YR5/4	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 15% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous all the way to the surface. C_{Ca} horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous, lighter color is due to a build up of $CaCO_3$. C horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous.

Soils Data

Site No. 65 Location 44.35.20-107.36.10		Elevation 2012
Dominant vegetation grass, sage, and Limber pine	% total ground cover 60	% good ground cover 40
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0	Landform sideslope on landslide (slump)	
Slope angle 50 / Aspect N20W	Erosion Class class 0	Precip. 38 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	33	7.5YR3/2	7.5YR3/2	acsi	m2cr	dsh mfr	wss wps	7+	as
C_{Ca}	71.7	10YR6/2	10YR6/1	acsil	m	dsh mfr	wss wps	7+	as
C	101.6+	10YR7/4	10YR6/4	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 10% (est.) angular gravel to cobble size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, slightly calcareous. C_{Ca} horizon, contains 60% (est.) angular gravel to cobble size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous, lighter color is due to a build up of $CaCO_3$. C horizon, contains 60% (est.) angular gravel to cobble size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous.

Soils Data

Site No. 66 Location 44.35.23-107.36.10 Elevation 2073

Dominant vegetation grass, and sage | % total ground cover 75 | % good ground cover 60

Parent material loamy carbonate colluvium | Formation name for underlying bedrock Gallatin

% surface covered by bedrock 0 | Landform sideslope on landslide (slump)

Slope angle 24 | Aspect NOE | Erosion Class class 0 | Precip. 38 cm.

Drainage class well-drained

Depth to bedrock: rippable 1.5 +; non-rippable 1.5 +

Depth to H_2O table (est.): seasonal 1.5 +; year around 1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	5	10YR4/3	10YR4/2	acsi	m2gr	dsh mfr	wss wps	7+	gs
B_1	20.3	10YR3/3	10YR3/2	acsi	m2abk	dsh mfr	wss wps	7-	ga
B_3	30.4	10YR4/3	10YR3/3	acsil	m2abk	dsh mfr	wss wps	7+	as
C_{Ca}	76.2	10YR7/2	10YR7/2	acsil	m	dsh mfr	wss wps	7+	as
C	101.6+	10YR6/4	10YR6/3	acsil	m	dsh mfr	wss wps	7+	

Comments A horizon, contains less than 10% (est.) angular gravel to cobble size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. B_1 horizon, poorly developed clay skins (10YR3/2), contains 10% (est.) angular gravel to cobble size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. B_3 horizon, contains 20% (est.) angular gravel to cobble size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. C_{Ca} horizon, contains 20% (est.) angular gravel to cobble size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous, lighter color is due to a build up of $CaCO_3$. C horizon, contains 20% (est.) angular gravel to cobble

Soils Data

Site No. 66 Location			Elevation
Dominant vegetation		% total ground cover	% good ground cover
Parent material		Formation name for underlying bedrock	
% surface covered by bedrock		Landform	
Slope angle	Aspect	Erosion Class	Precip.
Drainage class		Depth to H_2O table (est.) seasonal year around	
Depth to bedrock rippable non-rippable			

Profile description

Hori-zon	Depth	Color dry moist	Texture	Structure	Consistency dry wet	pH	Boundary

Comments size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous.

Soils Data

Site No. 67 Location 44.35.00-107.35.00		Elevation 2073	
Dominant vegetation Douglas fir		% total ground cover 80	% good ground cover 80
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform sideslope on landslide (slump)	
Slope angle 35	Aspect NOE	Erosion Class class 1	Precip. 39 cm.
Drainage class well drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_2	-5					ds mvfr	wso wpo	7-	cs
O_1	-2.6					ds mvfr	wso wpo	7-	as
A_2	7.6	10YR4/4	10YR3/3	acsil	m2pl	dsh mfr	wss wps	7+	cs
B	30.5	10YR4/3	10YR3/3	acsi	m1abk	ds mvfr	wso wpo	7+	cs
C	101.6+	10YR4/4	10YR4/3	acsi	m	ds mvfr	wso wpo	7+	

Comments A_2 horizon, contains 10% (est.) angular gravel to cobble size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, slightly calcareous. B horizon, contains 50% (est.) angular gravel to cobble size fragments of carbonate rock form the Gallatin, Bighorn, and Madison Formations. C horizon, contains 60% (est.) angular gravel to cobble size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. C_{Ca} horizon not observed.

Soils Data

Site No. 68 Location 44.35.20-107.35.10			Elevation 2012
Dominant vegetation		% total ground cover	% good ground cover
Parent material		Formation name for underlying bedrock	
% surface covered by bedrock		Landform	
Slope angle	Aspect	Erosion Class	Precip.
Drainage class		Depth to H_2O table (est.) seasonal year around	
Depth to bedrock rippable non-rippable			

Profile description

Hori-zon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments Grab sample in slide material, shows glauconitic shales and sandstones, small lingulas.

Soils Data

Site No. 69 Location 44.34.53-107.37.50		Elevation 1646	
Dominant vegetation junipers, and Douglas fir		% total ground cover 100	% good ground cover 80
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform talus cone	
Slope angle 52	Aspect N20E	Erosion Class class 0	Precip. 38 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_2	-2.6					ds mvfr	wso wpo	7-	as
O_1	-1.3					ds mvfr	wso wpo	7-	as
A_2	7.7	10YR4/3	10YR3/3	acsil	m2pl	dsh mfr	wss wps	7-	as
B	28	10YR5/4	10YR4/4	acsil	m2abk	dsh mfr	wss wps	7+	as
C_{Ca}	101.6+	10YR8/3	10YR8/3	acsil	m	dsh mfr	wss wps	7+	

Comments A_2 horizon, contains 10% (est.) angular gravel to cobble size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. B horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. C_{Ca} horizon, contains 80% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous, lighter color is due to a build up of $CaCO_3$.

Soils Data

Site No. 70 Location 44.34.54-107.37.49	Elevation 1951
Dominant vegetation: grass, forbs, and junipers	% total ground cover 100; % good ground cover 100
Parent material: loamy carbonate colluvium	Formation name for underlying bedrock: Gallatin
% surface covered by bedrock: 0	Landform: colluvial backfill on landslide (slump)
Slope angle 3; Aspect N30W	Erosion Class: class 0; Precip. 38 cm.
Drainage class: well-drained	Depth to H_2O table (est.): seasonal 1.5 +; year around 1.5 +
Depth to bedrock: rippable 1.5 +; non-rippable 1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	5	10YR4/2	10YR3/2	si	f1gr	ds mvfr	wso wpo	7-	as
B	25.6	10YR3/3	10YR3/2	si	m2abk	dsh mfr	wss wps	7+	as
C	101.6+	10YR4/2	10YR3/2	si	m	dsh mfr	wss wps	7+	

Comments B horizon, poorly developed clay skins (10YR4/2), weakly calcareous.

Soils Data

Site No. 71 Location 44.34.55-107.37.49		Elevation 1981	
Dominant vegetation grass, and sage	% total ground cover 50	% good ground cover 30	
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin		
% surface covered by bedrock 0	Landform ridgecrest on landslide (slump)		
Slope angle 8	Aspect N30W	Erosion Class class 0	Precip. 38 cm
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	5	10YR4/3	10YR3/3	acsi	m1fr	ds mvfr	wso wpo	7-	as
B	18	10YR4/3	10YR3/3	acsi	m2abk	dsh mfr	wss wps	7+	gs
C_{Ca}	20	10YR8/3	10YR8/3	acsi	m	dsh mfr	wss wps	7+	as
C	101.6+	10YR6/4	10YR5/4	acsi	m	dsh mfr	wss wps	7+	

Comments A horizon, contains less than 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. B horizon, contains less than 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. C_{Ca} horizon, contains less than 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous, lighter color is dueto a build up of $CaCO_3$. C horizon, contains less than 10% (est.) angular gravel to boulder size fragments of carbonate rock from theGallatin, Bighorn, and Madison Formations, strongly calcareous. This is the sight of an

Soils Data				
Site No. 71 Location			Elevation	
Dominant vegetation		% total ground cover		% good ground cover
Parent material		Formation name for underlying bedrock		
% surface covered by bedrock		Landform		
Slope angle	Aspect	Erosion Class	Precip.	
Drainage class		Depth to H_2O table (est.) seasonal year around		
Depth to bedrock rippable non-rippable				

Profile description

Hori-zon	Depth	Color dry moist	Texture	Structure	Consistency dry wet	pH	Boundary

Comments old forest fire, prefire vegetation was conifer (Douglas fir???).

Soils Data

Site No. 72 Location 44.34.50-107.37.45		Elevation 1890	
Dominant vegetation grass, and sage		% total ground cover 90	% good ground cover 80
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform sideslope on landslide (slump)	
Slope angle 8	Aspect N22E	Erosion Class class 2	Precip. 38 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	7.7	10YR3/3	10YR2/2	acsi	m1cr	ds mvfr	wso wpo	7-	gs
B	46	10YR4/3	10YR3/3	acsi	m2abk	dsh mfr	wss wps	7+	gs
C	101.6+	10YR5/4	10YR4/4	acsil	m	dsh mfr	wss wps	7+	

Comments A horizon, contains less than 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. B horizon, contains 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, slightly calcareous. C horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, strongly calcareous. This is the sight of an old forest fire, pre-fire vegetation was conifer (Douglas fir???), this would explain the lack of a C_{Ca} horizon.

Soils Data

Site No. 73 Location 44.35.00-107.35.20		Elevation 1981	
Dominant vegetation		% total ground cover	% good ground cover
Parent material		Formation name for underlying bedrock	
% surface covered by bedrock		Landform	
Slope angle	Aspect	Erosion Class	Precip.
Drainage class		Depth to H_2O table (est.) seasonal year around	
Depth to bedrock rippable non-rippable			

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments Grab sample of glauconitic shales.

Soils Data

Site No. 74 Location 44.34.58-107.33.45		Elevation 2012
Dominant vegetation grass, juniper, and Douglas fir	% total ground cover 70	% good ground cover 60
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0	Landform sideslope on landslide (slump)	
Slope angle 60 / Aspect N40W	Erosion Class class 1	Precip. 38 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 + / non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	12.8	10YR4/3	10YR3/3	acsl	f1gr	ds mvfr	wso wpo	7+	gs
B	53.8	10YR4/3	10YR3/3	acsl	m2abk	dsh mfr	wss wps	7+	as
C	101.6+	10YR5/4	10YR4/4	acsl	m	dsh nfr	wss wps	7+	

Comments A horizon, contains less than 10% (est.) angular gravel to cobble size fragments of carbonate and sandstone rock from the Gallatin, and Bighorn Formations, slightly calcareous. B horizon, contains less than 10% (est.) angular gravel to cobble size fragments of carbonate and sandstone rock from the Gallatin, and Bighorn Formations, slightly calcareous. C horizon, contains 10% (est.) angular gravel to cobble size fragments of carbonate and sandstone rock from the Gallatin, and Bighorn Formations.

Soils Data

Site No. 75 Location 44.34.54-107.34.44	Elevation 1963
Dominant vegetation juniper, gooseberry, and Doug. fir	% total ground cover 80 / % good ground cover 80
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin
% surface covered by bedrock 0	Landform sideslope on landslide (slump)
Slope angle 8 / Aspect N10W	Erosion Class class 4 / Precip. 38 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 + / year around 1.5 +
Depth to bedrock rippable 1.5 + / non-rippable 1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_2	-2.6					ds mvfr	wso wpo	7-	as
O_1	-1.3					ds mvfr	wso wpo	7-	as
A_2	7.7	10YR3/2	10YR3/2	acsi	m2pl	dsh mfr	wss wps	7+	as
B	20.5	10YR3/3	10YR3/2	acsi	m2abk	dsh mfr	wss wps	7+	as
C_{Ca}	69.1	10YR7/3	10YR7/3	acsi	m	dsh mfr	wss wps	7+	as
C	101.6+	10YR7/4	10YR6/4	acsi	m	dsh mfr	wss wps	7+	

Comments A_2 horizon, contains less than 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, slightly calcareous. B horizon, contains less that 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. C_{Ca} horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous, lighter color is due to a build up of $CaCO_3$. C horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, strongly calcareous.

Soils Data

Site No. 76 Location 44.34.15-107.36.40		Elevation 1920
Dominant vegetation grass, sage, and Douglas fir	% total ground cover 100	% good ground cover 90
Parent material weathered shale	Formation name for underlying bedrock Gros Ventre	
% surface covered by bedrock 0	Landform sideslope	
Slope angle 35	Aspect N30E	Erosion Class class 0	Precip. 38 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 0.13	non-rippable 1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	3.8	10YR5/3	10YR4/3	sil	f1gr	ds mvfr	wso wpo	7-	as
B	10.2	10YR4/3	10YR3/3	sil	m2abk	dsh mfr	wss wps	7-	as
C	12.8	10YR4/3	10YR3/3	sil	m	dsh mfr	wss wps	7-	as
R	12.8+	2.5Y6/2		sil				7-	

Comments Horizon thickness variable, C absent at times.

Soils Data

Site No. 77 Location 44.34.10-107.36.45		Elevation 1981	
Dominant vegetation grass, forbs, and Douglas fir	% total ground cover 100	% good ground cover 100	
Parent material weathered shale	Formation name for underlying bedrock Gros Ventre		
% surface covered by bedrock 0	Landform sideslope		
Slope angle 60	Aspect N20E	Erosion Class class 0	Precip. 38 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +	
Depth to bedrock ~~rippable~~ 0.46	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_2	-2.6					ds mvfr	wso wpo	7-	as
O_1	-1.3					ds mvfr	wso wpo	7-	as
A_2	5.0	10YR3/2	10YR2/2	l	m1pl	dsh mfr	wss wps	7-	as
B	30.5	10YR4/4	10YR3/3	sil	m2abk	dsh mfr	wss wps	7-	as
C	46	10YR4/4	10YR3/3	sil	m	dsh mfr	wss wps	7-	as
R	46+	2.5Y4/4		sil	m	ds mfi	ws wp	7-	

Comments

Soils Data

Site No. 78 Location 44.35.00-107.36.48 | Elevation 2024

Dominant vegetation: grass, gooseberries, and Doug. fir | % total ground cover 100 | % good ground cover 85

Parent material: loamy carbonate colluvium | Formation name for underlying bedrock: Gallatin

% surface covered by bedrock: 0 | Landform: sideslope on landslide (slump)

Slope angle: 55 | Aspect: N10E | Erosion Class: class 1 | Precip. 38 cm.

Drainage class: well-drained

Depth to bedrock		Depth to H_2O table (est.)	
rippable	non-rippable	seasonal	year around
1.5 +	1.5 +	1.5 +	1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_2	-5.1					ds mvfr	wso wpo	7-	as
O_1	-2.6					ds mvfr	wso wpo	7-	as
A_2	5.1	10YR3/3	10YR3/2	acsi	f1pl	ds mvfr	wso wpo	7+	gs
B_2	20.5	10YR4/3	10YR3/3	acsi	m2abk	dsh mfr	wss wps	7+	gs
B_3	35.8	2.5Y6/2	2.5Y5/2	acsi	f1abk	ds mvfr	wso wpo	7+	cs
C_{Ca}	101.6+	5Y7/2	5Y6/2	acsil	m	ds mvfr	wso wpo	7+	

Comments A_2 horizon, contains 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, slightly calcareous. B_2 horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, strongly calcareous. B_3 horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. C_{Ca} horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, lighter color is due to a build up of $CaCO_3$, highly calcareous.

Soils Data

Site No. 79 Location 44.34.35-107.36.48	Elevation 2146
Dominant vegetation Douglas fir	% total ground cover 94 / % good ground cover 75
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin
% surface covered by bedrock 0	Landform sideslope on landslide (slump)
Slope angle 12 / Aspect N50W	Erosion Class class 0 / Precip. 38 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 + / year around 1.5 +
Depth to bedrock rippable 1.5 + / non-rippable 1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_2	-5.1					ds mvfr	wso wpo	7-	as
O_1	-2.6					ds mvfr	wso wpo	7-	as
A_2	5.1	7.5YR3/2	7.5YR3/2	acsi	m2pl	dsh mfr	wss wps	7-	as
B	33.3	10YR3/3	10YR2/2	acsi	m2abk	dsh mfr	wss wps	7-	cs
C	101.6+	10YR6/4	10YR5/4	acsi	m	ds mvfr	wso wpo	7+	

Comments A_2 horizon, contains 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. B horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. C horizon, contains 60% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous.

Soils Data

Site No. 80 Location 44,34,70-107,37,00		Elevation 2131	
Dominant vegetation grass, sage, and Douglas fir	% total ground cover 100	% good ground cover 80	
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin		
% surface covered by bedrock 0	Landform sideslope on landslide (slump)		
Slope angle 10	Aspect N10E	Erosion Class class 1	Precip. 38 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +	
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	7.6	10YR3/3	10YR3/2	acsi	f2pl	dsh mfr	wss wps	7-	as
B	20.3	10YR4/3	10YR3/3	acsi	m3abk	dh mfi	ws wp	7+	cs
B_3	43.5	10YR6/4	10YR5/4	acsi	m3abk	dh mfi	ws wp	7+	as
C_{Ca}	101.6+	10YR7/2	10YR7/2	acsi	m	dh mfi	ws wp	7+	

Comments A horizon, contains less than 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. B horizon, discontinuous clay skins (10YR3/3), contains 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, slightly calcareous. B_3 horizon, contains 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. C_{Ca} horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, lighter color is due to a build up of $CaCO_3$, highly calc.

Soils Data

Site No. 81 Location 44.35.12-107.31.40	Elevation 1951	
Dominant vegetation grass, sage, and Douglas fir	% total ground cover 50	% good ground cover 35
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0	Landform sideslope on landslide (slump)	

Slope angle 50	Aspect N70W	Erosion Class class 1	Precip. 38 cm.

Drainage class well-drained		Depth to H_2O table (est.)	
Depth to bedrock		seasonal	year around
rippable	non-rippable		
1.5 +	1.5 +	1.5 +	1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	7.6	10YR5/4	10YR4/4	acsi	m1cr	ds mvfr	wso wpo	7+	as
B	17.8	10YR3/4	10YR3/3	acsi	m2abk	dsh mfr	wss wps	7+	gs
C_{Ca}	66.6	10YR7/3	10YR7/3	acsi	m	dsh mfr	wss wps	7+	as
C	101.6+	10YR6/3	10YR5/3	acsi	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, slightly calcareous all the way to the ground surface. B horizon, contains 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. C_{Ca} horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Fromations, also contains less than 10% (est.) green shale fragments (1.5 cm. and smaller) from the Gallatin, and Gros Ventre Fromations, lighter color is due to a build up of $CaCO_3$, highly calcareous. C horizon, contains 70% (est.) angular gravel

Soils Data								
Site No. 81 Location						Elevation		
Dominant vegetation			% total ground cover			% good ground cover		
Parent material			Formation name for underlying bedrock					
% surface covered by bedrock			Landform					
Slope angle	Aspect		Erosion Class		Precip.			
Drainage class			Depth to H_2O table (est.) seasonal year around					
Depth to bedrock rippable non-rippable								

Profile description										
Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, also contains less than 10% (est.) green shale fragments (1.5 cm. and smaller) from the Gallatin, and Gros Ventre Formations, highly calcareous.

Soils Data

Site No. 82 Location 44.35.13-107.35.07		Elevation 1981	
Dominant vegetation grass, sage, and Douglas fir		% total ground cover 100	% good ground cover 90
Parent material carbonate alluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform alluvial fan	
Slope angle 12	Aspect N30E	Erosion Class class 0	Precip. 38 cm.
Drainage class moderately well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	15.2	10YR3/3	10YR3/2	si	m2gr	dsh mfr	wss wps	7-	as
B	33.0	10YR3/3	10YR3/2	si	m2abk	dsh mfr	wss wps	7-	as
B_3	40.1	10YR5/4	10YR4/4	sil	m3abk	ds mfi	ws wp	7-	as
C	101.6+	10YR5/4	10YR4/4	sil	m	dsh mfr	wss wps	7+	

Comments B_3 horizon, mottled (c2d 10YR2/2). C horizon, contains 50% (est.) angular gravel to cobble size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations slightly calcareous.

Soils Data

Site No. 83 Location 44.35.15-107.36.46			Elevation 1902
Dominant vegetation	% total ground cover		% good ground cover
Parent material	Formation name for underlying bedrock		
% surface covered by bedrock	Landform		
Slope angle / Aspect	Erosion Class	Precip.	
Drainage class	Depth to H_2O table (est.) seasonal / year around		
Depth to bedrock rippable / non-rippable			

Profile description

Hori-zon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments Grab sample of Gros Ventre shale, south side of Shell Falls turnout.

Soils Data

Site No. 84 Location NE26,53N89W		Elevation 2427	
Dominant vegetation Douglas fir		% total ground cover 100	% good ground cover 90
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform colluvial backfill area on landslide (slump)	
Slope angle 3	Aspect NOW	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class moderately well drained		Depth to H_2O table (est.)	
Depth to bedrock		seasonal	year around
rippable 1.5 +	non-rippable 1.5 +	0.5	1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A_2	17.8	7.5YRN2/0	7.5YRN2/0	sic	m1pl	ds mvfr	wso wpo	7-	ai
B	101.6+	10YR3/3	10YR3/2	si	m1abk	ds mvfr	wso wpo	7+	

Comments A_2 horizon, very high in organic matter. B horizon, mottled (c2d 10YR3/2), slightly calcareous, contains an occasional fragments (1.5 cm.) of charcoal.

Soils Data

Site No. 85 Location NW19.53N89W		Elevation 2377	
Dominant vegetation: grass, sage, and forbs		% total ground cover 90	% good ground cover 75
Parent material: loamy carbonate and shale colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform: sideslope on landslide (debris slide)	
Slope angle 35	Aspect N50W	Erosion Class class 1	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	15.4	10YR3/3	10YR3/2	acsil	m2cr	dsh mfr	wss wps	7+	gs
B	46.1	10YR4/3	10YR3/3	acsi	m3abk	dh mfi	ws wp	7+	as
C	101.6+	10YR4/2	10YR3/2	acsil	m	dsh mfr	wss wps	7+	

Comments A horizon, contains 15% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, and Bighorn Formations, highly calcareous all the way to the ground surface. B horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, and Bighorn Formations, well-developed clay skins (10Yr3/2), highly calcareous. C horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, and Bighorn Formations, highly calcareous, contains inclusions, 20% (est.) 10 cm. in diamter, of A horizon material.

Soils Data

Site No. 86 Location NW19,53N89W | Elevation 2451

Dominant vegetation grass, sage, and forbs	% total ground cover 80	% good ground cover 60
Parent material loamy carbonate and shale colluvium	Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0	Landform ridgecrest on landslide (debris slide)	
Slope angle 3 / Aspect NOW	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained	Depth to H_2O table (est.)	
Depth to bedrock: rippable 1.5 + / non-rippable 1.5 +	seasonal 1.5 +	year around 1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	6.1	10YR3/3	10YR3/2	acsi	f2cr	dsh mfr	wss wps	7+	gs
B	14	10YR3/3	10YR3/2	acsi	f2abk	dsh mfr	wss wps	7+	as
C	101.6+	10YR5/4	10YR4/4	acsi	m	dsh mfr	wss wps	7+	

Comments A horizon, contains less than 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, and Bighorn Formations, slightly calcareous all the way to the ground surface. B horizon, contains 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, and Bighorn Formations, slightly calcareous. C horizon, contains 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, and Bighorn Formations, highly calcareous.

Soils Data

Site No. 87 Location SE19,53N89W		Elevation 2327	
Dominant vegetation grass, sage, and forbs	% total ground cover 100	% good ground cover 80	
Parent material loamy carbonate and shale colluvium	Formation name for underlying bedrock Precambrian		
% surface covered by bedrock 0	Landform floodplain		
Slope angle 5	Aspect S20W	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class somewhat poorly drained		Depth to H_2O table (est.) seasonal 0.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	10.2	10YR2/1	10YR2/1	l	m3cr	dh mfi	ws wp	7-	gs
B	74.2	10YR2/2	10YR2/2	sil	c3abk	dh mfi	ws wp	7+	gs
C	101.6+	10YR5/4	10YR4/4	si	m	dsh mfr	wss wps	7+	

Comments B horizon, slightly calcareous. C horizon, slightly calcareous, mottled (c2d 5Y4/2), contains 10% (est.) deeply weathered gravel size fragments of carbonate rock from the Gallatin, and Bighorn Formations. Profile as a whole is well-differentiated.

Soils Data

Site No. 88 Location NW31.53N89W			Elevation 2637
Dominant vegetation grass, sage, and forbs		% total ground cover 90	% good ground cover 80
Parent material sandy glacial outwash		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform saddle	
Slope angle 7	Aspect N20E	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A_1	5.1	10YR3/2	10YR3/2	si	m2cr	dsh mfr	wss wps	7+	gs
A_2	10.4	10YR3/2	10YR3/2	sil	m2pl	dsh mfr	wss wps	7+	gi
B	40.9	7.5YR4/4	7.5YR3/2	cl	f3abk	dh mfi	ws wp	7+	cs
C_I	61.4	10YR5/6	10YR5/4	fgs	m	dl ml	wso wpo	7+	as
C_{II}	69	10YR5/4	10YR5/4	csl	m2abk	dsh mfr	wss wps	7+	aw
C_{III}	122.9	10YR6/4	10YR6/4	gs	m	dl ml	wso wpo	7+	as
C_{IV}	145.9	10YR6/3	10YR6/3	g	m	dl ml	wso wpo	7+	as
C_V	156.7	10YR6/3	10YR6/3	cl	f3abk	dh mfi	ws wp	7+	as

Comments A_1 horizon, slightly calcareous. A_2 horizon, contains less than 10% (est.) gravel size fragments of dolomite and chert from the Madison Formation, slightly calcareous. B horizon, well developed clay skins (5YR4/4), slightly calcareous, contains less that 10% (est.) rounded gravel size fragments of igneous and metamorphic rock. C_I horizon, slightly calcareous, contains an occasional crystal crystalline rock fragment. C_{II} horizon, contains less than 10% (est.) rounded gravel size fragments of igneous and metamorphic rock, well-developed clay skins??? (10YR4/3), slightly calcareous. C_{III} horizon, made up of cross bedded sands with inter-bedded lenses of gravel (5 cm thick), gravel consists of

Soils Data

Site No. 88 Location			Elevation
Dominant vegetation	% total ground cover		% good ground cover
Parent material	Formation name for underlying bedrock		
% surface covered by bedrock	Landform		
Slope angle / Aspect	Erosion Class	Precip.	
Drainage class	Depth to H_2O table (est.) seasonal year around		
Depth to bedrock rippable non-ripplable			

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
C_{VI}	213.4+	10YR6/3	10YR6/3	s	m	dl ml	wso wpo	7+	

Comments fragments of igneous and metamorphic rock, moderately calcareous. C_{IV} horizon, gravel consists of deeply weathered igneous and metamorphic rock fragments (rounded to subrounded), some rock fragments have weathered to gruss, highly calcareous. C_V horizon, slightly calcareous. C_{VI} horizon, slightly calcareous.

Soils Data

Site No. 90 Location 44.35.30-107.32.15		Elevation 2499	
Dominant vegetation grass, sage, and forbs	% total ground cover 100		% good ground cover 80
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gros Ventre		
% surface covered by bedrock 0	Landform sideslope on landslide (debris slide)		
Slope angle 45	Aspect N90E	Erosion Class class 1	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Hori-zon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
Z	53.8	10YR4/1	10YR3/1	acsic	m	dsh mfr	wss wps	7+	ai
A	61.4	10YR3/2	10Yr3/2	sic	m1cr	ds mvfr	wso wpo	7+	gs
B	112.6	10YR3/3	10YR3/2	acsil	m2abk	dsh mfr	wss wps	7+	as
C	112.6+	10YR3/4	10YR3/3	acsl	m	ds mvfr	wso wpo	7+	

Comments Z horizon, this is a recent debris slide, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn and Madison Formations. B horizon, discontinuous clay skins (10YR2/2), contains less than 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. C horizon, contains 60% (est.) angular gravel to boulder size fragments of carbonate and sandstone rock from the Gros Ventre, Gallatin, Bighorn, and Madison Formations, slightly calcareous.

Soils Data

Site No. 91 Location 44.36.15-107.32.34		Elevation 2591	
Dominant vegetation grass, and Douglas fir		% total ground cover 100	% good ground cover 90
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform colluvial backfill on landslide (slump)	
Slope angle 0	Aspect NOW	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_2	-5.1					ds mvfr	wso wpo	7-	as
O_1	-2.6					ds mvfr	wso wpo	7-	as
A_2	2.6	5YR4/6	5YR3/4	si	f2pl	dsh mfr	wss wps	7-	as
B	40.1	5YR3/4	5YR3/3	sic	m1abk	ds mvfr	wss wpo	7-	gs
C	101.6+	10YR3/4	10YR3/3	sic	m	ds mvfr	wss wpo	7-	

Comments B horizon, clay skins (5YR3/3). C horizon, contains less that 1% (est.) rounded deeply weathered carbonate pebbles from the Gallatin, Bighorn, and Madison Formations.

Soils Data

Site No. 92 Location 44.36.06-107.32.40		Elevation 2591	
Dominant vegetation: grass, sage, and forbs	% total ground cover 90		% good ground cover 70
Parent material: loamy carbonate colluvium	Formation name for underlying bedrock: Gallatin		
% surface covered by bedrock: 0	Landform: sideslope on landslide (slump)		
Slope angle 8	Aspect N90E	Erosion Class: class 0	Precip. greater than 50 cm.
Drainage class: well-drained		Depth to H_2O table (est.)	
Depth to bedrock		seasonal	year around
rippable 1.5 +	non-rippable 1.5 +	1.5 +	1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	5.1	10YR3/3	10YR3/2	si	f1cr	ds mvfr	wso wpo	7-	as
B_1	17.9	10YR3/3	10YR3/2	si	m2abk	dsh mfr	wss wps	7+	gs
B	33.3	5YR4/6	5YR4/4	acsi	m	dsh mfr	wss wps	7+	

Comments B_1 horizon, clay skins (10YR2/2), slightly calcareous. B horizon, well-developed clay skins (5YR3/3), slightly calcareous. C horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations.

Soils Data

Site No. 93 Location 44.35.30-107.37.45		Elevation 1920
Dominant vegetation	% total ground cover	% good ground cover
Parent material	Formation name for underlying bedrock	
% surface covered by bedrock	Landform	
Slope angle / Aspect	Erosion Class / Precip.	
Drainage class	Depth to H_2O table (est.) seasonal / year around	
Depth to bedrock: rippable / non-rippable		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments Crystalline eratics, pink and white granites, some mafics (15% est.). Generally less than 0.6 meters in diameter and well rounded. Seem to be in line trending roughly N-S, from about 15 meters below the road to 90 meters above the road.

Soils Data

Site No. 94 Location 44.35.45-107.38.10		Elevation 1920	
Dominant vegetation: grass, sage, and forbs	% total ground cover 60		% good ground cover 50
Parent material: loamy carbonate colluvium	Formation name for underlying bedrock Gallatin		
% surface covered by bedrock 0	Landform sideslope on landslide (slump)		
Slope angle 0	Aspect S30E	Erosion Class class 1	Precip. less than 38 cm.
Drainage class somewhat excessively drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +	
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	5	10YR5/4	10YR4/4	acsil	f1cr	ds mvfr	wso wpo	7+	as
B	17.9	10YR5/4	10YR4/4	acsil	m3abk	dh mfi	ws wp	7+	gs
C_{Ca}	74.2	10YR7/4	10YR7/4	acsil	m	dsh mfr	wss wps	7+	cs
C	101.6+	10YR7/6	10YR6/6	acsil	m	dsh mfr	wss wps	7+	

Comments A horizon, contains 15% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous all the way to the ground surface. B horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. C_{Ca} horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, lighter color is due to a build up of $CaCO_3$, highly calcareous. C horizon, contains 60% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations,

Soils Data

Site No. 94 Location			Elevation
Dominant vegetation		% total ground cover	% good ground cover
Parent material		Formation name for underlying bedrock	
% surface covered by bedrock		Landform	
Slope angle	Aspect	Erosion Class	Precip.
Drainage class		Depth to H_2O table (est.) seasonal year around	
Depth to bedrock rippable non-rippable			

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments highly calcareous.

Soils Data

Site No. 95 Location 44.35.50-107.37.51		Elevation 1926	
Dominant vegetation grass, sage, and junipers		% total ground cover 50	% good ground cover 50
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform sideslope on landslide (slump)	
Slope angle 11	Aspect S35E	Erosion Class class 1	Precip. less than 38 cm.
Drainage class somewhat excessively drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	5	10YR5/3	10YR4/3	acsil	m-f1cr	ds mvfr	wso wpo	7+	as
B	22.9	10YR5/3	10YR4/3	acsil	m2abk	dsh mfr	wss wps	7+	cs
C_{Ca}	40.9	10YR8/4	10YR8/4	acsil	m	dsh mfr	wss wps	7+	cs
C	101.6+	5Y4/4	5Y4/3	acsil	m	dsh mfr	wss wps	7+	

Comments A horizon, contains 15% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous all the way to the ground surface. B horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. C_{Ca} horizon, contains 30% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, lighter color is due to a build up of $CaCO_3$, highly calcareous. C horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations,

Soils Data

Site No. 95 Location		Elevation	
Dominant vegetation	% total ground cover	% good ground cover	
Parent material	Formation name for underlying bedrock		
% surface covered by bedrock	Landform		
Slope angle	Aspect	Erosion Class	Precip.
Drainage class		Depth to H_2O table (est.) seasonal year around	
Depth to bedrock rippable non-rippable			

Profile description

Hori-zon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments highly calcareous.

Soils Data

Site No. 96 Location 44.35.51-107.35.10		Elevation 1926
Dominant vegetation Douglas fir	% total ground cover 90	% good ground cover 90
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0	Landform sideslope on landslide (slump)	
Slope angle 22 / Aspect S65W	Erosion Class class 1	Precip. less than 38 cm.
Drainage class somewhat excessively drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 + / non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
O_2	-5.1					ds mvfr	wso wpo	7-	as
O_1	-2.6					ds mvfr	wso wpo	7-	as
A_2	5.1	10YR5/4	10YR4/4	acsi	m-f2pl	dsh mfr	wss wps	7+	cs
B	15.4	5Y3/2	5Y3/2	acsi	f2abk	dsh mfr	wss wps	7+	as
C	101.6+	10YR5/4	10YR4/4	acsil	m	ds mvfr	wso wpo	7+	

Comments A_2 horizon, contains less than 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. B horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, moderately calcareous. C horizon, contains 70% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous.

Soils Data									
Site No. 97 Location 44.33.50-107.32.15						Elevation 2316			
Dominant vegetation				% total ground cover			% good ground cover		
Parent material				Formation name for underlying bedrock					
% surface covered by bedrock				Landform					
Slope angle		Aspect		Erosion Class		Precip.			
Drainage class				Depth to H_2O table (est.) seasonal year around					
Depth to bedrock rippable non-rippable									
Profile description									
Hori-zon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments Grab sample, landslide material

Soils Data

Site No. 98 Location 44.34.10-107.33.45		Elevation 2134	
Dominant vegetation		% total ground cover	% good ground cover
Parent material		Formation name for underlying bedrock	
% surface covered by bedrock		Landform	
Slope angle	Aspect	Erosion Class	Precip.
Drainage class		Depth to H_2O table (est.) seasonal year around	
Depth to bedrock rippable non-rippable			

Profile description

Hori-zon	Depth	Color dry moist	Texture	Structure	Consistency dry wet	pH	Boundary

Comments Grab sample, landslide material.

Soils Data

Site No. 99 Location NE26,48N87W		Elevation 2036	
Dominant vegetation grass, sage, and forbs	% total ground cover 70		% good ground cover 50
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin		
% surface covered by bedrock 0	Landform sideslope on landslide (slump)		
Slope angle 39	Aspect NOE	Erosion Class class 1	Precip. 38 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Hori-zon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	17.8	10YR3/3	10YR3/2	acsil	m1gr	ds mvfr	wso wpo	7+	gs
B_1	33	10YR3/3	10YR3/2	acsil	m1abk	ds mvfr	wso wpo	7+	gs
B_2	58.4	10YR4/3	10YR3/3	acsil	m2abk	dsh mfr	wss wps	7+	gs
C	101.6+	10YR5/3	10YR4/3	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains less than 10% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, slightly calcareous all the way to the surface. B_1 horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, moderately calcareous. B_2 horizon, contains 25% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, strongly calcareous. C horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn and Madison Formations, strongly calcareous.

Soils Data

Site No. 101 Location NE13.48N87W		Elevation 2286	
Dominant vegetation grass, sage, and forbs		% total ground cover 70	% good ground cover 50
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform talus cone	
Slope angle 16	Aspect NOE	Erosion Class class 1	Precip. 38 cm.
Drainage class well-drained		Depth to H_2O table (est.)	
Depth to bedrock		seasonal	year around
rippable 1.5 +	non-rippable 1.5 +	1.5 +	1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	25.4	10YR3/3	10YR3/2	acsil	m1gr	ds mvfr	wso wpo	7+	as
B	42.3	10YR5/3	10YR4/3	acsil	m2abk	dsh mfr	wss wps	7+	as
C	101.6+	10YR5/3	10YR4/3	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 25% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. B horizon, contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. C horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations.

Soils Data

Site No. 102 Location NE26,48N87W			Elevation 1978
Dominant vegetation grass, and sage	% total ground cover 50		% good ground cover 30
Parent material glacial outwash ?	Formation name for underlying bedrock		
% surface covered by bedrock 0	Landform sideslope on landslide (slump)		
Slope angle 3 / Aspect N45W	Erosion Class class 1		Precip. 38 cm.
Drainage class well-drained	Depth to H_2O table (est.)		
Depth to bedrock: rippable 1.5 + / non-rippable 1.5 +	seasonal 1.5 +		year around 1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	12.7	10YR4/3	10YR3/3	l	m1cr	ds mvfr	wso wpo	7+	gs
B	30.5	10YR4/3	10YR3/3	sl	m1abk	ds mvfr	wso wpo	7+	gs
C	35.6	10YR5/4	10YR4/3	gsl	m	ds mvfr	wso wpo	7+	gs
C_{Ca}	101.6+	10YR8/3	10YR8/3	gsl	m	ds mvfr	wso wpo	7+	

Comments A horizon, weakly calcareous all the way to the ground surface. B horizon, weakly calcareous. C horizon, contains 30% (est.) rounded igneous and metamorphic cobbles and boulders, 75% or greater which have decayed to gruss, slightly calcareous. C_{Ca} horizon, contains 30% (est.) rounded igneous and metamorphic cobbles and boulders, 75% or greater of which have decayed to gruss, highly calcareous.

Soils Data

Site No. 103 Location NW26,48N87W		Elevation 1859	
Dominant vegetation: grass, sage, and juniper	% total ground cover 70	% good ground cover 50	
Parent material: loamy carbonate colluvium	Formation name for underlying bedrock Gallatin		
% surface covered by bedrock 0	Landform sideslope on landslide (slump)		
Slope angle 8	Aspect N80W	Erosion Class class 1	Precip. 38 cm.
Drainage class well-drained	Depth to H_2O table (est.)		
Depth to bedrock: rippable 1.5 +; non-rippable 1.5 +	seasonal 1.5 +	year around 1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	5	10YR3/3	10YR3/2	si	m2cr	dsh mfr	wss wps	7-	gs
B	55.9	10YR3/4	10YR3/3	acsi	m2abk	dsh mfr	wss wps	7+	as
C	101.6+	10YR4/3	10YR3/3	acsi	m	dsh mfr	wss wps	7+	

Comments B horizon, contains 30% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, very slightly calcareous. C horizon, contains 80% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous.

Soils Data

Site No. 104 Location NW25.48N87W			Elevation 1951	
Dominant vegetation grass, and sage	% total ground cover 60		% good ground cover 40	
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin			
% surface covered by bedrock 0	Landform sideslope on landslide (slump)			
Slope angle 33	Aspect N40E	Erosion Class class 1	Precip. 38 cm.	
Drainage class well-drained		Depth to H_2O table (est.)		
Depth to bedrock		seasonal	year around	
rippable 1.5 +	non-rippable 1.5 +	1.5 +	1.5 +	

Profile description

Hori-zon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	27.9	5YR3/3	5YR3/2	acsil	micr	ds mvfr	wso wpo	7+	as
C	101.6+	5YR3/4	5YR3/3	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, slightly calcareous all the way to the ground surface. C horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous.

Soils Data

Site No. 105 Location NE24,48N87W			Elevation 2103
Dominant vegetation grass, sage, and juniper	% total ground cover 90		% good ground cover 70
Parent material glacial outwash ???	Formation name for underlying bedrock ridgecrest		
% surface covered by bedrock 0	Landform ridgecrest		
Slope angle 3	Aspect N40W	Erosion Class class 0	Precip. 38 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	5	10YR3/3	10YR3/2	scl	f1cr	ds mvfr	wso wpo	7-	gs
B	22.9	10YR3/4	10YR3/3	scl	m2abk	dsh mfr	wss wps	7-	gs
B_3	33	10YR4/3	10YR3/3	scl	m2abk	dsh mfr	wss wps	7-	gs
C	101.6+	10YR5/4	10YR4/3	scl	m	ds mvfr	wso wpo	7-	

Comments A horizon, contains 20% (est.) rounded igneous and metamorphic cobbles and boulders. B horizon, contains 40% (est.) rounded igneous and metamorphic cobbles and boulders, less than 10% (est.) have decayed to gruss. C horizon, contains 50% (est.) rounded igneous and metamorphic cobbles and boulders, less than 10% (est.) have decayed to gruss.

Soils Data

Site No. 106 Location SW18,48N86W	Elevation 2207
Dominant vegetation grass, and sage	% total ground cover 90 ; % good ground cover 70
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin
% surface covered by bedrock 0	Landform ridgecrest on landslide (slump)
Slope angle 4 ; Aspect N90E	Erosion Class class 1 ; Precip. 38 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 + ; year around 1.5 +
Depth to bedrock rippable 1.5 + ; non-rippable 1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	6.4	10YR3/3	10YR3/2	csil	m1cr	ds mvfr	wso wpo	7-	cs
B	25.4	10YR3/4	10YR3/3	csil	m2abk	dsh mfr	wss wps	7+	cs
B_{Ca}	66	10YR5/4	10YR4/3	csl	m2abk	dsh mfr	wss wps	7+	cs
C_{Ca}	101.6+	10YR6/4	10YR5/3	csl	m	dsh mfr	wss wps	7+	

Comments A horizon, contains 40% (est.) rock fragments. 24% (est.) are rounded igneous and metamorphic cobbles and boulders, 16% (est.) are angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. B horizon, same as A horizon regarding rock fragment content, slightly calcareous. B_{Ca} horizon, contains 40% (est.) rock fragments. 24% (est.) are rounded igneous and metamorphic cobbles and boulders, 20% of these have decayed to gruss, The remaining igneous rocks have a well-developed carbonate coating 0.8 cm. thick. The remaining 16% of the rock fragments are angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations.

Soils Data

Site No.106 Location		Elevation	
Dominant vegetation	% total ground cover	% good ground cover	
Parent material	Formation name for underlying bedrock		
% surface covered by bedrock	Landform		
Slope angle	Aspect	Erosion Class	Precip.
Drainage class		Depth to H_2O table (est.) seasonal year around	
Depth to bedrock rippable non-rippable			

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments B_{Ca} horizon is highly calcareous. C_{Ca} horizon, same as B_{Ca} horizon regarding rock fragment content, also highly calcareous.

Soils Data

Site No. 107 Location SW24,48N87W		Elevation 2027	
Dominant vegetation grass, sage, and juniper	% total ground cover 80	% good ground cover 60	
Parent material glacial till	Formation name for underlying bedrock Gallatin		
% surface covered by bedrock 0	Landform lateral moraine		
Slope angle 0	Aspect NOW	Erosion Class class 0	Precip. 38 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +	
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	15.2	10YR4/3	10YR3/3	cl	m2cr	dsh mfr	wss wps	7-	gs
B	76.2	10YR4/4	10YR4/3	cl	m2abk	dsh mfr	wss wps	7-	gs
C	101.6+	10YR5/3	10YR4/3	csl	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 40% (est.) rounded igneous and metamorphic cobbles and boulders. B horizon, contains 50% (est.) rounded igneous and metamorphic cobbles and boulders. In the A and B horizon the cobbles and boulders are etched but few have decayed to gruss. C horizon, contains 50% (est.) rounded igneous and metamorphic cobbles and boulders. In the C horizon the cobbles and boulders are coated with carbonate ($CaCO_3$) to a thickness of 0.1 to 0.3 cm., 25% (est.) of the rock fragments have weathered to gruss.

Soils Data

Site No. 108 Location SE23.48N87W		Elevation 2057	
Dominant vegetation grass, and sage	% total ground cover 80	% good ground cover 60	
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform talus cone	
Slope angle 10	Aspect N90E	Erosion Class class 0	Precip. 38 cm.
Drainage class well-drained		Depth to H_2O table (est.)	
Depth to bedrock		seasonal	year around
rippable 1.5 +	non-rippable 1.5 +	1.5 +	1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	7.6	10YR3/3	10YR3/2	acsil	m1cr	ds mvfr	wso wpo	7+	gs
B	35.6	10YR5/4	10YR4/3	acsil	m2abk	dsh mfr	wss wps	7+	as
C_{Ca}	61	10YR7/4	10YR6/4	acsil	m	ds mvfr	wso wpo	7+	as
C	101.6+	10YR5/4	10YR4/4	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 30% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, slightly calcareous all the way to the ground surface. B horizon, contains 30% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. C_{Ca} horizon, contains 30% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, lighter color is due to a build up of $CaCO_3$, highly calcareous. C horizon, contains 30% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous.

Soils Data

Site No. 109 Location SW24,48N87W		Elevation 1975	
Dominant vegetation grass, and sage		% total ground cover 80	% good ground cover 60
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform talus cone	
Slope angle 12	Aspect N90E	Erosion Class class 0	Precip. 38 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	7.6	10YR4/3	10YR3/3	acsil	micr	ds mvfr	wso wpo	7+	gs
B	30.5	10YR6/3	10YR5/3	acsil	m1abk	ds mvfr	wso wpo	7+	as
C_{Ca}	61	10YR7/3	10YR7/3	acsil	m	ds mvfr	wso wpo	7+	gs
C	101.6+	10YR5/4	10YR4/4	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 30% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, slightly calcareous all the way to the ground surface. B horizon, contains 30% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. C_{Ca} horizon, contains 30% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, lighter color is due to a build up of $CaCO_3$, highly calcareous. C horizon, contains 30% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous.

Soils Data

Site No. 110 Location SW24.48N87W		Elevation 2018	
Dominant vegetation grass, and sage	% total ground cover 70		% good ground cover 60
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin		
% surface covered by bedrock 0	Landform talus cone		
Slope angle 9	Aspect N85W	Erosion Class class 0	Precip. 38 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	10.2	10YR3/3	10YR3/2	acsil	m2pl	dsh mfr	wss wps	7+	gs
B	27.9	10YR4/3	10YR3/3	acsil	m2abk	dsh mfr	wss wps	7+	gs
C_{Ca}	78.7	10YR7/3	10YR7/3	acsil	m	ds mvfr	wso wpo	7+	gs
C	101.6+	10YR5/3	10YR4/3	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, slightly calcareous all the way to the ground surface. B horizon, contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. C_{Ca} horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, lighter color is due to a build up of $CaCO_3$, highly calcareous. C horizon, contains 50% (est.) gravel to boulder size rock fragments. 45% (est.) of these are angular gravel to boulder size fragments of carbonate rock from the

Soils Data					
Site No. 110 Location				Elevation	
Dominant vegetation		% total ground cover		% good ground cover	
Parent material		Formation name for underlying bedrock			
% surface covered by bedrock		Landform			
Slope angle	Aspect	Erosion Class		Precip.	
Drainage class		Depth to H_2O table (est.) seasonal year around			
Depth to bedrock rippable non-rippable					

Profile description							
Hori-zon	Depth	Color dry moist	Texture	Structure	Consistency dry wet	pH	Boundary

Comments Gallatin, Bighorn, and Madison Formations, highly calcareous. The remaining 5% (est.) are rounded igneous and metamorphic boulders, highly calcareous.

Soils Data

Site No. 111 Location SE12,48N87W			Elevation 2271
Dominant vegetation grass, and sage		% total ground cover 70	% good ground cover 70
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform talus cone	
Slope angle 20	Aspect N7E	Erosion Class class 0	Precip. 38 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Hori-zon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	15.5	10YR3/3	10YR3/2	acsil	m1cr	ds mvfr	wso wpo	7-	cs
B	45.7	10YR3/3	10YR3/2	acsil	m2abk	dsh mfr	wss wps	7-	as
C	58.4	10YR4/3	10YR3/3	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. B horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. C horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. Pit discontinued at 58.4 cm. when large rock encountered.

Soils Data

Site No. 112 Location NE12,48N87W | Elevation 2365

Dominant vegetation: Douglas fir, and Engleman Spruce | % total ground cover 100 | % good ground cover 100

Parent material: loamy carbonate colluvium | Formation name for underlying bedrock: Gallatin

% surface covered by bedrock: 0 | Landform: talus cone

Slope angle: 10 | Aspect: N7E | Erosion Class: class 0 | Precip. 38 cm.

Drainage class: well-drained

Depth to bedrock — rippable: 1.5 + ; non-rippable: 1.5 +

Depth to H_2O table (est.) — seasonal: 1.5 + ; year around: 1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A_2	6.4	10YR2/2	10YR2/2	sil	m1pl	ds mvfr	wso wpo	7-	as
B	45.7	10YR3/2	10YR2/2	acsil	m1abk	ds mvfr	wso wpo	7-	

Comments B horizon, contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. At 45.7 discontinued pit when unable to dig through large boulders of Bighorn Dolomite.

Soils Data

Site No. 113 Location NE23.48N87W		Elevation 2304	
Dominant vegetation grass, and sage		% total ground cover 80	% good ground cover 60
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform talus cone	
Slope angle 19	Aspect N13E	Erosion Class class 0	Precip. 38 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	11.4	7.5YR3/2	7.5YR3/2	acsil	m1cr	ds mvfr	wso wpo	7-	gs
B	38.1	7.5YR3/2	7.5YR3/2	acsil	m1abk	ds mvfr	wso wpo	7-	gs
C	101.6+	10YR4/3	10YR3/3	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 25% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. B horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. C horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, slightly calcareous.

Soils Data

Site No. 114 Location SE23,53N89W		Elevation 2390	
Dominant vegetation grass, and sage	% total ground cover 90	% good ground cover 70	
Parent material glacial till	Formation name for underlying bedrock		
% surface covered by bedrock 0	Landform lateral moraine		
Slope angle 0	Aspect NOW	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	20.3	10YR3/2	10YR2/2	cl	m1gr	ds mvfr	wso wpo	7-	as
B	55.9	10YR5/4	10YR4/4	cscl	m2abk	dsh mfr	wss wps	7+	cs
C	101.6+	10YR6/6	10YR5/6	csl	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 30% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock. B horizon, contains 50% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock, very slightly calcareous. C horizon, contains 80% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock, slightly calcareous.

Soils Data

Site No. 115 Location NE23,53N89W		Elevation 2380	
Dominant vegetation grass, and sage	% total ground cover 90		% good ground cover 70
Parent material glacial till	Formation name for underlying bedrock		
% surface covered by bedrock 0	Landform lateral moraine		
Slope angle 3	Aspect N54W	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal	year around	
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +	1.5 +	1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	22.9	10YR3/2	10YR2/2	cl	m2gr	dsh mfr	wss wps	7-	as
B	33	10YR4/3	10YR3/3	cl	m-c2abk	dsh mfr	wss wps	7-	as
B_{Ca}	50.8	10YR4/4	10YR4/3	cl	m-c2abk	dsh mfr	wss wps	7+	as
C_1	76.2	2.5Y4/4	2.5Y4/2	cl	m	dsh mfr	wss wps	7+	gs
C_2	101.6+	5Y4/3	5Y4/2	cl	m	dsh mfr	wss wps	7+	

Comments A horizon, contains 15% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock. B horizon, contains 15% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock. In the A and B horizons the igneous and metamorphic rocks are etched and pitted but there is no gruss or carbonate coating on the rocks. B_{Ca} horizon, contains 30% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock, highly calcareous. C_1 horizon, contains 30% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock. C_2 horizon, contains 30% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock. In the B_{Ca} and C horizons

Soils Data

Site No. 115 Location		Elevation	
Dominant vegetation		% total ground cover	% good ground cover
Parent material		Formation name for underlying bedrock	
% surface covered by bedrock		Landform	
Slope angle	Aspect	Erosion Class	Precip.
Drainage class		Depth to H_2O table (est.) seasonal / year around	
Depth to bedrock rippable	non-rippable		

Profile description

Hori-zon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments approximately 20% of the igneous and metamorphic rocks are decayed into gruss, they also have a carbonate coating ($CaCO_3$) 0.3 cm. thick. C_1 and C_2 are highly calcareous. C_2 horizon is mottled (c2d 5Y7/3).

Soils Data

Site No. 116 Location SE23, 53N89W		Elevation 2329
Dominant vegetation grass, and sage	% total ground cover 90	% good ground cover 70
Parent material glacial till	Formation name for underlying bedrock	
% surface covered by bedrock 0	Landform lateral moraine	
Slope angle 4 / Aspect N65E	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal / year around	
Depth to bedrock rippable 1.5 + / non-rippable 1.5 +	1.5 + / 1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	20.3	10YR3/4	10YR3/3	csl	f2gr	dsh mfr	wss wps	7-	as
B	48.3	7.5YR5/4	7.5YR4/4	csl	c2abk	dsh mfr	wss wps	7-	as
C	101.6+	10YR6/4	10YR5/4	csl	m	ds mvfr	wso wpo	7-	

Comments A horizon, contains 30% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock. B horizon, contains 50% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock. C horizon, contains 60% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock.

Soils Data

Site No. 117 Location SE23, 53N89W			Elevation 2286
Dominant vegetation grass, and sage	% total ground cover 90		% good ground cover 70
Parent material glacial till	Formation name for underlying bedrock		
% surface covered by bedrock 0	Landform lateral moraine		
Slope angle 0	Aspect NOW	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.)	
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +	seasonal 1.5 +	year around 1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	12.7	10YR3/3	10YR3/2	cl	c2cr	dsh mfr	wss wps	7-	as
B	43.2	7.5YR4/4	7.5YR4/2	cl	m2abk	dsh mfr	wss wps	7-	as
C	101.6+	10YR6/3	10YR5/3	cl	m	dsh mfr	wss wps	7-	

Comments A horizon, contains 30% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock. B horizon, contains 50% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock. C horizon, contains 50% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock.

Soils Data

Site No. 118 Location SE23, 53N89W		Elevation 2301
Dominant vegetation grass, and sage	% total ground cover 90	% good ground cover 70
Parent material glacial till	Formation name for underlying bedrock	
% surface covered by bedrock 0	Landform lateral moraine	
Slope angle 0 / Aspect NOW	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 + / non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	17.8	10YR3/4	10YR3/3	cl	m2cr	dsh mfr	wss wps	7-	as
B	40.6	7.5YR4/4	7.5YR4/2	cl	m2abk	dsh mfr	wss wps	7-	as
C	101.6+	7.5YR6/4	7.5YR5/4	cl	m	dsh mfr	wss wps	7-	

Comments A horizon, contains 30% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock. B horizon, contains 50% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock. C horizon, contains 50% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock. C horizon contains cobbles that are etched and pitted but no gruss or carbonate coating on cobbles or boulders.

Soils Data

Site No. 119 Location SE19,53N90W	Elevation 1414
Dominant vegetation grass, sage, and prickly pear	% total ground cover 50 · % good ground cover 30
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gros Ventre
% surface covered by bedrock 0	Landform sideslope on landslide (slump)
Slope angle 0 · Aspect N40E	Erosion Class class 1 · Precip. 25 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 + · year around 1.5 +
Depth to bedrock rippable 1.5 + · non-rippable 1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
Z	-91.4	10YR7/4	10YR6/4	acsi	m	ds mvfr	wso wpo	7+	aw
A	20.3	7.5YR4/4	7.5YR4/2	acsi	c2abk	dsh mfr	wss wps	7+	as
B_1	39.4	10YR5/4	10YR4/4	acsi	c2abk	ds mvfr	wso wpo	7+	as
B_2	50.8	10YR6/4	10YR5/4	acsi	c2abk	ds mvfr	wso wpo	7+	as
A	58.4	7.5YR4/4	7.5YR4/2	acsi	m2abk	ds mvfr	wso wpo	7+	as
B	137.2	10YR6/4	10YR5/4	acsi	c2abk	ds mvfr	wso wpo	7+	

Comments Z horizon, contains 60% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. A horizon, contains 30% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. B_1 horizon, contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. B_2 horizon, contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. A horizon, contains 30% (est.) gravel to cobble size fragments of

Soils Data

Site No. 119 Location		Elevation	
Dominant vegetation		% total ground cover	% good ground cover
Parent material		Formation name for underlying bedrock	
% surface covered by bedrock		Landform	
Slope angle	Aspect	Erosion Class	Precip.
Drainage class		Depth to H_2O table (est.) seasonal	year around
Depth to bedrock rippable	non-rippable		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. B_2 horizon, contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous.

Soils Data

Site No. 120 Location SW12, 53N90W		Elevation 1554	
Dominant vegetation grass, sage, and forbs	% total ground cover 50	% good ground cover 30	
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gros Ventre		
% surface covered by bedrock 0	Landform ridgecrest on landslide (slump)		
Slope angle 0	Aspect NOW	Erosion Class class 0	Precip. 25 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	10.2	10YR5/3	10YR4/3	acsi	m1abk	ds mvfr	wso wpo	7+	gs
C_1	30.5	10YR7/4	10YR6/4	acsi	m	ds mvfr	wso wpo	7+	as
C_{Ca}	58.4	10YR8/2	10YR8/2	acsi	m	ds mvfr	wso wpo	7+	cs
C_2	101.6+	5YR6/4	5YR5/4	acsi	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous all the way to the ground surface. C_1 horizon, contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. C_{Ca} horizon, contains 30% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous, lighter color is due to a build up of $CaCO_3$. C_2 horizon, contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations,

Soils Data

Site No. 120 Location		Elevation	
Dominant vegetation		% total ground cover	% good ground cover
Parent material		Formation name for underlying bedrock	
% surface covered by bedrock		Landform	
Slope angle	Aspect	Erosion Class	Precip.
Drainage class		Depth to H_2O table (est.) seasonal year around	
Depth to bedrock rippable non-rippable			

Profile description

Hori-zon	Depth	Color dry moist	Texture	Structure	Consistency dry wet	pH	Boundary

Comments highly calcareous.

Soils Data

Site No. 121 Location NW15,54N90W		Elevation 1676	
Dominant vegetation grass, sage, and prickly pear		% total ground cover 50	% good ground cover 30
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform ridgecrest on landslide (slump)	
Slope angle 0	Aspect NOW	Erosion Class class 1	Precip. 25 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	8.9	10YR4/3	10YR3/3	acsi	flabk	ds mvfr	wso wpo	7+	cs
C	101.6+	7.5YR6/4	7.5YR5/4	acsi	m	ds mvfr	wso wpo	7+	

Comments A horizon, contains 30% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous all the way to the ground surface. C horizon, contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. Profile as a whole is only poorly devleoped.

Soils Data

Site No. 122 Location 44.34.40-107.40.10		Elevation 1859	
Dominant vegetation grass, sage, and scattered pine	% total ground cover 50		% good ground cover 50
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin		
% surface covered by bedrock 0	Landform ridgecrest		
Slope angle 0	Aspect NOE	Erosion Class class 1	Precip. greater than 25 cm.
Drainage class imperfectly drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +	
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	12.7	10YR4/3	10YR3/3	acsi	f1cr	ds mvfr	wso wpo	7+	as
C_1	27.9	10YR5/4	10YR4/4	acsi	m	ds mvfr	wso wpo	7+	as
C_{Ca}	35.6	10YR7/4	10YR6/4	acsil	m	dsh mfr	wss wps	7+	as
C_2	101.6+	5Y7/1	5Y6/1	ac	m	dh mfi	ws wp	7+	

Comments A horizon, contains 20% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous all the way to the ground surface. C_1 horizon, contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. C_{Ca} contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous, lighter color is due to a build up of $CaCO_3$. C_2 horizon, contains 75% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. Mottled, (m2p)

Soils Data				
Site No. 122 Location			Elevation	
Dominant vegetation		% total ground cover		% good ground cover
Parent material		Formation name for underlying bedrock		
% surface covered by bedrock		Landform		
Slope angle	Aspect	Erosion Class	Precip.	
Drainage class		Depth to H_2O table (est.) seasonal year around		
Depth to bedrock rippable non-rippable				

Profile description

Hori-zon	Depth	Color dry moist	Texture	Structure	Consistency dry wet	pH	Boundary

Comments (5G6/1) and (m2p 2.5YR3/4). I do not understand this, this pit is from a ridge summit and is well-drained at the present time.

Soils Data

Site No. 123 Location 44.34.50-107.34.50		Elevation 2310	
Dominant vegetation grass, and sage		% total ground cover 75	% good ground cover 50
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0		Landform ridgecrest on landslide (slump)	
Slope angle 0	Aspect NOW	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	12.7	10YR2/2	10YR2/2	acsil	f1gr	ds mvfr	wso wpo	7+	as
B	22.9	10YR3/2	10YR3/2	acsil	m2abk	dsh mfi	wss wps	7+	gs
C	101.6+	5Y3/2	5Y3/2	acsil	m	dsh mfi	wss wps	7+	

Comments A horizon, contains 40% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, calcareous all the way to the ground surface. B horizon, 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. C horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations.

Soils Data

Site No. 124 Location 44.35.45-107.34.45		Elevation 2362
Dominant vegetation grass, and sage	% total ground cover 40	% good ground cover 30
Parent material loamy carbonate colluvium	Formation name for underlying bedrock Gallatin	
% surface covered by bedrock 0	Landform ridgecrest on landslide (slump)	
Slope angle 0 / Aspect NOW	Erosion Class class 3	Precip. greater than 50 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 + / non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
C	101.6+	10YR5/4	10YR4/4	acsil	m	ds mvfr	wso wpo	7+	

Comments C horizon, contains 50% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations. This is in a different vegetation zone, origionally it was a conifer forest which was burned off in the 1890's so the soil may not be comparable to 123. However, on the rounded ridge crests and hummocks there is no A horizon present. C horizon is at the surface, either the A horizon was never present or it has been eroded away.

Soils Data

Site No. 125 Location SE20, 53N89W			Elevation 2487
Dominant vegetation grass, sage, and forbs		% total ground cover 80	% good ground cover 80
Parent material glacial till		Formation name for underlying bedrock	
% surface covered by bedrock 0		Landform lateral moraine	
Slope angle 0	Aspect NOW	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	17.8	10YR2/2	10YR2/2	csl	m1cr	ds mvfr	wso wpo	7-	gs
B	61	7.5YR4/4	7.5YR4/2	csl	m2abk	dsh mfi	wss wps	7-	as
C	101.6+	10YR4/3	10YR4/2	csl	m	ds mvfr	wso wpo	7-	

Comments A horizon, contains 10% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock. B horizon, contains 20% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock, rock fragments are deeply etched and pitted, feldspars are altered for distance of 0.3 cm. from outer edge of fragments. C horizon, contains 40% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock, rock fragments are deeply etched and pitted, feldspar crystals are altered 0.3 cm. back from the surface of the fragments. In places the rock fragments have actually become a gruss.

Soils Data

Site No. 126 Location NW23, 53N89W				Elevation 2286	
Dominant vegetation grass, sage, and forbs		% total ground cover 75		% good ground cover 60	
Parent material glacial till, and landslide debris		Formation name for underlying bedrock Gros Ventre			
% surface covered by bedrock 0		Landform Ground moraine			
Slope angle 0	Aspect NOW	Erosion Class class 0		Precip. greater than 50 cm.	
Drainage class well-drained		Depth to H_2O table (est.)			
Depth to bedrock		seasonal		year around	
rippable 1.5 +	non-rippable 1.5 +	1.5 +		1.5 +	

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	20.3	10YR2/2	10YR2/2	sl	f1cr	ds mvfr	wso wpo	7-	as
B	50.8	10YR3/3	10YR3/2	acsl	m1abk	ds mvfr	wso wpo	7-	ai
C	101.6+	10YR5/3	10YR4/3	acsil	m	ds mvfr	wso wpo	7+	

Comments A horizon, igneous and metamorphic boulders are scattered around on the ground surface. B horizon, contains 10%(est.) rounded gravel to boulder size fragments of igneous and metamorphic rock, rock near bottem of horizon have decayed to gruss. C horizon, contains 60% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations.

Soils Data

Site No. 127 Location NW23, 53N89W		Elevation 2268	
Dominant vegetation grass, sage, and forbs		% total ground cover 80	% good ground cover 80
Parent material glacial outwash???		Formation name for underlying bedrock	
% surface covered by bedrock 0		Landform outwash terrace???	
Slope angle 7	Aspect S60W	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	25.4	10YR2/1	10YR2/1	sl	c2cr	ds mfi	wso wpo	7-	gs
B	53.3	10YR3/3	10YR3/2	sl	m2abk	dsh mfi	wss wps	7-	gs
C	101.6+	10YR4/3	10YR4/2	sl	m	dsh mfi	wss wps	7-	

Comments Parent material in this case may be outwash although can observe no bedding.

Soils Data

Site No. 128 Location NE33, 53N88W			Elevation 2707
Dominant vegetation grass		% total ground cover 40	% good ground cover 40
Parent material glacial till		Formation name for underlying bedrock	
% surface covered by bedrock 0		Landform lateral moraine	
Slope angle 0	Aspect NOW	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A_1	5	10YR2/2	10YR2/2	l	f1cr	ds mvfr	wso wpo	7-	ai
A	17.8	7.5YR3/2	7.5YR3/2	cl	f1cr	ds mvfr	wso wpo	7-	gs
C	101.6+	10YR4/3	10YR4/2	cl	m	ds mvfr	wso wpo	7-	

Comments A horizon, contains 50% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock. C horizon, contains 20% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock.

Soils Data

Site No. 129 Location NE30, 53N88W			Elevation 2490
Dominant vegetation grass, sage, and forbs	% total ground cover 90		% good ground cover 70
Parent material glacial till	Formation name for underlying bedrock		
% surface covered by bedrock 0	Landform lateral moraine???		
Slope angle 0 / Aspect NOW	Erosion Class class 0		Precip. greater than 50 cm.
Drainage class well-drained	Depth to H_2O table (est.) seasonal 1.5 +		year around 1.5 +
Depth to bedrock rippable 1.5 + / non-rippable 1.5 +			

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A_1	7.6	5YR2/1	5YR2/1	l	f1cr	ds mvfr	wso wpo	7-	as
A	17.8	5YR2/2	5YR2/2	sil	m1cr	ds mvfr	wso wpo	7-	ai
B	45.7	7.5YR3/2	7.5YR3/2	sil	c2abk	dsh mfi	wss wps	7-	gs
B_3	53.3	10YR3/3	10YR3/2	gsl	m1abk	ds mvfr	wso wpo	7-	gs
C	101.6+	10YR4/3	10YR4/2	sg	m	ds mvfr	wso wpo	7-	

Comments B_3 horizon contains 50% (est.) rounded gravel to cobble size fragments of igneous and metamorphic rock. C horizon, contains 70% (est.) rounded gravel to cobble size fragments of igneous and metamorphic rock, contains occasional pods (7.6-12.7cm.) of very dark grayish brown (10YR3/2) loamy material, may be decayed roots. This may be Bull Lake till or outwash, just up the ridge from here there are igneous boulders scattered around on the surface, as well as to the NE in the woods.

Soils Data

Site No. 130 Location NE23, 53N89W		Elevation 2396	
Dominant vegetation grass, sage, and forbs		% total ground cover 80	% good ground cover 60
Parent material loamy carbonate colluvium		Formation name for underlying bedrock Gross Ventre	
% surface covered by bedrock 0		Landform ridgecrest on landslide (slump)	
Slope angle 0	Aspect NOW	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.) seasonal 1.5 +	year around 1.5 +
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +		

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A_1	5.1	10YR2/2	10YR2/2	si	f1cr	ds mfi	wso wpo	7-	as
A	17.8	10YR2/2	10YR2/2	si	m1cr	ds mvfr	wso wpo	7+	as
B	40.6	10YR2/2	10YR2/2	sgsi	c2abk	dsh mfi	wss wps	7+	gs
B_3	73.7	10YR3/2	10YR3/2	acsi	m2abk	dsh mfi	wss wps	7+	ai
C_{Ca}	101.6+	10YR6/3	10YR6/2	acsi	m	ds mvfr	wso wps	7+	

Comments A horizon, very slightly calcareous. B horizon, calcareous. B_3 horizon, contains 15% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous. C_{Ca} horizon, contains 30% (est.) angular gravel to boulder size fragments of carbonate rock from the Gallatin, Bighorn, and Madison Formations, highly calcareous, lighter color is due to a build up of $CaCO_3$.

Soils Data

Site No. 131 Location SE21,53N88W		Elevation 2551	
Dominant vegetation grass, sage, and forbs		% total ground cover 80	% good ground cover 80
Parent material glacial till		Formation name for underlying bedrock	
% surface covered by bedrock 0		Landform lateral moraine	
Slope angle 0	Aspect NOW	Erosion Class class 0	Precip. greater than 50 cm.
Drainage class well-drained		Depth to H_2O table (est.)	
Depth to bedrock rippable 1.5 +	non-rippable 1.5 +	seasonal 1.5 +	year around 1.5 +

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary
A	20	10YR2/2	10YR2/2	csl	m1cr	ds mvfr	wso wpo	7-	gs
B	60.5	7.5YR4/4	7.5YR4/2	csl	m2abk	dsh mfi	wss wps	7-	as
C	101.6+	10YR4/3	10YR3/3	csl	m	ds mvfr	wso wpo	7-	

Comments A horizon, contains 10% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock. B horizon, contains 20% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock, rock fragments are deeply etched and pitted, feldspars are altered for distance of 0.3 cm. from outer edge of fragments. C horizon, contains 40% (est.) rounded gravel to boulder size fragments of igneous and metamorphic rock, rock fragments are deeply etched and pitted, feldspar crystals are altered 0.3 cm. back from the surface of the fragment. In places the rock fragments have actually become a gruss.

Soils Data

Site No. 132 Location RC6 - 76			Elevation
Dominant vegetation	% total ground cover		% good ground cover
Parent material	Formation name for underlying bedrock		
% surface covered by bedrock	Landform		
Slope angle / Aspect	Erosion Class	Precip.	
Drainage class	Depth to H_2O table (est.) seasonal / year around		
Depth to bedrock rippable / non-rippable			

Profile description

Hori-zon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Cor -ats Grab sample of silts

Soils Data

Site No. 133 Location RC1 - 76			Elevation
Dominant vegetation		% total ground cover	% good ground cover
Parent material		Formation name for underlying bedrock	
% surface covered by bedrock		Landform	
Slope angle	Aspect	Erosion Class	Precip.
Drainage class		Depth to H_2O table (est.) seasonal year around	
Depth to bedrock rippable non-rippable			

Profile description

Hori-zon	Depth	Color dry moist	Texture	Structure	Consistency dry wet	pH	Boundary

Comments Grab sample of silts.

Soils Data

Site No. 134 Location 44.35.54-107.31.42		Elevation 2512	
Dominant vegetation		% total ground cover	% good ground cover
Parent material		Formation name for underlying bedrock	
% surface covered by bedrock		Landform	
Slope angle	Aspect	Erosion Class	Precip.
Drainage class		Depth to H_2O table (est.) seasonal year around	
Depth to bedrock rippable non-rippable			

Profile description

Hori-zon	Depth	Color dry moist	Texture	Structure	Consistency dry wet	pH	Boundary

Comments Grab sample of green colluvium

Soils Data

Site No. 135 Location 44.35.55-107.31.40			Elevation 2536
Dominant vegetation		% total ground cover	% good ground cover
Parent material		Formation name for underlying bedrock	
% surface covered by bedrock		Landform	
Slope angle	Aspect	Erosion Class	Precip.
Drainage class		Depth to H_2O table (est.) seasonal year around	
Depth to bedrock rippable non-rippable			

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments Grab sample of green colluvium.

Soils Data			
Site No. 136 Location 44.35.56-107.31.39		Elevation 2576	
Dominant vegetation	% total ground cover		% good ground cover
Parent material	Formation name for underlying bedrock		
% surface covered by bedrock	Landform		
Slope angle	Aspect	Erosion Class	Precip.
Drainage class		Depth to H_2O table (est.) seasonal year around	
Depth to bedrock rippable non-rippable			

Profile description

Horizon	Depth	Color dry	Color moist	Texture	Structure	Consistency dry	Consistency wet	pH	Boundary

Comments Grab sample of green colluvium