MASS WASTING BASICS

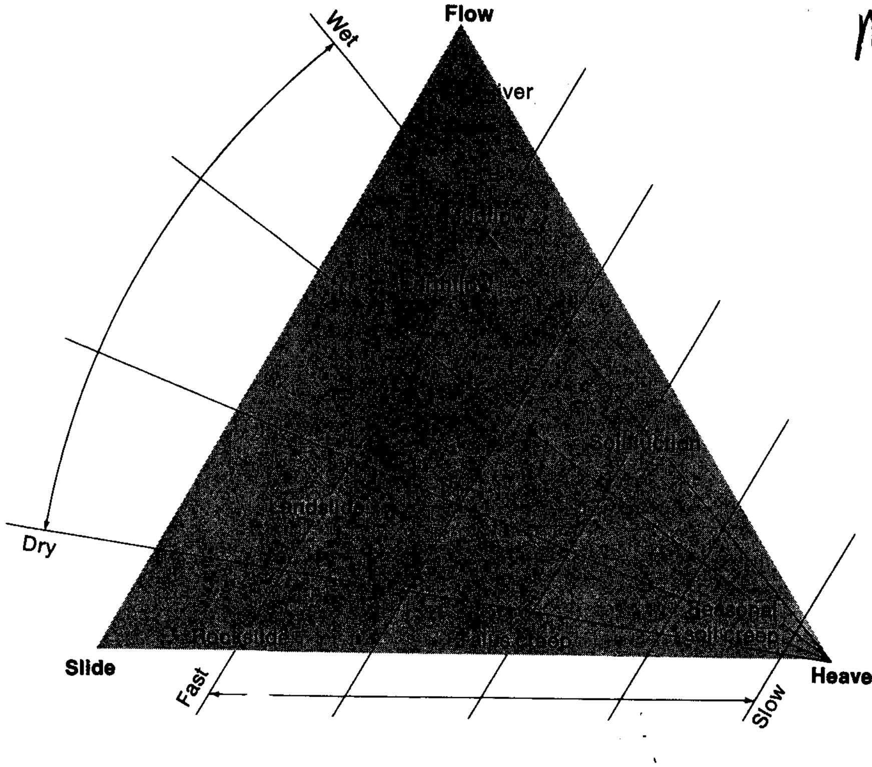

Figure 4.27
Classification of mass movement processes.
(From M. A. Carson and M. Kirkby, *Hillslope Form and Process*, copyright 1972 Cambridge University Press, Cambridge.)

TABLE 4.5 Factors that Influence Stress and Resistance in Slope Materials

Factors that Increase Shear Stress	Factors that Decrease Shear Strength
Removal of lateral support	Weathering and other physicochemical reactions
Erosion (rivers, ice, waves)	Disintegration (lowers cohesion)
Human activity (e.g., quarries, road cuts)	Hydration (lowers cohesion)
Addition of mass	Base exchange
Natural (e.g., rain, talus)	Solution
Human (e.g., fills, ore stockpiles, buildings)	Drying
Earthquakes	Pore water
Regional tilting	Buoyancy
Removal of underlying support	Capillary tension
Natural (e.g., undercutting, solution, weathering)	Structural changes
Human activity (mining)	Remolding
Lateral pressure	Fracturing
Natural (swelling, expansion by freezing, water addition)	

After Varnes (1958).

In most analyses the vertical height of the water table above the slide plane is expressed as a fraction of the soil thickness above the plane (m), where $m = 1.0$ if the water table is at the surface, and $m = 0$ if it is at or below the sliding plane. Thus, the pore pressure can be expressed as

$$\mu = \gamma_w mh \cos^2\theta$$

and

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

The following hypothetical example will show how to determine whether the slope is stable or close to failure. If laboratory tests tell us that $\phi = 10°$, $c = 45$ lb/ft^2,

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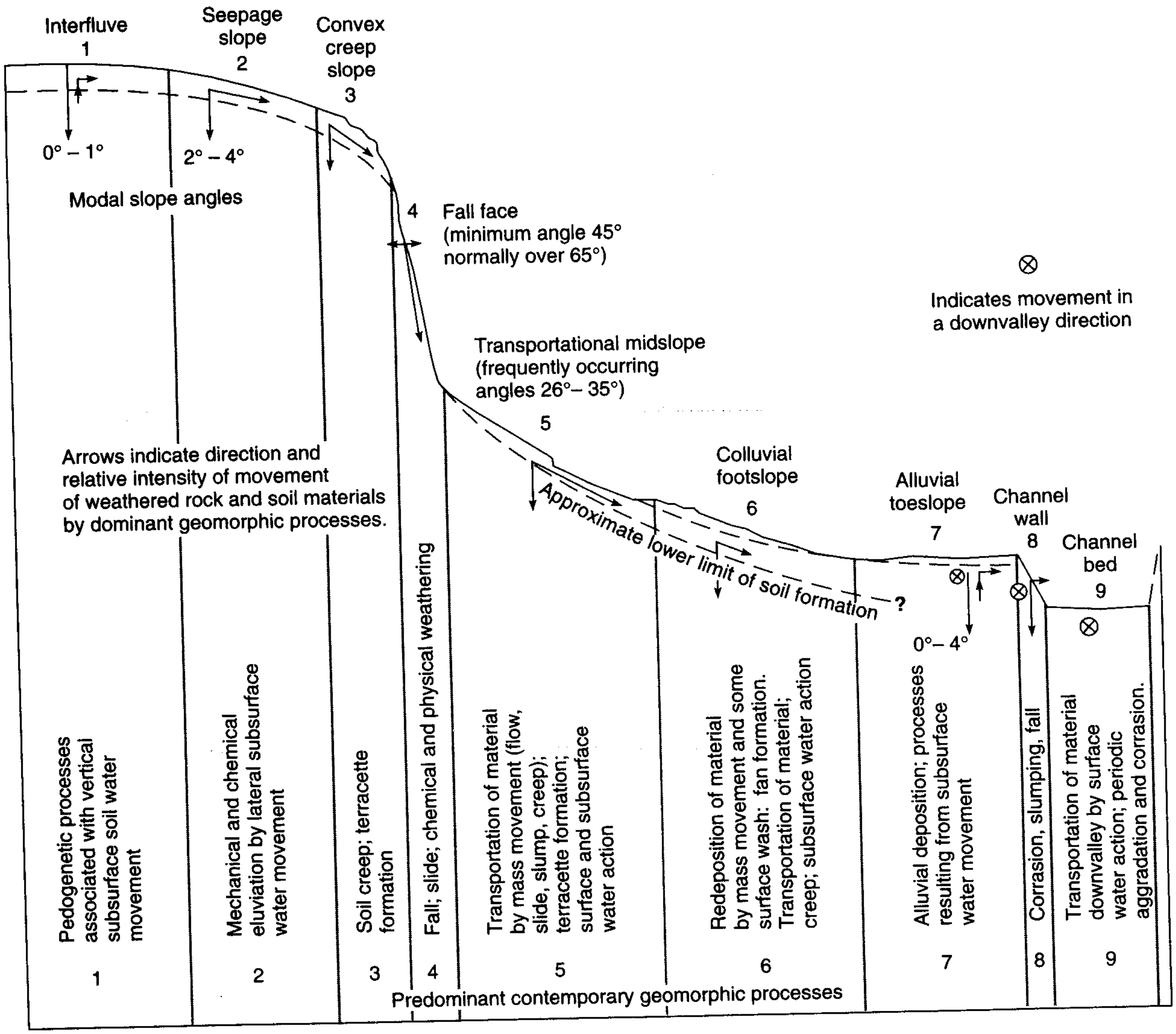

Figure 4.53
Diagrammatic representation of the hypothetical nine-unit landsurface model.
(Redrawn from J. B. Dalrymple, et al., "A Hypothetical Nine-Unit Landsurface Model," *Zeitschrift für Geomorphologie* 12:60–76, 1968. Used by permission of Gebrüder Borntraeger Verlagsbuchhandlung, Stuttgart.)

mountainous terrain where erosion is rapid, and are normally characterized by thin, weakly developed rocky soils. The rate of physical weathering tends to be at a maximum when the thickness of the residuum (the soil and colluvium) is minimal (fig. 4.54). Chemical weathering, which proceeds most efficiently under a significant cover of residuum, will be slowed, however, when the residuum becomes so thick that it interrupts the movement of water to the bedrock weathering front (an example of negative feedback). Numerous examples of weathering-limited slopes can be seen on slick-rock slopes developed in sandstones of the Colorado Plateau (Oberlander 1977; Howard and Kochel 1988). In contrast, **transport-limited slopes** are formed where the rate of weathering is more rapid than erosion. Slopes produced under this regime normally develop on any unconsolidated parent material regardless of environment, but they are typically dominant in humid-temperate zones where vegetation cover is continuous. These profiles are less affected by parent rock and more dependent on the type and rate of slope processes.

Selby (1982) has made a cogent argument that weathering-limited slopes are directly dependent on the relative resistance of the underlying parent rocks. As evidence, he has demonstrated a high correlation between rock mass strength (see table 4.4) and the angle developed on various slope segments (fig. 4.55). A line drawn around the data points shown in figure 4.55 creates what Selby calls the *strength equilibrium envelope,* and the slopes represented by points within that envelope are

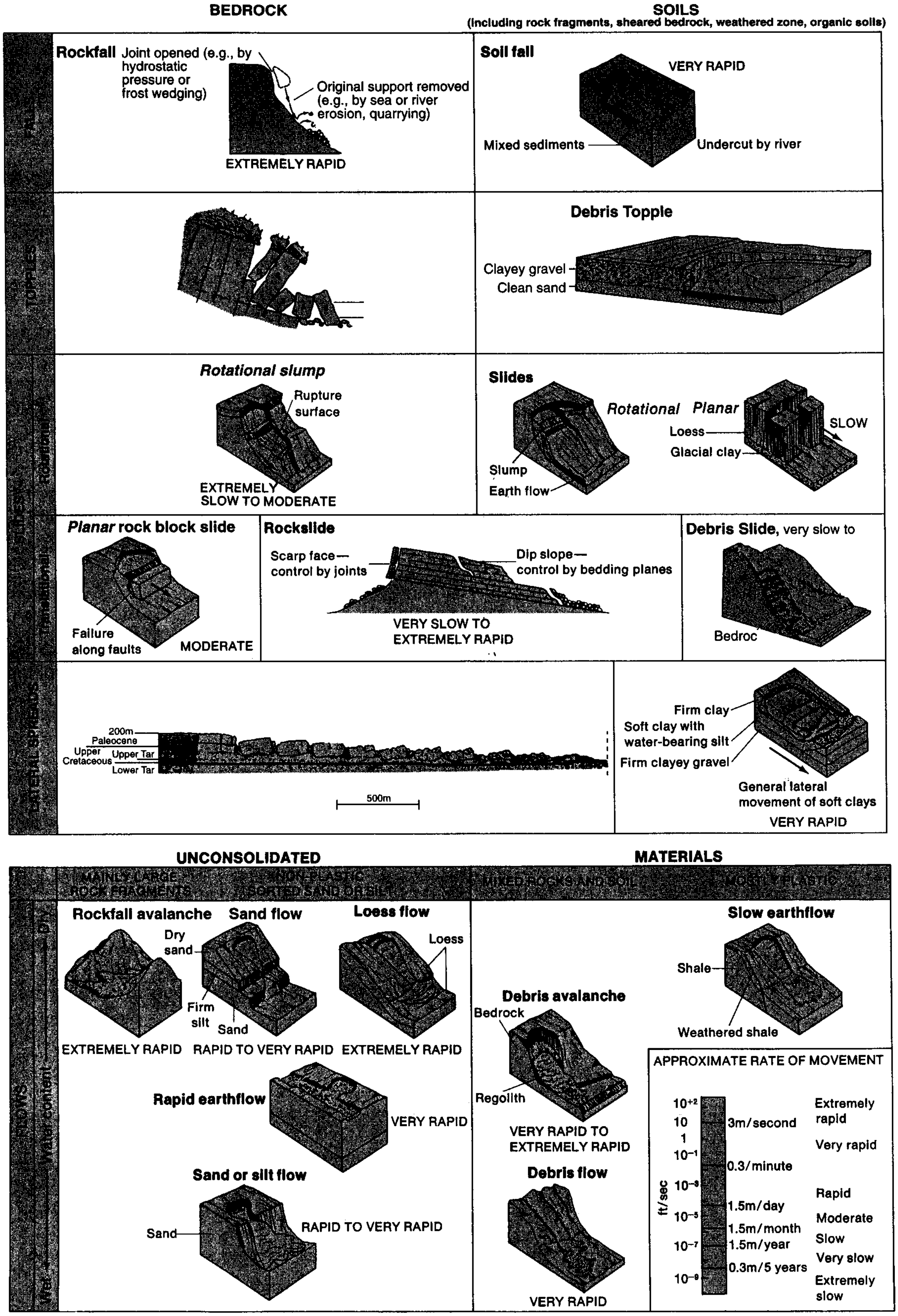

Figure 4.36
Classification of landslides.
(From D. J. Varnes, 1978, "Landslides: Analysis and Control," *TRB Special Report 176,* Transportation Research Board, National Research Council, Washington, D.C. Used by permission.)

of a particular rock type but is a relative feature determined by how rapidly slopes developed on the rock retreat and whether the rock stands relatively high in the local topography (Young 1972). In other words, it is not so much the rock itself that determines resistance, but whether the slopes formed over the rock are controlled by processes of weathering or processes of removal. In weathering-controlled slopes, resistance is related to how rapidly the rock is weathered and is a direct function of the rock properties. In transport-limited slopes, the resistance is attributable to the rate at which regolith can be eroded, and the properties of the weathered mass and the type and magnitude of the erosional processes become important in slope development. The downslope-grading of transport-limited slopes can be explained by the direct relationship between slope gradient and the rate of downslope material transport. For these reasons, the resistance of a particular rock type and its influence on slopes can be reversed if the rock is located in different climates. For example, the characteristics of slopes formed on limestones in humid climates contrast markedly with those developed in arid climates.

With regard to climatic influence, geomorphologists have long recognized that the most common slope profile in humid-temperate regions has a distinct convex upper slope and concave lower slope. Contrary to some beliefs, straight slope segments do occur in regions with humid-temperate climate, and some profiles do contain steep cliff faces. Most cliff faces, however, are ephemeral in the sense that as soon as undercutting ceases a talus slope forms and will extend upslope until it covers the original cliff wall (fig. 4.56). If the lithology of the rock sequence underlying the slope is not uniform, cliff faces may persist because resistant units are maintained as caprocks where the weaker underlying strata retreat faster, essentially undercutting the stronger rocks.

Convex upper slopes are usually attributed to soil creep; the lower concavity probably results from soil wash, although not all slopes have this segment, particularly when there is active erosion at the slope base (Strahler 1950). The convex-concave profile is most likely to be attained after mass movements have produced a long-term angular stability. At this stage, creep and wash become the dominant slope processes; the straight segment, representing stability of slope material, is gradually diminished in size. The processes of water erosion on slopes will be discussed in the next chapter. Recognize here, however, that water flowing over and through slope material combines with mass movement to mold slope profiles, and in some cases water erosion may be the dominant process involved.

Semiarid and arid climates tend to engender slope profiles that are more angular than those found in humid-temperate regions, even though the same convex, straight, and concave segments may be present (fig. 4.57). Steep cliffs usually are present above a straight, debris-covered segment that normally stands at angles between 25° and 35°. At the base of the straight segment a pronounced change in slope occurs, and angles decrease over a short distance to less than 5°, a normal slope for most desert plains. The limited vegetal cover and low precipitation in arid zones assure that mass movements occur at higher angles and that creep is subordinated to wash. As a result, the upper slope convexity, so prominent in humid regions, is much less pronounced. However, convex bedrock slopes are common in selected semiarid regions where jointing characteristics of the rock promote development of extensive exfoliation (Bradley 1963).

Straight segments are maintained by the wash process, which is accelerated on the sparsely vegetated surfaces. Unlike similar segments in humid climates, these usually have only a thin veneer of rock debris. Thus they are not like slopes of accumulation, talus slopes, but probably represent true slopes of transportation, on which the amount of debris supplied to the straight segment from the cliff face or from weathering of the underlying rocks is removed in equal quantities to the desert plain. The angle of slope represents a balance between the processes that break debris down and the actual transporting mechanism (Schumm and Chorley 1966). Most geomorphologists feel that a general relationship between particle size and slope angle can be demonstrated. Our treatment of semiarid slopes has been greatly oversimplified. A lengthy overview of slope evolution in the Colorado Plateau by Howard and Kochel (1988) highlights the complex interactions between chemical and physical weathering processes, mass wasting, and groundwater-related processes as they work on sandstone.

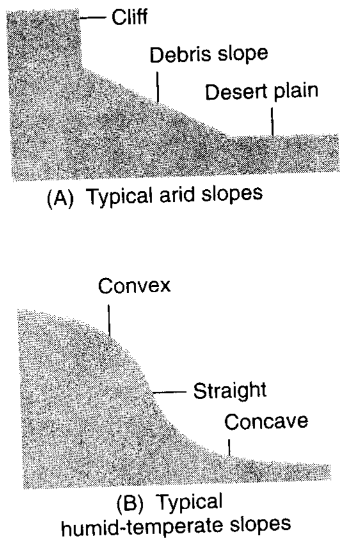

Figure 4.57
Typical slope profiles in (A) arid regions and (B) humid-temperate regions.

Although other climatic regimes have characteristic slope forms, in most cases they are produced by the same mechanics that operate in the humid-temperate or arid zones. In the periglacial environment a special influence is exerted by magnified frost activity; a more extensive treatment of that environment is presented in chapter 11.

Very little research has focused on what aspects of hillslope profiles are most closely related to climate. A study by Toy (1977), however, utilized a rigorous statistical analysis to compare slope properties within two extended traverses in the United States (Kentucky to Nevada and Montana to New Mexico) along which considerable climatic variation occurs. The selection of sampling localities was stringent. Parent rock at each measuring site was restricted to shales dipping at less than 5°. Each slope analyzed was south-facing, within 5 miles of a weather station having records for the same 21-year period used as the climatic base, and had no effects of human activity. Toy found that climate could account for 59 percent of the variability in the upper convex segments and 43 percent of the variability in the slope of the straight segments. Arid slopes in this study were shorter, had steeper straight segments, and had shorter radii of curvatures developed at the convex crests than slopes in humid regions. In addition, of the climatic variables used in the study, those most closely associated with slope variations were spring and summer precipitation, potential evapotranspiration, and water availability (total precipitation minus total potential evapotranspiration during the 21-year period).

Toy's findings cannot be used to make sweeping generalizations about climatic effects on slope profiles because they apply only to one type of parent rock. However, the study demonstrates the type of research design needed to estimate the influence of one geomorphic factor by reducing or eliminating the effects of others.

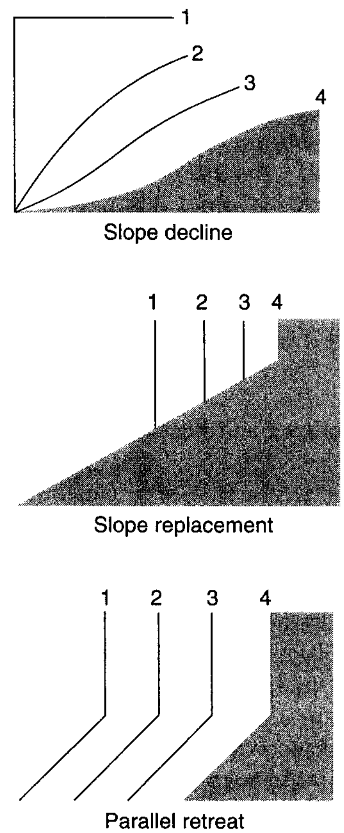

Figure 4.58
Three hypotheses of slope evolution. Higher numbers indicate increasing age of the slope.
(Adapted from A. Young, *Slopes*. fig. 14., 1972, Oliver and Boyd Publishers. Used by permission of A. Young.)

Slope Evolution

In addition to geology and climate, the factor of time can also be considered as an independent variable. Its effect, however, is difficult to determine, especially when the time interval involved is very long. As we saw in chapter 1, some of the great debates in geomorphology revolve around the question of how slopes respond to continued erosion. Do slopes progressively flatten through time in steps or stages? Or do slopes reach an equilibrium between form and geomorphic factors that is maintained through time as slopes retreat in a parallel manner? These questions are not easily answered.

Three main types of slope evolution have been suggested: slope decline, slope replacement, and parallel retreat (fig. 4.58). In *slope decline,* the steep upper slope erodes more rapidly than the basal zone, causing a flattening of the overall angle. It is usually accompanied by a developing convexity on the upper slope and concavity near the base. Slope decline alone cannot explain a concave profile on the lower slope unless some deposition occurs at the base. In *slope replacement,* the steepest angle is progressively replaced by the upward expansion of a gentler slope near the base. This process tends to enlarge the overall concavity of the profile, which may be in either a segmented or a smoothly curved form. Slopes evolving by *parallel retreat* are characterized by the maintenance of constant angles on the steepest part of the slope. Absolute lengths of slope parts do not change except in the concave zone, which gets longer with time.

Studies of hillslope evolution have also documented adjustments in the location of lateral convexities and concavities. Some of these studies highlight the concept of *gully gravure* (Bryan 1940), which describes how concave slope drainages (hollows) become armored with coarse colluvium shed off of neighboring convex slopes (noses), shifting drainage laterally in a manner such that the unarmored noses are preferentially eroded. In this manner, the former noses swap geomorphic roles with

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Table 5-2. Surficial Map Criteria for the Central Appalachians (after Kite, 1994).

A. Type I Criteria: Age, Origin, Landform, Material.

1. Age of Surficial Material
- H = Holocene (< 10,000 years old)
- W = Wisconsin (ca. 89 to 10 ka)
- I = Illinoian
- P = Pleistocene Undifferentiated
- EP = Early Pleistocene
- MPI= Middle Pleistocene
- LP = Late Pleistocene
- Q = Quaternary Undifferentiated
- CZ = Cenozoic Undifferentiated

2. Origin / Surficial Process

A. Hillslope
- r = residuum (in situ regolith)
- c = colluvium (mass wasting)
- ds = debris slide
- rf = rock fall or topple

B. Valley Bottom
- a = stream alluvium (normal flow)
- hcf = hyperconcentrated flow
- df = debris flow
- sw = slackwater deposition

C. Lacustrine
- l = lacustrine deposit, undiff.
- lb = lake-bottom deposit
- ld = lacustrine deltaic

D. Other
- g = glaciofluvial, undifferentiated
- go = glacial outwash
- e = eolian
- co = collapse (solution)
- cr = cryoturbation
- x = anthropogenic disturbance
- f = artificial fill
- rk = bedrock (process n/a)

3. Landform Units

A. Hillslope
- n = nose
- sl = side slope
- h = hollow
- veneer = < 2m of regolith
- blanket = > 2 m of regolith
- bf = boulder field
- bs = boulder stream
- pg = patterned ground
- tls = talus deposits

3. Landform Units (Cont.)

B. Valley Bottom
- ch = channel
- fp = floodplain (RI </= 2-3 yr)
- t = terrace (t1, t2 …tn; height AMRL)
- f = fan
- f-t = fan terrace (f1, f2 …fn; height AMRL)
- a = apron (footslope deposit)
- lo = lobe
- lv = levee
- ox = oxbow, abandoned channel

C. Other
- ft = flow track (debris flows)
- hm = hummocky topography
- rb = rock-block slide deposits
- x = excavated, fill, disturbed ground
- d = delta
- du = dune

4. Material (Composition and Texture)
- b = boulders (>256 mm; clast supported)
- c = cobbles (64-256 mm; clast supported)
- p = pebbles (4-64 mm; clast supported)
- g = gravel (>2 mm; clast supported)
- sg = mixed sand and gravel
- s = sand (0.05-2.0 mm)
- st = silt (0.002-0.05 mm)
- cy = clay (<0.002 mm)
- l = loam (mix of sand, silt, clay)
- d = diamicton undifferentiated
- bbd = very bouldery diamicton
- bd = bouldery diamicton
- cd = cobbly diamicton
- pd = pebbly diamicton
- ds = sandy matrix diamicton
- dt = silty matrix diamicton
- dy = clayey-matrix diamicton
- rk = bedrock (modify with lithology)
- rs = rotten stone, saprolite
- tr = travertine
- tu = tufa
- ma = marl
- og = organic-rich sediment
- w = water
- u = unkown

B. Type II Criteria: 2-D Surface Features

1. Karst
- bv = blind valley
- ca = cave (human entry)
- == Active cave passage
- = = Abandoned cave passage
- dv = dry valley
- kw = karst window
- sk = sinkhole (doline)
- skst = sinking stream
- ks = karst spring

2. Hillslope
- hs = headscar
- ds = debris-slide scar
- ls = landslide scar undifferentiated
- rs = rotational slide (slump) scar
- ts = translational slide scar
- rb = rock-block slide scar
- tc = terracettes

3. Other
- wf = water fall
- w = water, lake, reservoir
- Spring
- wt = wetland, undifferentiated
- wh = wetland, heath
- wm = wetland, marsh
- ws = swamp
- quarry (with highwall)
- gravel pit
- deep mine opening
- strip mine (with highwall)
- mine subsidence zone
- rc = rock city
- Scarp
- Meander scroll on floodplain
- Lacustrine strandline

C. Type III Criteria: - Data Reference Points

- Sandwhich symbols showing stratigraphy
- Depth to bedrock (drilling or seismic data)
- Minimum depth to bedrock (log data)
- Test hole / boring
- Well
- RE = refusal (in test boring)
- Hand-auger hole, shovel hole,
- Fossil locality
- Paleocurrent direction
- Observation Point

SURFICIAL MAPPING METHODOLOGY

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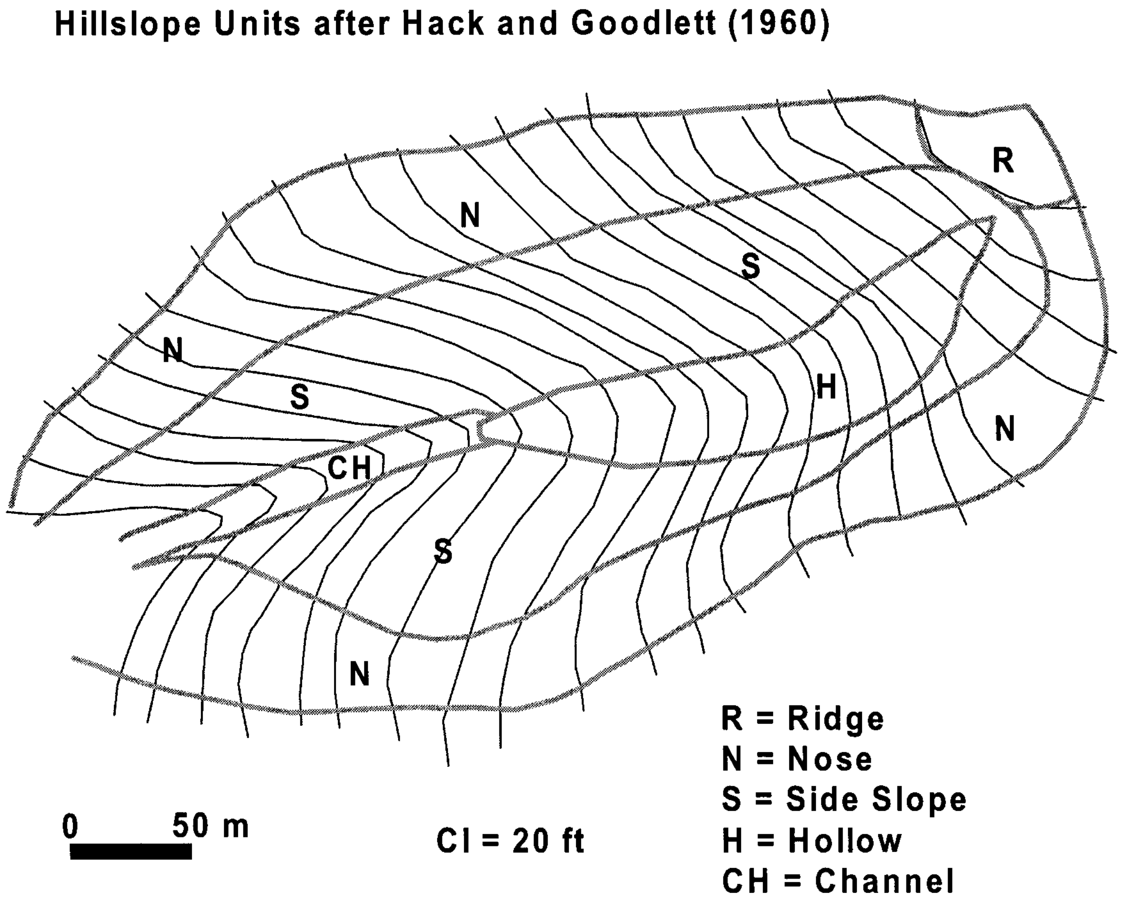

Figure 5-1. Hillslope landform elements after Hack and Goodlett (1960). Net transport flow paths are divergent on nose, covergent in hollows, and parallel on side slopes (Reneau and others, 1989). Noses represent drainage divides between zero- to first-order tributaries. Ridge crests serve as drainage divides between higher-order watersheds.

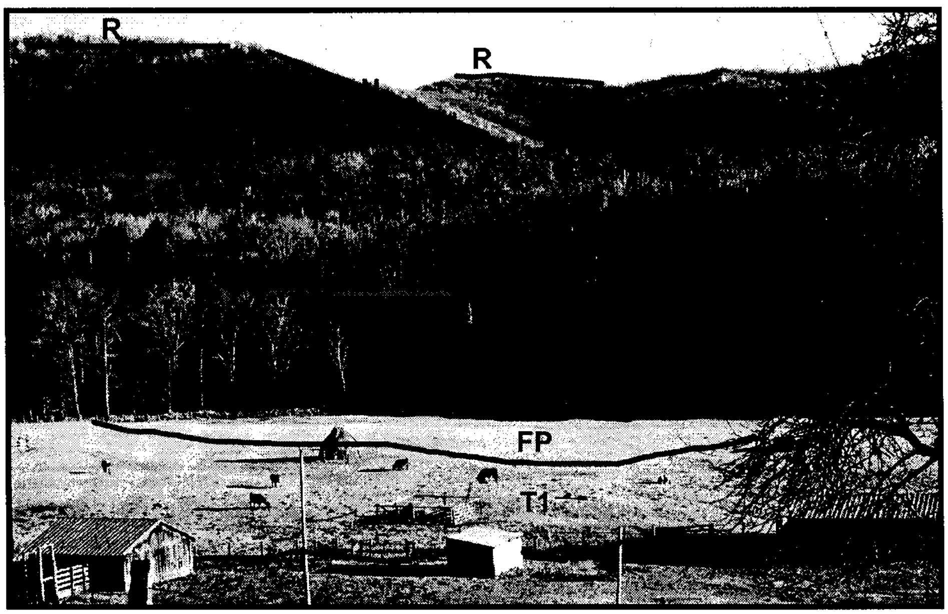

Figure 5-2. Principal landform elements recognized in the unglaciated, humid-mountainous landscape of the central Appalachians. Label identification is as follows: R = ridge, N = nose, S = side slope, H = hollow, CH = channel, FP = floodplain, T1 = low terrace, T2 = intermediate terrace, F-t = Fan terrace. Photograph is from the North Fork basin, Pocahontas County, West Virginia. See text for discussion.

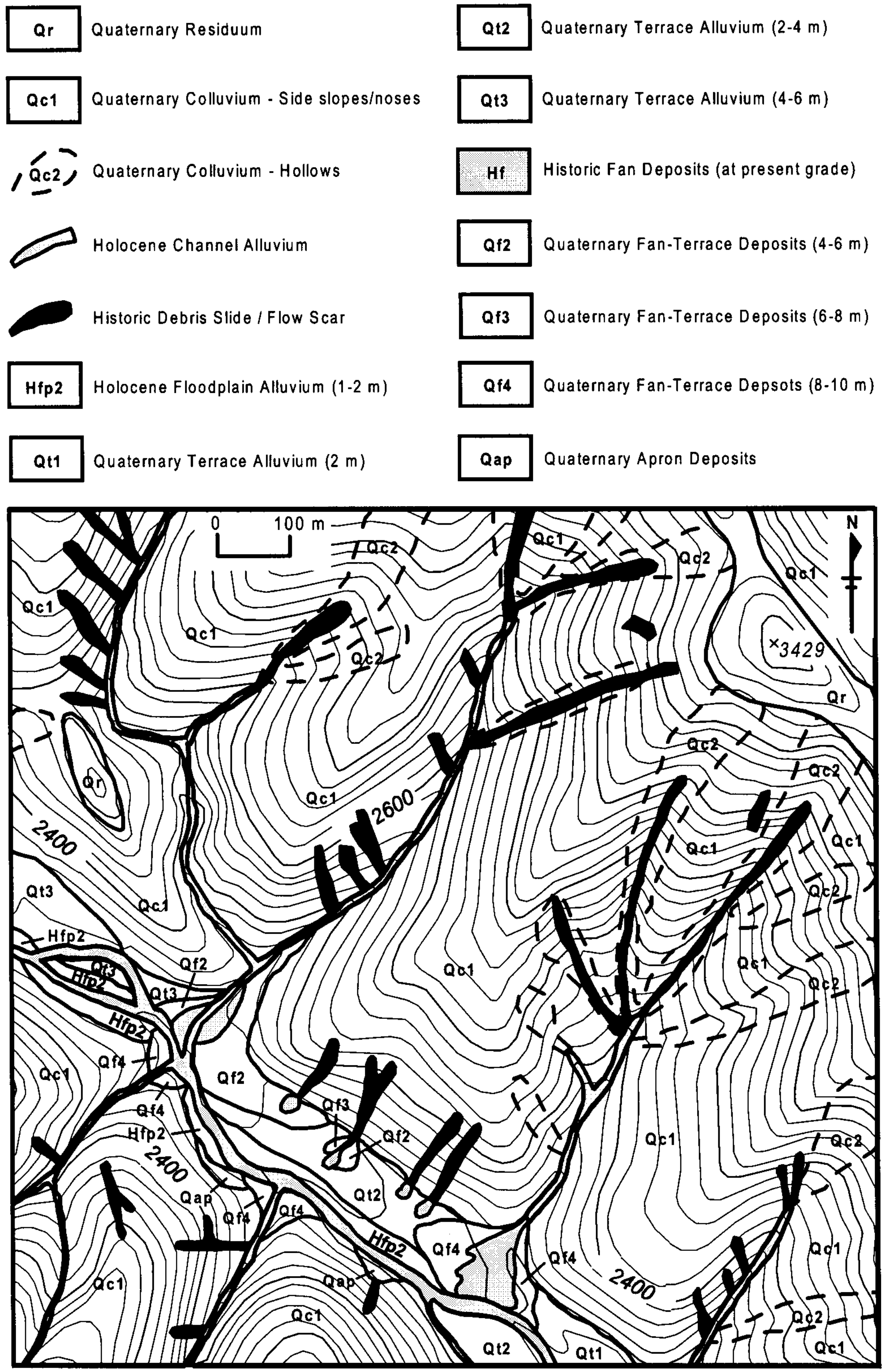

Figure 5-7. Portion of the surficial geology map for the Little River area, Augusta County, Virginia. Features were originally mapped at a scale of 1:9,600 (Taylor and Kite, 1998). Refer to Table 5-3 for an expanded explanation of map units. Contour interval = 40 ft.

Table 5-3. Example Application of Surficial Map Criteria at the Little River Basin, Augusta County, VA.

Map Unit Label	Map Unit Description	Age	Origin (Process)	Landform	Material (Texture)	Four-Fold Identifier	Comments
Qr	Quaternary Residuum	Quaternary (Undiff.)	Residuum	Ridge-Veneer	Cobble- to Boulder-Diamicton with Silty Loam Matrix	(Q,r,r-v,c-bdt-l)	Predominantly associated with ridge crests supported by the Pocono Formation.
Qc1	Quaternary Colluvium (Side Slopes)	Quaternary (Undiff.)	Colluvium	Nose-Side Slope Veneer	Cobble- to Boulder-Diamicton with Silty Loam Matrix	(Q,c1,n/s-v,c-bdtl)	Predominantly associated with side slopes underlain by the Hampshire Formation. Includes the Hazleton and Hazleton-Lehew soils series (Hockman and others, 1979).
Qc2	Quaternary Colluvium (Hollows)	Quaternary (Undiff.)	Colluvium	Hollow Veneer	Cobble- to Boulder-Diamicton with Silty Loam Matrix	(Q,c2,h-v,c-bdt-l)	Predominantly associated with zero- to first-order hollows underlain by the Hampshire Formation.
Qbf	Quaternary Boulder Field	Quaternary (Undiff.)	Colluvium (periglacial?)	Boulder Field	Cobbles and Boulders	(Q,c,bf,c-b)	Equant to irregularly shaped side slopes covered by greater than 80% cobbles and boulders. Commonly interpreted as the product of Pleistocene periglacial slope processes.
Qbs	Quaternary Boulder Stream	Quaternary (Undiff.)	Colluvium (periglacial?)	Boulder Stream	Cobbles and Boulders	(Q,c,bs,c-b)	Elongate valley-bottom areas covered by greater than 80% cobbles and boulders. Commonly interpreted as the product of Pleistocene periglacial slope processes.
Hch	Holocene Channel Alluvium	Holocene	Alluvium	Channel and Narrow Floodplain	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(H,a,ch,c-b-pl)	Fluvial channel deposits associated with first- to sixth-order streams. Unit includes channel alluvium and portions of adjacent floodplain too small to map at the given scale.
Hfp1	Holocene Floodplain Alluvium (0.5 to 1.0 m surface)	Holocene	Alluvium	Floodplain	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(H,a,fp1,c-b-pl)	Floodplain alluvium associated with second- to sixth-order streams. Unit includes low-lying surfaces 0.5 to 1.0 m above present channel grade with a flood recurrence interval of approximately 3 to 5 years.
Hfp2	Holocene Floodplain Alluvium (1.0 to 2.0 m surface)	Holocene	Alluvium	Floodplain	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(H,a,fp2,c-b-pl)	Floodplain alluvium associated with second- to sixth-order streams. Unit includes low-lying surfaces 1.0 to 2.0 m above present channel grade with a flood recurrence interval of approximately 3 to 5 years.
Hfp2A	Holocene Floodplain Alluvium (1.0 to 2.0 m surface)	Holocene	Alluvium	Floodplain	Sandy Loam	(H,a,fp2A,s-l)	Sandy slack-water deposits upstream from Hearthstone Lake. Unit includes low-lying surfaces 1.0-2.0 m above present channel grade with a flood recurrence interval of approximately 3 to 5 years. Buried root flares common.

Table 5-3 (Cont.).

Map Unit Label	Map Unit Description	Age	Origin (Process)	Landform	Material (Texture)	Four-Fold Identifier	Comments
Hfp2B	Holocene Floodplain Alluvium (1.0 to 2.0 m surface)	Holocene	Alluvium	Floodplain	Clayey Loam	(H,a,fp2B,cy-l)	Clayey slack-water deposits immediately upstream from Hearthstone Lake. Unit includes low-lying surfaces 1.0-2.0 m above present channel grade with a flood recurrence interval of approximately 3 to 5 years. Mud cracks and buried root flares common.
Hd	Holocene (Historic) Delta Deposits	Holocene (Historic)	Lacustrine Delta	Delta	Sandy Loam	(H,ld,d,s-l)	Historic lacustrine delta deposits associated with the flood-control reservoir at Hearthstone Lake.
Qt1	Quaternary Low-Terrace Alluvium (2.0 m surface)	Quaternary (Undiff.)	Alluvium	Terrace (Floodplain?)	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(Q,a,t1,c-b-pl)	Low-terrace deposits associated with second- to sixth-order streams. Unit includes low terrace surfaces 1.0 to 2.0 m above present channel grade with a flood recurrence interval greater than 5 years.
Qt2	Quaternary Terrace Alluvium (2.0 to 4.0 m surface)	Quaternary (Undiff.)	Alluvium	Terrace	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(Q,a,t2,c-b-pl)	Terrace deposits associated with third- to sixth-order streams. Unit includes terrace surfaces 2.0 to 4.0 m above present channel grade.
Qt3	Quaternary Terrace Alluvium (4.0 to 6.0 m surface)	Quaternary (Undiff.)	Alluvium	Terrace	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(Q,a,t3,c-b-pl)	Terrace deposits associated with third- to sixth-order streams. Unit includes terrace surfaces 4.0 to 6.0 m above present channel grade.
Qt4	Quaternary Terrace Alluvium (6.0 to 8.0 m surface)	Quaternary (Undiff.)	Alluvium	Terrace	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(Q,a,t4,c-b-pl)	Terrace deposits associated with third- to sixth-order streams. Unit includes terrace surfaces 4.0 to 6.0 m above present channel grade.
Hf	Holocene (Historic) Fan Deposits (undissected)	Holocene	Alluvium - Debris Flow(?)	Fan	Cobbles and Boulders, Gravel Diamicton	(H,a-df?,f,c-bdt-l)	Historic fan deposits commonly associated with first- to second-order hollows at stream-tributary junctions. Identified by fresh deposits, disturbed and buried vegetation. Primarily the result of June 1949 flood event.
Qf	Quaternary Fan Deposits (undissected)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f,c-bdt-l)	Fan deposits commonly associated with first-order hollows at stream-tributary junctions. Identified by older tree stands and lack of fresh appearance.
Qf1	Quaternary Fan-Terrace Deposits (2.0 to 4.0 m surface)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f1,c-bdt-l)	Entrenched fan surfaces commonly located at stream tributary junctions. Diamicton may be crudely stratified with imbricated gravely-loam facies.

Table 5-3 (Cont.).

Map Unit Label	Map Unit Description	Age	Origin (Process)	Landform	Material (Texture)	Four-Fold Identifier	Comments
Qf2	Quaternary Fan-Terrace Deposits (4.0 to 6.0 m surface)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f2,c-bdt-l)	Entrenched fan surfaces commonly located at stream tributary junctions. Diamicton may be crudely stratified with imbricated gravely-loam facies.
Qf3	Quaternary Fan-Terrace Deposits (6.0 to 8.0 m surface)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f3,c-bdt-l)	Entrenched fan surfaces commonly located at stream tributary junctions. Diamicton may be crudely stratified with imbricated gravely-loam facies.
Qf4	Quaternary Fan-Terrace Deposits (8.0 to 10.0 m surface)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f4,c-bdt-l)	Entrenched fan surfaces commonly located at stream tributary junctions. Diamicton may be crudely stratified with imbricated gravely-loam facies.
Qf5	Quaternary Fan-Terrace Deposits (>10.0 m surface)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f5,c-bdt-l)	Entrenched fan surfaces commonly located at stream tributary junctions. Diamicton may be crudely stratified with imbricated gravely-loam facies.
Qap	Quaternary Apron Deposits	Quaternary (Undiff.)	Colluvium	Apron	Cobble- to Boulder-Diamicton with Silty Loam Matrix	(Q,c,ap,c-bdt-l)	Footslope deposits > 2.0 m in thickness. Commonly located at break in gradient between steeper side slopes and valley-bottoms.
Hds	Holocene (Historic) Debris Slide / Flow Scar	Holocene (Historic)	Debris Slide / Debris Flow	Scar	Commonly Scoured to Bedrock	(H,ds/df,sc,rk)	Slide scars associated with the June 1949 flood event. Debris slides transformed into debris flows with attendant erosion of surficial materials to bedrock. Identified by youthful and disturbed vegetation. Bedrock surfaces may be scratched and striated.

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APPENDIX 7
Table for length conversion

Unit	mm	cm	m	km	in	ft	yd	mi
1 millimeter	1	0.1	0.001	10^{-6}	0.0397	0.00328	0.00109	6.21×10^{-7}
1 centimeter	10	1	0.01	0.0001	0.3937	0.0328	0.0109	6.21×10^{-6}
1 meter	1000	100	1	0.001	39.37	3.281	1.094	6.21×10^{-4}
1 kilometer	10^{6}	10^{5}	1000	1	39,370	3281	1093.6	0.621
1 inch	25.4	2.54	0.0254	2.54×10^{-5}	1	0.0833	0.0278	1.58×10^{-5}
1 foot	304.8	30.48	0.3048	3.05×10^{-4}	12	1	0.333	1.89×10^{-4}
1 yard	914.4	91.44	0.9144	9.14×10^{-4}	36	3	1	5.68×10^{-4}
1 mile	1.61×10^{6}	1.01×10^{5}	1.61×10^{3}	1.6093	63,360	5280	1760	1

APPENDIX 8
Table for area conversion

Unit	cm^2	m^2	km^2	ha	in^2	ft^2	yd^2	mi^2	ac
1 sq. centimeter	1	0.0001	10^{-10}	10^{-8}	0.155	1.08×10^{-3}	1.2×10^{-4}	3.86×10^{-11}	2.47×10^{-8}
1 sq. meter	10^{4}	1	10^{-6}	10^{-4}	1550	10.76	1.196	3.86×10^{-7}	2.47×10^{-4}
1 sq. kilometer	10^{10}	10^{6}	1	100	1.55×10^{9}	1.076×10^{7}	1.196×10^{6}	0.3861	247.1
1 hectare	10^{8}	10^{4}	0.01	1	1.55×10^{7}	1.076×10^{5}	1.196×10^{4}	3.861×10^{-3}	2.471
1 sq. inch	6.452	6.45×10^{-4}	6.45×10^{10}	6.45×10^{-8}	1	6.94×10^{-3}	7.7×10^{-4}	2.49×10^{-10}	1.574×10^{-7}
1 sq. foot	929	0.0929	9.29×10^{-8}	9.29×10^{-6}	144	1	0.111	3.587×10^{-8}	2.3×10^{-5}
1 sq. yard	8361	0.8361	8.36×10^{-7}	8.36×10^{-5}	1296	9	1	3.23×10^{-7}	2.07×10^{-4}
1 sq. mile	2.59×10^{10}	2.59×10^{6}	2.59	259	4.01×10^{9}	2.79×10^{7}	3.098×10^{6}	1	640
1 acre	4.04×10^{7}	4047	4.047×10^{-3}	0.4047	6.27×10^{6}	43,560	4840	1.562×10^{-3}	1

APPENDIX 9
Table for volume conversion

Unit	mL	liters	m^3	in^3	ft^3	gal	ac-ft	million gal
1 milliliter	1	0.001	10^{-6}	0.06102	3.53×10^{-5}	2.64×10^{4}	8.1×10^{-10}	2.64×10^{-10}
1 liter	10^{3}	1	0.001	61.02	0.0353	0.264	8.1×10^{-7}	2.64×10^{-7}
1 cu. meter	10^{6}	1000	1	61,023	35.31	264.17	8.1×10^{-4}	2.64×10^{-4}
1 cu. inch	16.39	1.64×10^{-2}	1.64×10^{-5}	1	5.79×10^{-4}	4.33×10^{-3}	1.218×10^{-8}	4.329×10^{-9}
1 cu. foot	28,317	28.317	0.02832	1728	1	7.48	2.296×10^{-5}	7.48×10^{6}
1 U.S. gallon	3785.4	3.785	3.78×10^{-3}	231	0.134	1	3.069×10^{-6}	10^{6}
1 acre-foot	1.233×10^{9}	1.233×10^{6}	1233.5	75.27×10^{6}	43,560	3.26×10^{5}	1	0.3260
1 million gallons	3.785×10^{9}	3.785×10^{6}	3785	2.31×10^{8}	1.338×10^{5}	10^{6}	3.0684	1

APPENDIX 10
Table for time conversion

Unit	sec	min	hours	days	years
1 second	1	1.67×10^{-2}	2.77×10^{-4}	1.157×10^{-5}	3.17×10^{-8}
1 minute	60	1	1.67×10^{-2}	6.94×10^{-4}	1.90×10^{-6}
1 hour	360	60	1	4.17×10^{-2}	1.14×10^{-4}
1 day	8.64×10^{4}	1440	24	1	2.74×10^{-3}
1 year	3.15×10^{7}	5.256×10^{5}	8760	365	1

APPENDIX 9.A.
Conversion Tables

Length

Unit	Equivalent[1,2]					
	millimeters	inches	feet	meters	kilometers	miles
millimeters	1	3.937×10^{-2}	3.281×10^{-3}	1×10^{-3}	1×10^{-6}	6.214×10^{-7}
inches	25.4	1	8.33×10^{-2}	2.54×10^{-2}	2.54×10^{-5}	1.578×10^{-5}
feet	304.8	12	1	0.3048	3.048×10^{-4}	1.894×10^{-4}
meters	1,000	39.37	3.281	1	1×10^{-3}	6.214×10^{-4}
kilometers	1×10^{6}	3.937×10^{4}	3,281	1,000	1	0.6214
miles	1.609×10^{6}	6.336×10^{4}	5,280	1,609	1.609	1

Area

Unit	Equivalent[1,2]						
	square inches	square feet	square meters	acres	hectares	square kilometers	square miles
square inches	1	6.944×10^{-3}	6.452×10^{-4}	1.594×10^{-8}	6.452×10^{-8}	6.452×10^{-10}	2.491×10^{-10}
square feet	144	1	9.29×10^{-2}	2.296×10^{-5}	9.29×10^{-9}	9.29×10^{-8}	3.587×10^{-8}
square meters	1,550	10.76	1	2.471×10^{-4}	1×10^{-4}	1×10^{-6}	3.861×10^{-7}
acres	6.273×10^{6}	4.356×10^{4}	4,047	1	0.4047	4.047×10^{-3}	1.563×10^{-3}
hectares	1.55×10^{7}	1.076×10^{5}	1×10^{4}	2.471	1	0.01	3.861×10^{-3}
square kilometers	1.55×10^{9}	1.076×10^{7}	1×10^{6}	247.1	100	1	0.3861
square miles	4.014×10^{9}	2.788×10^{7}	2.59×10^{6}	640	259	2.59	1

Volume

Unit	Equivalent[1,2]						
	cubic inches	liters	gallons	cubic feet	cubic yards	cubic meters	acre-ft
cubic inches	1	1.639×10^{-2}	4.329×10^{-3}	5.787×10^{-4}	2.143×10^{-5}	1.639×10^{-5}	1.329×10^{-8}
liters	61.02	1	0.2642	3.531×10^{-2}	1.308×10^{-3}	0.001	8.106×10^{-7}
gallons	231.0	3.785	1	0.1337	4.951×10^{-3}	3.785×10^{-3}	3.068×10^{-6}
cubic feet	1,728	28.32	7.481	1	3.704×10^{-2}	2.832×10^{-3}	2.296×10^{-5}
cubic yards	4.666×10^{4}	764.6	202.0	27	1	0.7646	6.198×10^{-4}
cubic meters	6.102×10^{4}	1,000	264.2	35.31	1.308	1	8.106×10^{-4}
acre-ft	7.527×10^{7}	1.233×10^{6}	3.259×10^{5}	4.356×10^{4}	1,613	1,233	1

Discharge (flow rate, volume/time)

Unit	Equivalent[1,2]				
	gallons per minute	liters per second	acre-feet per day	cubic feet per second	cubic meters per day
gallons per minute	1	6.309×10^{-2}	4.419×10^{-3}	2.228×10^{-3}	5.45
liters per second	15.85	1	7.005×10^{-2}	3.531×10^{-2}	86.4
acre-feet per day	226.3	14.28	1	0.5042	1,234
cubic feet per second	448.8	28.32	1.983	1	2,447
cubic meters per day	1.369×10^{9}	8.64×10^{7}	6.051×10^{6}	3.051×10^{6}	1

Appendix 9.A. Continued

Velocity

Unit	Equivalent[1,2]				
	feet per day	kilometers per hour	feet per second	miles per hour	meters per second
feet per day	1	1.27×10^{-5}	1.157×10^{-5}	7.891×10^{-6}	3.528×10^{-6}
kilometers per hour	7.874×10^{4}	1	0.9113	0.6214	0.2778
feet per second	8.64×10^{4}	1.097	1	0.6818	0.3048
miles per hour	1.267×10^{5}	1.609	1.467	1	0.447
meters per second	2.835×10^{5}	3.6	3.281	2.237	1

Mass

Unit	Equivalent[1,2]							
	ounce	pound	kilogram	metric slug	slug	short ton	metric ton	long ton
ounce	1	6.25×10^{-2}	2.835×10^{-2}	2.891×10^{-3}	1.943×10^{-3}	3.125×10^{-5}	2.835×10^{-5}	2.79×10^{-5}
pound	16	1	0.4536	4.625×10^{-2}	3.108×10^{-2}	5×10^{-4}	4.536×10^{-4}	4.464×10^{-4}
kilogram	35.28	2.205	1	0.102	6.852×10^{-2}	1.102×10^{-3}	0.001	9.842×10^{-4}
metric slug	345.9	21.62	9.807	1	0.6721	92.51	9.807×10^{-3}	9.651×10^{-3}
slug	514.7	32.17	14.59	1.49	1	62.17	1.459×10^{-2}	1.436×10^{-2}
short ton	3.2×10^{4}	2,000	907.2	92.51	62.16	1	0.907	0.8929
metric ton	3.528×10^{4}	2,205	1,000	102	68.52	1.103	1	0.9842
long ton	3.584×10^{4}	2,240	1,016	103.7	69.63	1.12	1.016	1

Force

Unit	Equivalent[1,2]			
	dyne	newton	$pound_{force}$	$kilogram_{force}$
dynes	1	1×10^{-5}	2.248×10^{-6}	1.02×10^{-6}
newtons	1×10^{5}	1	0.2248	0.102
$pound_{force}$	4.448×10^{5}	4.448	1	0.4536
$kilogram_{force}$	9.807×10^{5}	9.807	2.205	1

Density

Unit	Equivalent[1,2]				
	pounds per cubic inch	pounds per cubic feet	pounds per gallon	grams per cubic centimeter	grams per liter
pounds per cubic inch	1	1,728	231	27.68	2.768×10^{4}
pounds per cubic feet	5.787×10^{-4}	1	0.1337	1.6×10^{-2}	16.02
pounds per gallon	4.33×10^{-3}	7.481	1	0.1198	119.8
grams per cubic centimeter	3.61×10^{-2}	62.43	8.345	1	1,000
grams per liter	3.61×10^{-5}	6.24×10^{-2}	8.35×10^{-3}	0.001	1

TABLE 4.1 English and SI Units

1 N = 1 Kg·m/sec²

Parameter	English Unit	SI Unit	Conversion Factor	Dimensional Formula
Force	pound (lb)	newton (N)	1 lb = 4.448 N	ML/T^2
Mass	slug	kilogram (kg)	1 slug = 14.594 kg	M
Length	foot (ft)	meter (m)	1 ft = 0.3048 m	L
Time	second (s)	second	1 s = 1 s	T
Density	slug/ft³	kg/m³	1 slug/ft³ = 515.4 kg/m³	M/L^3
Specific weight	lb/ft³	N/m³	1 lb/ft³ = 157.1 N/m³	M/L^2T^2
Pressure	lb/ft²	N/m²	1 lb/ft² = 47.88 N/m²	M/LT^2
Dynamic viscosity	lb-s/ft²	N·s/m²	1 lb-s/ft² = 47.88 N·s/m²	M/LT
Bulk modulus	lb/ft²	N/m²	1 lb/ft² = 47.88 N/m²	M/LT^2

g = Acceleration due to gravity = 9.8 m/sec²

Equations for areas and volumes

Circumference of circle = 3.1416 × dia = 6.2832 × radius
Area of circle = 0.7854 × (dia)² = 3.1416 × (radius)²
Area of sphere = 3.1416 × (dia)²
Volume of sphere = 0.5236 × (dia)³
Area of triangle = 0.5 × base × height
Area of trapezoid = 0.5 × sum of the two parallel sides × height
Area of square, rectangle, or parallelogram = base × height
Volume of pyramid = area of base × 1/3 height
Volume of cone = 0.2618 × (dia of base)² × height
Volume of cylinder = 0.7854 × height × (dia)²

Pressure

Unit	Equivalent[1,2]										
	pounds per square inch	pounds per square feet	atmospheres	kilograms per square centimeter	kilograms per square meter	inches of water (68°F)[3]	feet of water (68°F)[3]	inches of mercury (32°F)[4]	millimeters of mercury (32°F)[4]	bars	kilo Pascals
pounds per square inch	1	144	6.805×10^{-2}	7.031×10^{-2}	703.1	27.73	2.311	2.036	51.72	6.895×10^{-2}	6.895
pounds per square feet	6.945×10^{-3}	1	4.73×10^{-4}	4.88×10^{-4}	4.882	0.1926	1.605×10^{-2}	1.414×10^{-2}	0.3591	4.79×10^{-4}	4.79×10^{-2}
atmospheres	14.7	2,116	1	1.033	1.033×10^{4}	407.5	33.96	29.92	760	1.013	101.3
kilograms per square centimeter	14.22	2,048	0.9678	1	1×10^{4}	394.4	32.87	28.96	735.6	0.9807	98.07
kilograms per square meter	1.422×10^{-3}	0.2048	9.678×10^{-5}	0.001	1	3.944×10^{-2}	3.287×10^{-3}	2.896×10^{-3}	7.356×10^{-2}	9.807×10^{-5}	9.807×10^{-3}
inches of water (68°F)[3]	3.609×10^{-2}	5.197	2.454×10^{-3}	2.53×10^{-3}	25.38	1	8.333×10^{-2}	7.343×10^{-2}	1.865	2.49×10^{-3}	0.249
feet of water (68°F)[3]	0.4328	62.32	2.945×10^{-2}	3.043×10^{-2}	304.3	12	1	0.8812	22.38	2.984×10^{-2}	2.984
inches of mercury (32°F)[4]	0.4912	70.73	3.342×10^{-2}	3.453×10^{-2}	345.3	13.62	1.135	1	25.4	3.386×10^{-2}	3.386
millimeters of mercury (32°)[4]	1.934×10^{-2}	2.785	1.316×10^{-3}	1.36×10^{-3}	13.6	0.5362	4.468×10^{-2}	3.937×10^{-2}	1	1.333×10^{-3}	0.1333
bars	14.5	2,089	0.9869	1.02	1.02×10^{4}	402.2	33.51	29.53	750.1	1	100
kilo Pascals	0.145	20.89	9.869×10^{-3}	1.02×10^{-2}	102	4.022	0.3351	0.2953	7.501	0.01	1

Handy Scientific Data

PHYSICS

FORMULAS

- **Composition of Forces**
The resultant of two forces acting at an angle upon a given point is equal to the diagonal of a parallelogram of which the two force vectors are sides. The equilibrant equals the magnitude of the resultant, but acts in the opposite direction.

- **Accelerated Motion**
$v = at$, or $v = gt$
v is final velocity; a is acceleration, or g is acceleration due to gravity; t is time

- **Accelerated Motion**
$s = \frac{1}{2}at^2$ or $s = \frac{1}{2}gt^2$
s is total distance; a is acceleration, or g is acceleration due to gravity; t is time

- **Accelerated Motion**
$v = \sqrt{2as}$, or $v = \sqrt{2gs}$
v is final velocity; a is acceleration, or g is acceleration due to gravity; s is total distance

- **Newton's Second Law of Motion**
$F = ma$
F is force; m is mass; a is acceleration

- **Impulse and Momentum**
$Ft = mv$
F is force; t is time; the product Ft is impulse; m is mass; v is velocity; the product mv is momentum

- **Centrifugal Force**
$\text{Centrifugal Force} = \frac{mv^2}{r}$
m is mass; v is velocity; r is radius of path

- **Work**
$W = Fs$
W is work; F is force; s is distance

- **Potential Energy**
$P.E. = mgh$
P.E. is potential energy; m is mass; g is acceleration due to gravity; h is vertical distance

- **Kinetic Energy**
$K.E. = \frac{1}{2}mv^2$
K.E. is kinetic energy; m is mass; v is velocity

RELATIONS BETWEEN COMMON UNITS

LENGTH
1 in = 2.540 cm
1 ft = 30.48 cm
1 micron (μ) = 0.000001 m = 0.001 mm = 10^{-4} cm
1 millionth micron ($\mu\mu$) = 10^{-10}
1 Angstrom Unit = 10^{-8} cm

VOLUME
1 Liter = 1000 cm³ = 61.024 in³ = 1.05671 qt.

MASS
1 lb = 453.59 g.
1 kg = 2.2046 lb

ANGLES
1 circumference = 360° = 2π radians
1 radian = 57.2958°

DENSITY
1 gr / cm³ = 62.4 lb / ft³ .

WORK OR ENERGY
1 ft-lb = 1.356 X 10^7 ergs
1 joule = 10^7 ergs
1 gr cal = 4.186 X 10^7 ergs
1 B.T.U. = 777.8 ft-lb = 252.2 g cal

POWER
1 H.P. = 33,000 ft lb / min
= 550 ft lb / sec = 746 watts
1 watt = 1 joule/second

ELECTRICAL UNITS
1 ampere = 10^{-1} ob amps = 3 X 10^9 ESU
1 volt = 10^8 EMU = ⅓ X 10^{-2} ESU
1 coulomb = 10^{-1} EMU = 3 X 10^9 ESU
1 ohm = 10^9 EMU = ⅑ X 10^{-11} ESU
1 farad = 10^{-9} EMU = 9 X 10^{11} ESU
1 henry = 10^9 EMU = ⅑ X 10^{11} ESU

PHYSICAL CONSTANTS

$C = 2.9979 \times 10^8$ m/s
$G = 6.6720 \times 10^{-11}\ m^3 \cdot s^{-2} \cdot kg^{-1}$
$e = 1.6022 \times 10^{-19}$ C
$e/m_e = 1.7588 \times 10^{11}\ C \cdot kg^{-1}$
$F = 9.6485 \times 10^4\ C \cdot mol^{-1}$
$V_m = 22.4138 \times 10^{-3} m^3 \cdot mol^{-1}$
$h = 6.6262 \times 10^{-34} J \cdot s$
$R = 8.3144\ J \cdot mol^{-1} \cdot k^{-1}$
$N_A = 6.0220 \times 10^{23}\ mol^{-1}$
Atomic Mass Unit $\mu = 1.6606 \times 10^{-27}$ kg
$M_e = 9.1094 \times 10^{-31}$ kg
1 Kilogram Calorie (Nutrition Calorie) = 4.1868 Kilojoules
1 BTU = 1.0551kJ

CHEMISTRY

SYMBOLS OF SOME PARTICLES

electron	$_{-1}e^0$	deuteron	$_1H^2$
neutron	$_0n^1$	triton	$_1H^3$
proton	$_1H^1$	alpha particle	$_2He^4$

OXIDATION STATE OF SOME RADICALS

CH_3COO^-	ClO_4^-	$H_2PO_4^-$	NO_3^-
CO_3^{--}	$Cr_2O_7^{--}$	H_3O^+	OH^-
$C_2O_4^{--}$	HCO_3^-	Hg_2^{++}	PO_3^{---}
ClO^-	HPO_4^{--}	MnO_4^-	PO_4^{---}
ClO_2^-	HSO_3^-	NH_4^+	SO_3^{--}
ClO_3^-	HSO_4^-	NO_2^-	SO_4^{--}

PERIODIC TABLE OF THE ELEMENTS

Atomic weights conform to the 1961 values of the Commission on Atomic Weights.

KEY: Atomic Mass (Weight) — 12.01115; Symbol — C; Atomic Number — 6

Transition Elements

Period	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
1	1.00797 H 1																1.00797 H 1	4.0026 He 2
2	6.939 Li 3	9.0122 Be 4											10.811 B 5	12.01115 C 6	14.0067 N 7	15.9994 O 8	18.9984 F 9	20.183 Ne 10
3	22.9898 Na 11	24.312 Mg 12											26.9815 Al 13	28.086 Si 14	30.9738 P 15	32.064 S 16	35.453 Cl 17	39.948 Ar 18
4	39.102 K 19	40.08 Ca 20	44.956 Sc 21	47.90 Ti 22	50.942 V 23	51.996 Cr 24	54.9380 Mn 25	55.847 Fe 26	58.9332 Co 27	58.71 Ni 28	63.54 Cu 29	65.37 Zn 30	69.72 Ga 31	72.59 Ge 32	74.9216 As 33	78.96 Se 34	79.909 Br 35	83.80 Kr 36
5	85.47 Rb 37	87.62 Sr 38	88.905 Y 39	91.22 Zr 40	92.906 Nb 41	95.94 Mo 42	(99) Tc 43	101.07 Ru 44	102.905 Rh 45	106.4 Pd 46	107.870 Ag 47	112.40 Cd 48	114.82 In 49	118.69 Sn 50	121.75 Sb 51	127.60 Te 52	126.9044 I 53	131.30 Xe 54
6	132.905 Cs 55	137.34 Ba 56	138.91 La 57	178.49 Hf 72	180.948 Ta 73	183.85 W 74	186.2 Re 75	190.2 Os 76	192.2 Ir 77	195.09 Pt 78	196.967 Au 79	200.59 Hg 80	204.37 Tl 81	207.19 Pb 82	208.980 Bi 83	(210) Po 84	(210) At 85	(222) Rn 86
7	(223) Fr 87	(226) Ra 88	(227) Ac 89															

Lanthanide Series

140.12 Ce 58	140.907 Pr 59	144.24 Nd 60	(147) Pm 61	150.35 Sm 62	151.96 Eu 63	157.25 Gd 64	158.924 Tb 65	162.50 Dy 66	164.930 Ho 67	167.26 Er 68	168.934 Tm 69	173.04 Yb 70	174.97 Lu 71

Actinide Series

232.038 Th 90	(231) Pa 91	238.03 U 92	(237) Np 93	(242) Pu 94	(243) Am 95	(247) Cm 96	(247) Bk 97	(249) Cf 98	(254) Es 99	(253) Fm 100	(256) Md 101	(254) No 102	(257) Lw 103

Numbers in parentheses are mass numbers of most tables or most common isotope.

STANDARD OXIDATION POTENTIALS

Ionic Concentrations 1 molal in water at 25°C

Half cell Reaction	E° (volts)
$Li = Li^+ + e$	3.05
$Rb = Rb^+ + e^-$	2.93
$K = K^+ + e^-$	2.93
$Cs = Cs^+ + e^-$	2.92
$Ba = Ba^{++} + 2e^-$	2.90
$Sr = Sr^{++} + 2e^-$	2.89
$Ca = Ca^{++} + 2e^-$	2.87
$Na = Na^+ + e^-$	2.71
$Mg = Mg^{++} + 2e^-$	2.37
$Be = Be^{++} + 2e^-$	1.85
$Al = Al^{+++} + 3e^-$	1.66
$Mn = Mn^{++} + 2e^-$	1.18
$Zn = Zn^{++} + 2e^-$	0.76
$Cr = Cr^{+++} + 3e^-$	0.74
$Fe = Fe^{++} + 2e^-$	0.44
$Cd = Cd^{++} + 2e^-$	0.40
$Co = Co^{++} + 2e^-$	0.28
$Ni = Ni^{++} + 2e^-$	0.25
$Sn = Sn^{++} + 2e^-$	0.14
$Pb = Pb^{++} + 2e^-$	0.13
$H_2 = 2H^+ + 2e^-$	0.00
$Sn^{++} = Sn^{++++} + 2e^-$	—0.15
$Cu^+ = Cu^{++} + e^-$	—0.15
$Cu = Cu^{++} + 2e^-$	—0.34
$2I^- = I_2 + 2e^-$	—0.53
$Fe^{++} = Fe^{+++} + e^-$	—0.77
$2Hg = Hg_2^{++} + 2e^-$	—0.79
$Ag = Ag^+ + e^-$	—0.80
$Hg_2^{++} = 2Hg^{++} + 2e^-$	—0.92
$2Br^- = Br_2(l) + 2e^-$	—1.07
$NO + 2H_2O = NO_3^- + 4H^+ + 4e^-$	—0.96
$2H_2O = O_2 + 4H^+ + 4e^-$	—1.23
$2Cr^{+++} + 7H_2O = Cr_2O_7^{--} + 14H^+ + 6e^-$	—1.33
$2Cl^- = Cl_2 + 2e^-$	—1.36
$Au = Au^{+++} + 3e^-$	—1.50
$Mn^{+2} + 4H_2O = MnO_4^- + 8H^+ + 5e$	—1.51
$2F^- = F_2 + 2e^-$	—2.87

′	44°		′	′	44°		′	′	44°		′
	Tang	Cotang			Tang	Cotang			Tang	Cotang	
0	.96569	1.03553	60	20	.97700	1.02355	40	40	.98843	1.01170	20
1	.96625	1.03493	59	21	.97756	1.02295	39	41	.98901	1.01112	19
2	.96681	1.03433	58	22	.97813	1.02236	38	42	.98958	1.01053	18
3	.96738	1.03372	57	23	.97870	1.02176	37	43	.99016	1.00994	17
4	.96794	1.03312	56	24	.97927	1.02117	36	44	.99073	1.00935	16
5	.96850	1.03252	55	25	.97984	1.02057	35	45	.99131	1.00876	15
6	.96907	1.03192	54	26	.98041	1.01998	34	46	.99189	1.00818	14
7	.96963	1.03132	53	27	.98098	1.01939	33	47	.99247	1.00759	13
8	.97020	1.03072	52	28	.98155	1.01879	32	48	.99304	1.00701	12
9	.97076	1.03012	51	29	.98213	1.01820	31	49	.99362	1.00642	11
10	.97133	1.02952	50	30	.98270	1.01761	30	50	.99420	1.00583	10
11	.97189	1.02892	49	31	.98327	1.01702	29	51	.99478	1.00525	9
12	.97246	1.02832	48	32	.98384	1.01642	28	52	.99536	1.00467	8
13	.97302	1.02772	47	33	.98441	1.01583	27	53	.99594	1.00408	7
14	.97359	1.02713	46	34	.98499	1.01524	26	54	.99652	1.00350	6
15	.97416	1.02653	45	35	.98556	1.01465	25	55	.99710	1.00291	5
16	.97472	1.02593	44	36	.98613	1.01406	24	56	.99768	1.00233	4
17	.97529	1.02533	43	37	.98671	1.01347	23	57	.99826	1.00175	3
18	.97586	1.02474	42	38	.98728	1.01288	22	58	.99884	1.00116	2
19	.97643	1.02414	41	39	.98786	1.01229	21	59	.99942	1.00058	1
20	.97700	1.02355	40	40	.98843	1.01170	20	60	1.00000	1.00000	0
′	Cotang	Tang	′	′	Cotang	Tang	′	′	Cotang	Tang	′
	45°				45°				45°		

APPENDIX 8. EQUIVALENCE OF SOME UNITS OF WEIGHT AND MEASURE

Underlined figures are exact; others are rounded off. Condensed from Letter Circular 1035 (Jan., 1960) of the U.S. Department of Commerce, National Bureau of Standards, Washington 25, D.C.

1 in. = 0.08333 ft; 0.02778 yd; 2.54 cm.
1 ft = 12 in.; 0.6061 rods; 0.3048 m; 0.0001894 mi
1 yd = 3 ft; 0.9144 m; 0.1818 rods; 0.0005682 mi
1 m = 1000 mm; 100 cm; 10 decimeters 0.1 dekameters; 0.01 hectometers; 0.001 km
1 m = 39.37 in.; 3.2808 ft; 1.0936 yd; 0.0006214 mi
1 fathom = 6 ft; 1.8288 m
1 rod = 198 in.; 16.5 ft; 5.5 yd
1 chain = 100 links; 66 ft; 0.0125 mi; 20.117 m;
1 mi = 5280 ft; 1760 yd; 320 rods; 1609.344 m;
1 nautical mi = 6076.1 ft; 1852 m
1 sq in. = 6.4516 sq cm; 0.00694 sq ft
1 sq ft = 144 sq in.; 0.1111 sq yd; 0.0929 sq m
1 sq yd = 1296 sq in.; 9 sq ft; 0.8361 sq m
1 sq m = 1551 sq in.; 10.76 sq ft; 1.196 sq yd
1 acre = 43560 sq ft; 4840 sq yd; 0.405 hectares; 0.00156 sq mi
1 sq mi = 640 acres; 259 hectares
1 cu cm = 0.0610 cu in.; 0.000001 cu m
1 cu in. = 0.0005787 cu ft; 16.387 cu cm
1 cu ft = 1728 cu in.; 0.03704 cu yd; 0.0283 cu m; 7.480 gal (U.S.)
1 cu yd = 46656 cu in.; 27 cu ft; 0.7645 cu m
1 cu m = 35.315 cu ft; 1.3079 cu yd
1 gal (U.S.) = 231 cu in; 128 fl oz; 0.1337 cu ft; 3.785 liters
1 liter = 61.025 cu in.; 0.2642 gal (U.S.); 0.0353 cu ft
1 acre ft = 43560 cu ft; 325851 gal (U.S.); 1233.5 cu m
1 oz (avoir.) = 437.5 grains; 28.350 grams; 0.0625 lbs (avoir.)
1 gram = 15.432 grains; 0.03527 oz (avoir.); 0.002205 lbs (avoir.)
1 short (net) ton = 2000 lbs; 0.9072 metric ton; 0.8929 long (gross) ton

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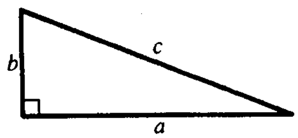
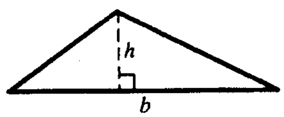
GEOMETRIC FORMULAS

Triangles



Right Triangle

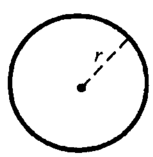
Pythagorean Theorem $a^2 + b^2 = c^2$



Any Triangle

Area $A = \frac{1}{2}bh$

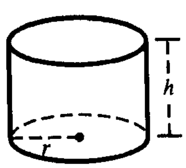
Circles



Area $A = \pi r^2$

Circumference $C = 2\pi r$

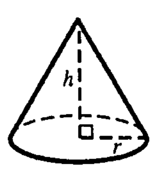
Cylinders



Surface Area $S = 2\pi r^2 + 2\pi rh$

Volume $V = \pi r^2 h$

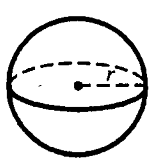
Cones



Surface Area $S = \pi r^2 + \pi r\sqrt{r^2 + h^2}$

Volume $V = \frac{1}{3}\pi r^2 h$

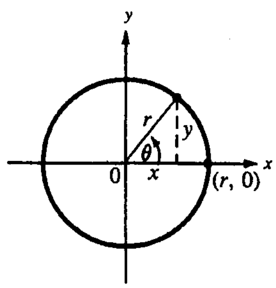
Spheres



Surface Area $S = 4\pi r^2$

Volume $V = \frac{4}{3}\pi r^3$

TRIGONOMETRIC FUNCTIONS AND LAWS



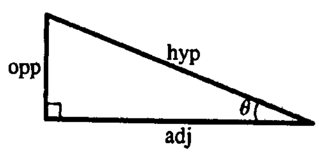
- **Definitions Based on the Circle**

$\cos\theta = \frac{x}{r}$ $\quad$ $\sec\theta = \frac{r}{x}$

$\sin\theta = \frac{y}{r}$ $\quad$ $\csc\theta = \frac{r}{y}$

$\tan\theta = \frac{y}{x}$ $\quad$ $\cot\theta = \frac{x}{y}$

For the unit circle, $r = 1$

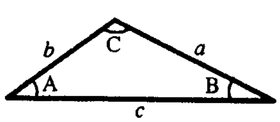


- **Definitions Based on the Right Triangle**

$\cos\theta = \frac{\text{adj}}{\text{hyp}}$ $\quad$ $\sec\theta = \frac{\text{hyp}}{\text{adj}}$

$\sin\theta = \frac{\text{opp}}{\text{hyp}}$ $\quad$ $\csc\theta = \frac{\text{hyp}}{\text{opp}}$

$\tan\theta = \frac{\text{opp}}{\text{adj}}$ $\quad$ $\cot\theta = \frac{\text{adj}}{\text{opp}}$



- **Law of Sines**

$$\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}$$

- **Law of Cosines**

$$a^2 = b^2 + c^2 - 2\,bc\cos A$$

$$\cos A = \frac{b^2 + c^2 - a^2}{2\,bc}$$

ALGEBRAIC PROPERTIES AND FORMULAS

- **Properties of Inequalities**

If $a < b$, then $a + c < b + c$
If $a < b$ and $b < c$, then $a < c$
If $a < b$ and $c > 0$, then $ac < bc$
If $a < b$ and $c < 0$, then $ac > bc$
If $ab > 0$ and $a < b$, then $\frac{1}{a} > \frac{1}{b}$

- **Properties of Absolute Value**

$|a| = a$ if $a \geq 0$
$|a| = -a$ if $a < 0$
$|-a| = |a|$
$|ab| = |a||b|$
$|a + b| \leq |a| + |b|$
$|a|^2 = a^2$

- **Properties of Exponents**

$a \neq 0$ and m and n are integers
$a^n = \underbrace{a \cdot a \cdot a \cdot \ldots a}_{n \text{ factors}}$ if $n > 0$
$a^{1/n}$ = the n^{th} root of a
$a^{-n} = \frac{1}{a^n}$
$a^{m/n} = (a^{1/n})^m$

If p and q are positive rational numbers
$(a^p)^q = a^{p \cdot q} = (a^{1/p})^q$
$a^{p/q} = (a^{1/q})^p$
$a^p a^q = a^{p+q}$
$\frac{a^p}{a^q} = a^{p-q}$
$(ab)^p = a^p b^p$
$\left(\frac{a}{b}\right)^p = \frac{a^p}{b^p}$
$\left(\frac{a}{b}\right)^{-1} = \frac{1}{(a/b)} = \frac{b}{a}$

- **Properties of Polynomials**

$(x + y)^2 = x^2 + 2xy + y^2$
$(x - y)^2 = x^2 - 2xy + y^2$
$(x + y)^3 = x^3 + 3x^2y + 3xy^2 + y^3$
$(x - y)^3 = x^3 - 3x^2y + 3xy^2 - y^3$
$x^2 - y^2 = (x + y)(x - y)$
$x^3 + y^3 = (x + y)(x^2 - xy + y^2)$
$x^3 - y^3 = (x - y)(x^2 + xy + y^2)$

- **Properties of Logarithms**

Suppose $a \neq 1$, $a > 0$, $x > 0$, and $w > 0$.
$a^{\log_a x} = x$
$\log_a a^x = x$
$\log_a a = 1$
$\log_a 1 = 0$
$\log_a xw = \log_a x + \log_a w$
$\log_a x^r = r \log_a x$
$\log_a \frac{x}{w} = \log_a x - \log_a w$
$\log x = \log_{10} x$
$\ln x = \log_e x$

- **The Quadratic Formula**

$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ are the solutions to
$ax^2 + bx + c = 0$

- **The Binomial Formula**

$$(x + y)^n = x^n + \binom{n}{1}x^{n-1}y + \binom{n}{2}x^{n-2}y^2 + \cdots + \binom{n}{j}x^{n-j}y^j + \cdots + \binom{n}{n-1}xy^{n-1} + y^n$$

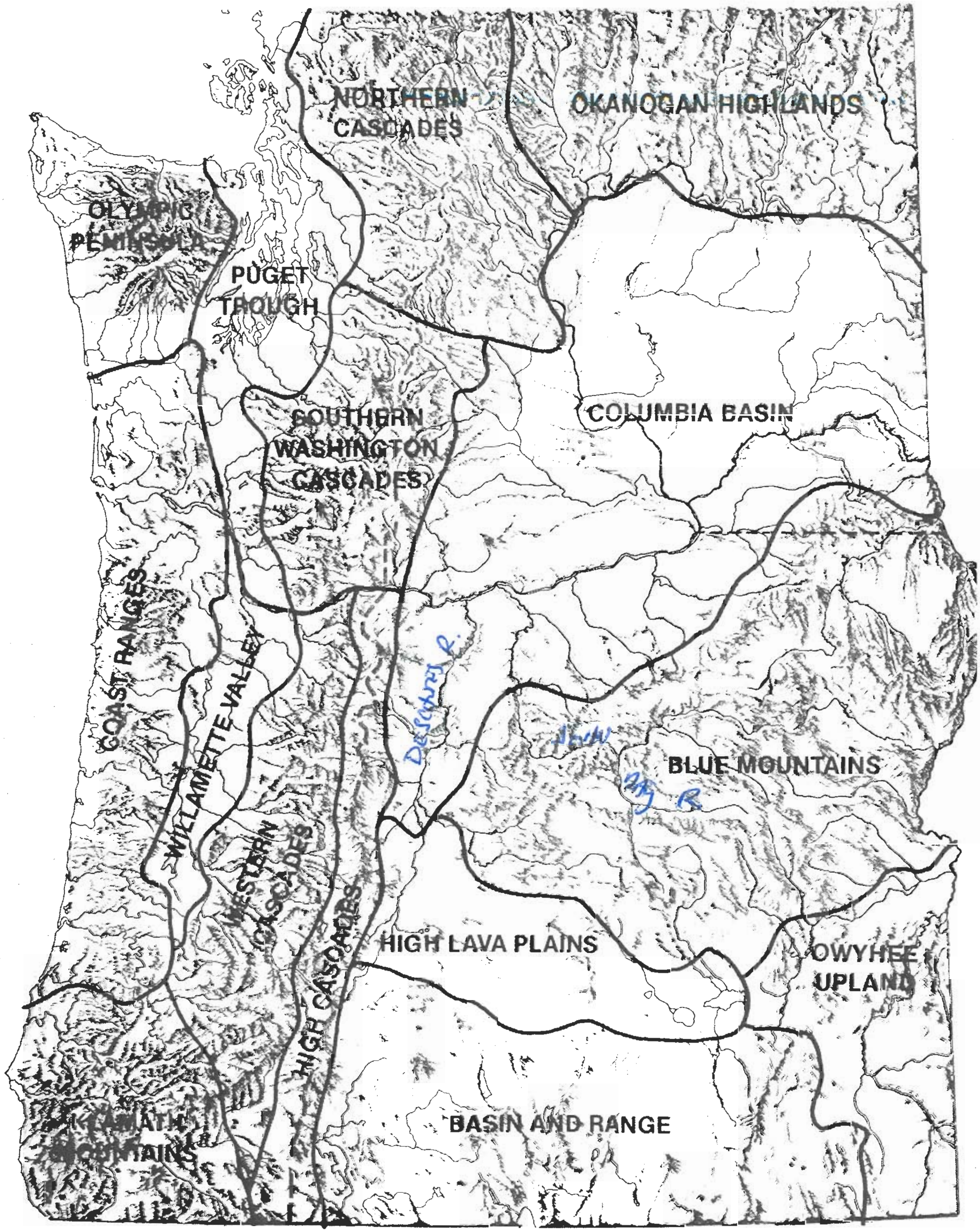
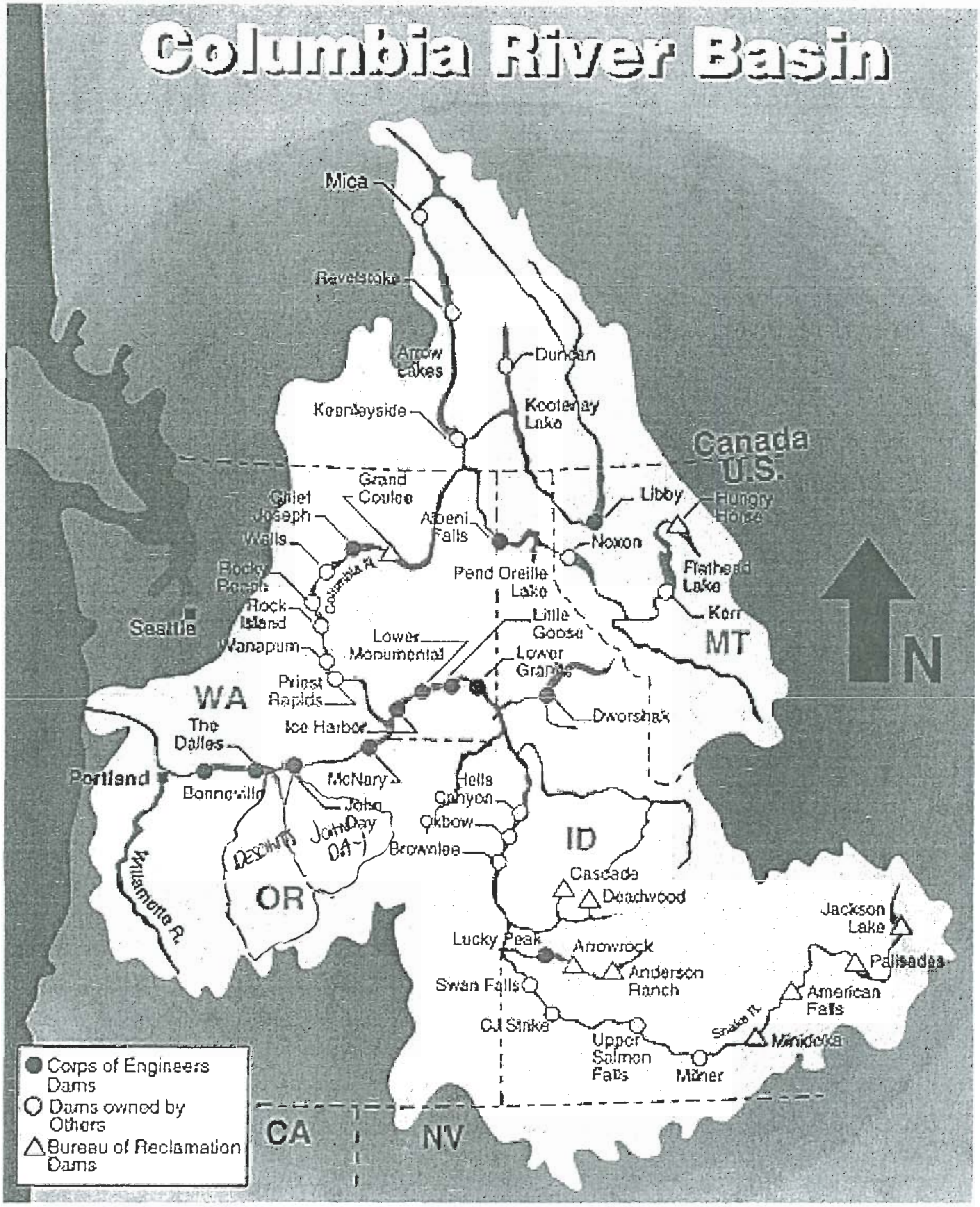


Figure 2. — Physiographic and geological provinces of Oregon and Washington.


Columbia River Basin
Mica
Revelstoke
Arrow Lakes
Duncan
Keenleyside
Kootenay Lake
Canada
U.S.
Grand Coulee
Chief Joseph
Libby
Hungry Horse
Albeni Falls
Wells
Noxon
Columbia R.
Flathead Lake
Pend Oreille Lake
Rocky Reach
Rock Island
Kerr
Seattle
Little Goose
Wanapum
Lower Monumental
MT
Lower Granite
Priest Rapids
N
WA
Dworshak
The Dalles
Ice Harbor
Portland
McNary
Hells Canyon
Bonneville
John Day
Oxbow
Brownlee
ID
Willamette R.
OR
Cascade
Deadwood
Jackson Lake
Lucky Peak
Arrowrock
Palisades
Anderson Ranch
Swan Falls
American Falls
CJ Strike
Snake R.
Minidoka
Upper Salmon Falls
Milner
Corps of Engineers Dams
Dams owned by Others
Bureau of Reclamation Dams
CA
NV

131A

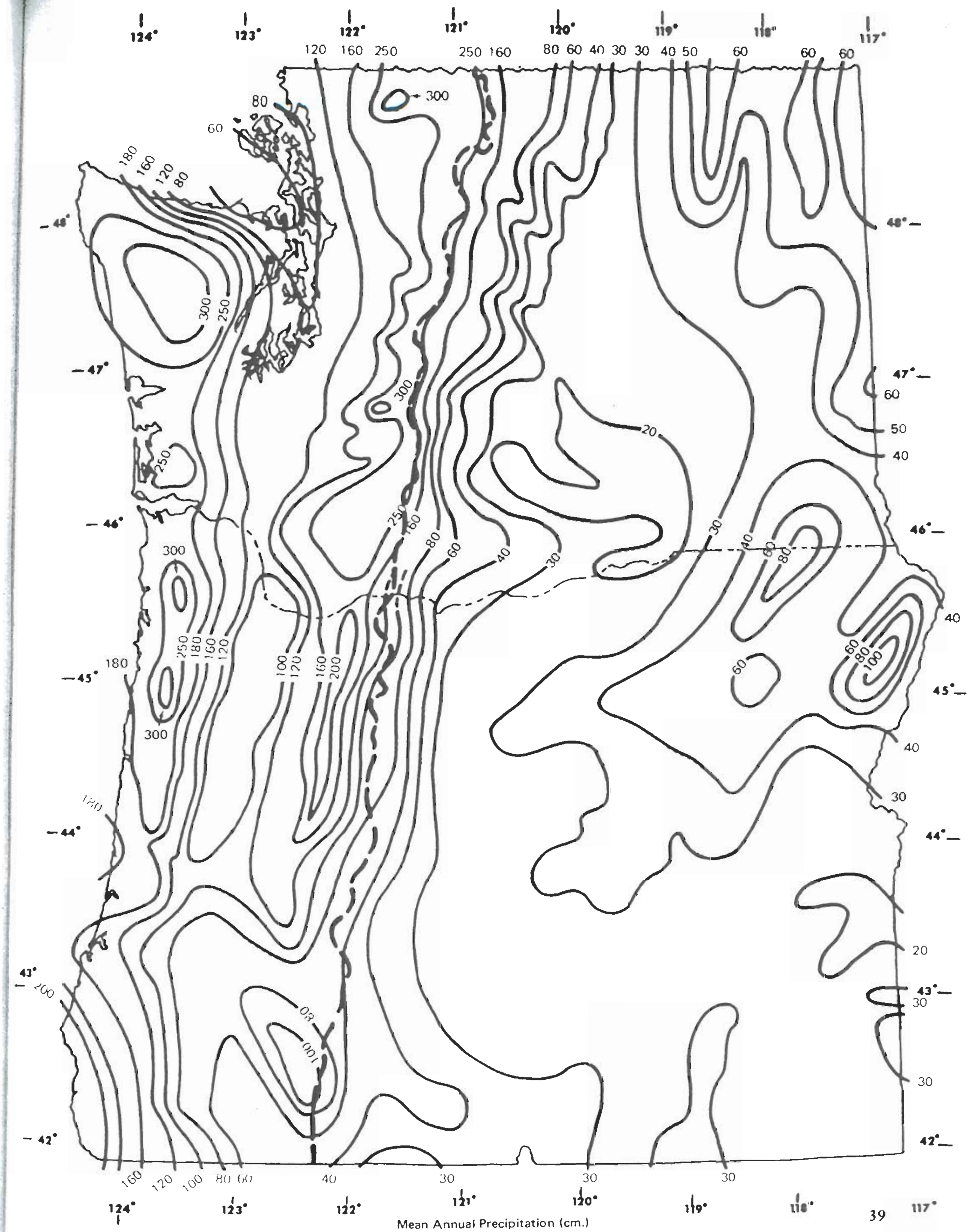


Figure 23. — Mean annual precipitation in Oregon and Washington (U.S. Weather Bureau 1960a, b).

NAL

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Province
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PSA

PR

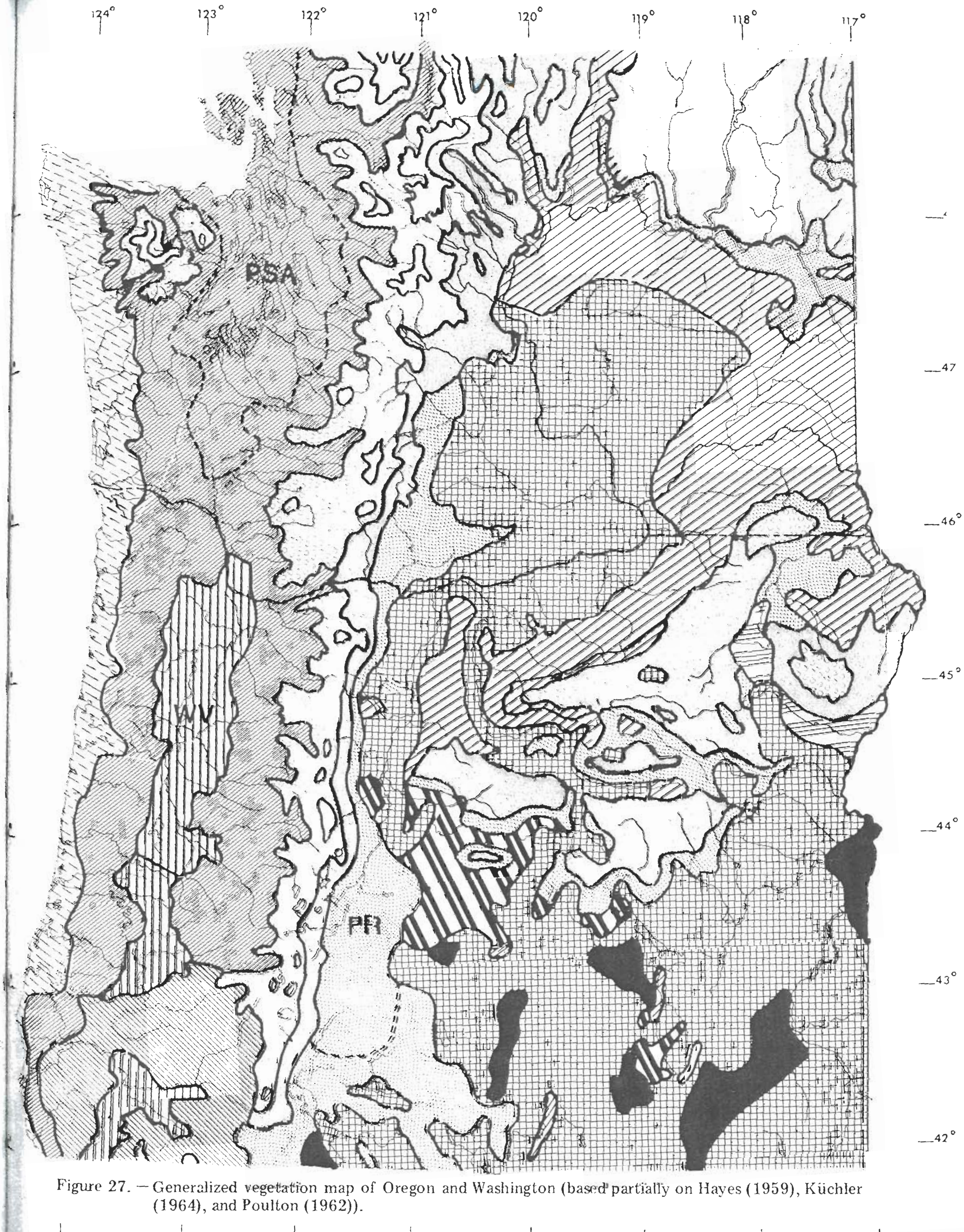

Figure 27. — Generalized vegetation map of Oregon and Washington (based partially on Hayes (1959), Küchler (1964), and Poulton (1962)).

124° 123° 122° 121° 120° 119° 118° 117°

(SEE NEXT PAGE FOR KEY)

CHAPTER III. MAJOR VEGETATIONAL AREAS

Vegetation—natural plant communities—can be organized in numerous ways. Unfortunately, no single system is completely satisfactory either in providing a logical "cell" for all community types or a structure suitable for all users of a volume of this type. It is much the same problem that exists in plant taxonomy, i.e., structuring a linear system when a multidimensional classification is really necessary.

We begin our classifications by recognizing four major groupings (fig. 27): (1) forests, (2) grasslands and shrub-grass communities (hereafter referred to as steppe and shrub-steppe, respectively), (3) interior valleys of western Oregon (Chapter V)[1] and (4) timberline (subalpine parklands) and alpine regions (Chapter X).[2] The two broad physiognomic divisions of forest and steppe can be further divided geographically. Distinctive forest regions are found in western Washington and northwestern Oregon (Chapter IV), interior southwestern Oregon (Chapter VI), and in eastern Washington and Oregon (Chapter VII). Steppe and shrub-steppe are separable into those found in the Columbia Basin Province (primarily in eastern Washington) (Chapter VIII) and in central and southeastern Oregon (Chapter IX).

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[1] Here and throughout this book, western Washington or Oregon refers to the region west of the crest of the Cascade Range and eastern Washington or Oregon to the area east of the crest.

[2] Communities found on unique, specialized habitats or in geographic anomalies form a fifth group; they are considered in Chapter XI and will not be discussed further here.

Legend

FORESTED REGIONS

- *Picea sitchensis* Zone
- *Tsuga heterophylla* Zone
  - Puget Sound area [PSA]
- Mixed Conifer and Mixed Evergreen Zones
- *Pinus ponderosa* Zone (broad sense)
  - Pumice region [PR]
- *Abies grandis* and *Pseudotsuga menziesii* Zones
- Subalpine forests (including *Abies amabilis*, *A. lasiocarpa*, *A. magnifica shastensis*, and *Tsuga mertensiana* Zones)

INTERIOR VALLEYS OF WESTERN OREGON

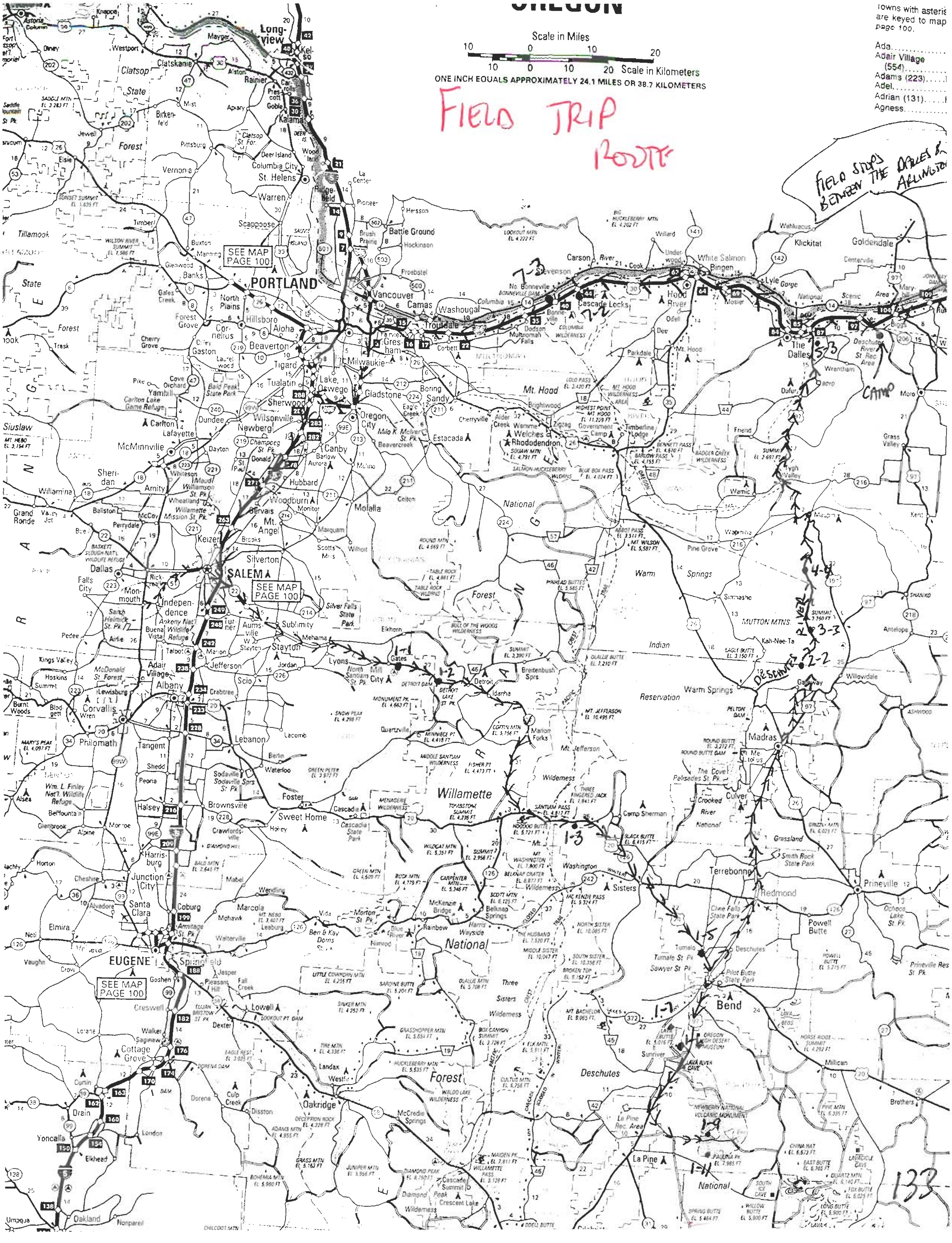
- Willamette valley [WV]
- Umpqua and Rogue valleys

STEPPE REGIONS

- STEPPE (without *Artemisia tridentata*)
- SHRUB-STEPPE (with *Artemisia tridentata*)
- DESERT SHRUB
- *Juniperus occidentalis* Zone

TIMBERLINE AND ALPINE REGIONS

132B


OREGON
Scale in Miles
10 0 10 20
10 0 10 20 Scale in Kilometers
ONE INCH EQUALS APPROXIMATELY 24.1 MILES OR 38.7 KILOMETERS
Towns with asterisk are keyed to map page 100.
Ada
Adair Village (554)
Adams (223)
Adel
Adrian (131)
Agness
FIELD TRIP ROUTE
FIELD STOPS BETWEEN THE DALLES & ARLINGTON
CAMP
PORTLAND
SALEM
EUGENE
SEE MAP PAGE 100
Vancouver
Longview
Astoria
The Dalles
Hood River
Mt. Hood
Madras
Redmond
Bend
Prineville
Sisters
Albany
Corvallis
Springfield
Oakridge
La Pine
Willamette National Forest
Deschutes National Forest
Warm Springs Indian Reservation
133

ARE WE HAVING FUN YET??

Yeats et al., 1996

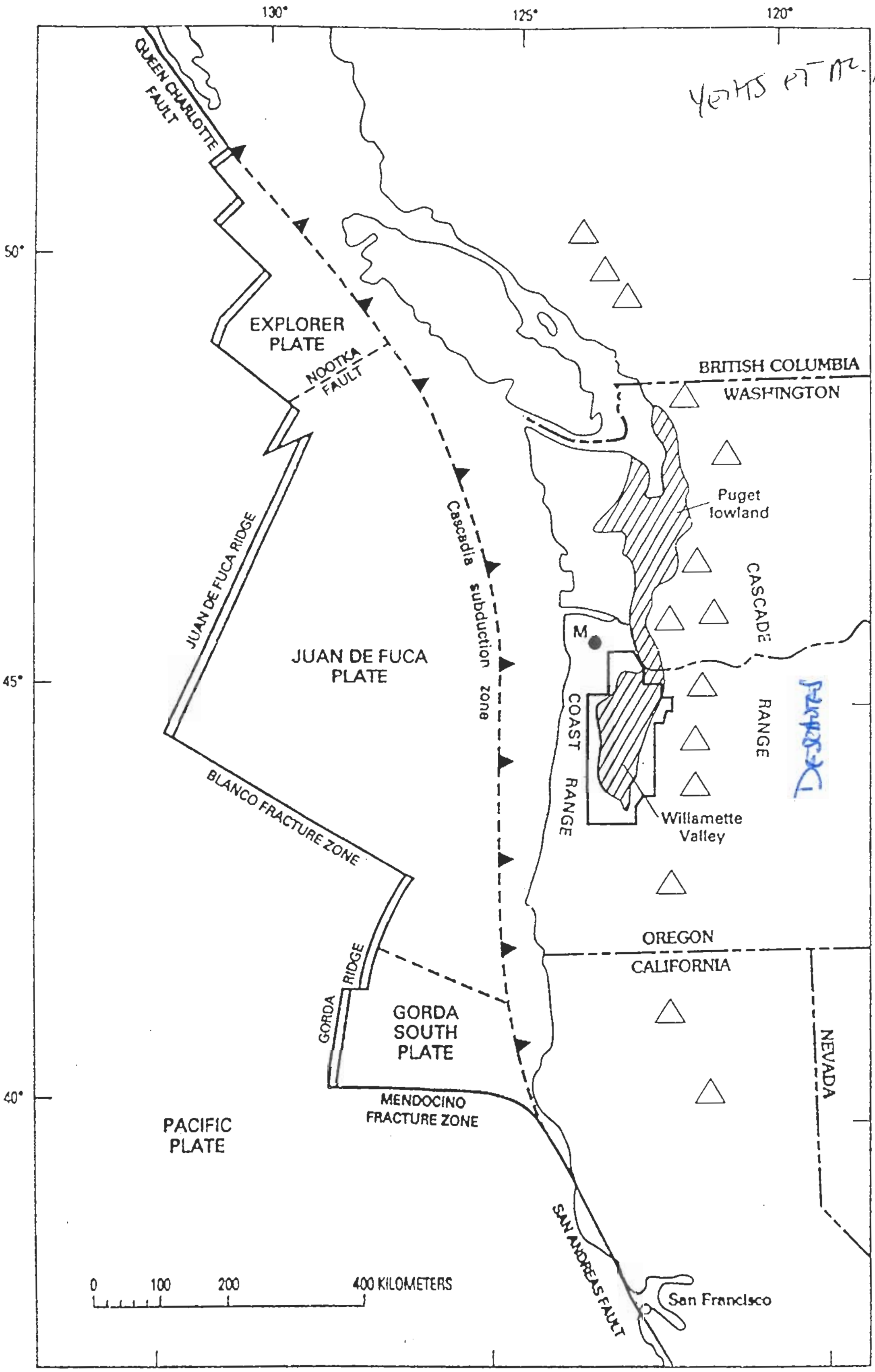
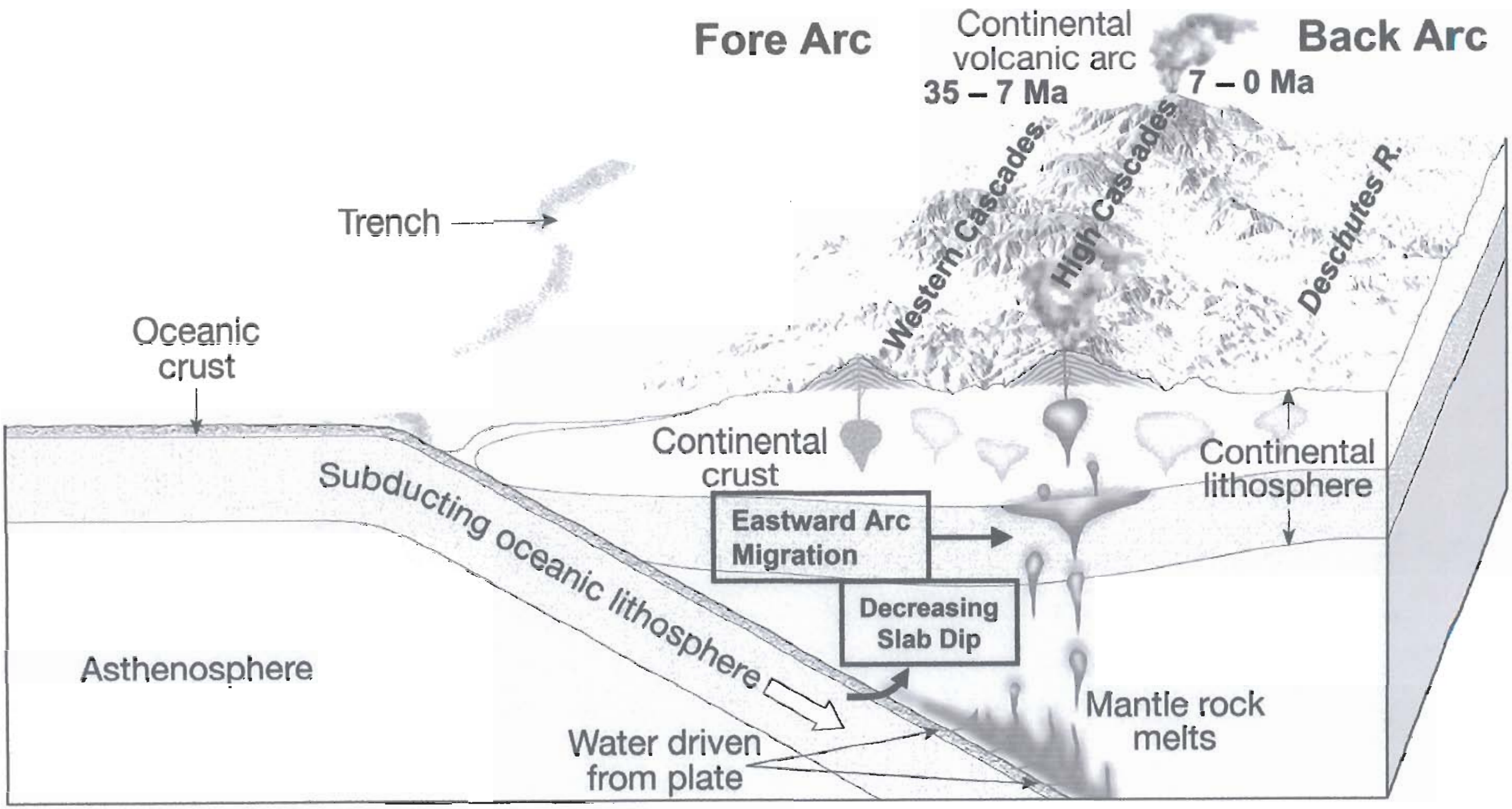


Figure 76. Plate boundaries of the Pacific Northwest showing locations of tectonic features and the Willamette Valley study area. Heavy line, study-area boundary; hatched area, Willamette Valley and Puget lowland; sawteeth denote upper plate of thrust fault. Major stratovolcanoes are shown by open triangles. Dot labeled "M" in northwestern Oregon is the Mist gas field.

133B

Cascadia Subduction Zone



133B-1

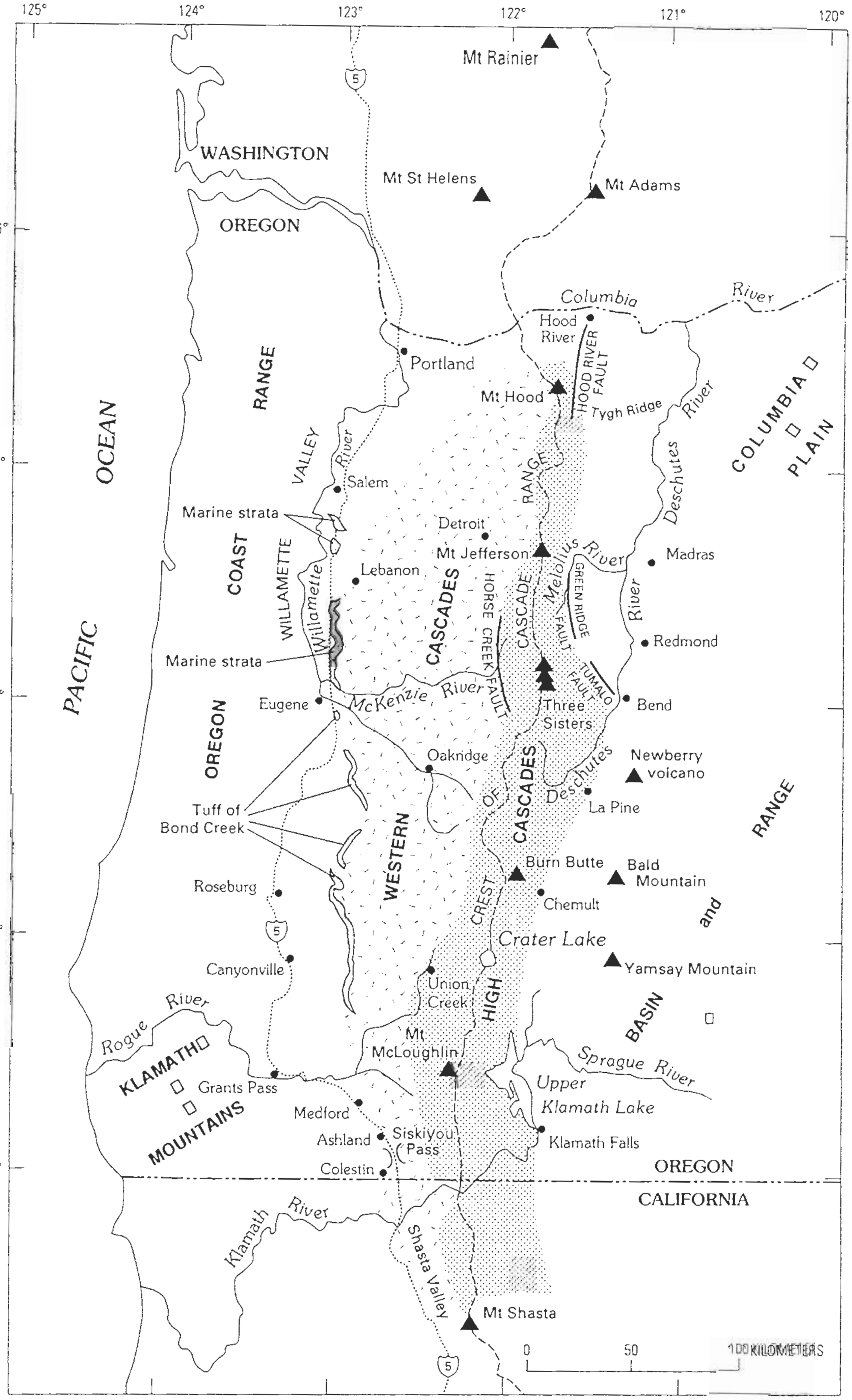


Figure 1. Index map showing geographic locations, physiographic provinces and subdivisions, and some faults and lithologic units mentioned in text. Approximate extent of Western and High Cascades (patterned areas) shown for Oregon and northern California. These two subprovince names are not used in Washington or south of Mount Shasta in California, where the Cascade Range lacks a continuous belt of upper Pliocene and Quaternary volcanic rocks.

133C

(1) rhyolite, more than 70 percent SiO_2; (2) dacite, 62 to 70 percent SiO_2; (3) andesite, 57 to 62 percent SiO_2; (4) basalt and basaltic andesite (mafic andesite or olivine andesite of many workers), less than 57 percent SiO_2.

Ideally, it would be better to subdivide the last category into two separate groups, basalt and basaltic andesite. Maps of the major volcanoes now have such detail (see sources of mapping), and many parts of the Quaternary arc (for example, from Mount Jefferson to Columbia River) could be subdivided fairly realistically. In contrast, maps for other extensive areas (including our own early reconnaissance work) lack sufficient detail and supporting chemical analyses. Consequently the entire compositional range of basalt and basaltic andesite is shown as a single unit.

AGE

Age is another important criterion used to categorize Cascade volcanism. The choices of temporal subdivisions, while somewhat arbitrary, are based on a mixture of traditional chronostratigraphic units and the more or less instantaneous geologic events (such as magnetic reversals) that punctuate Earth's history.

Map-unit ages are based on more than 600 isotopic ages (Cascade Range in Oregon as of December, 1994). We stress, however, that this map shows geology as interpreted from field studies; lithostratigraphic relations take precedent over isotopic determinations. For example, in order to clearly depict lithologic relations with overlying and underlying units, an andesitic sequence (unit Ta_1) shown as 7 to 2 m.y. in age might include a few andesite flows whose ages are somewhat outside this interval.

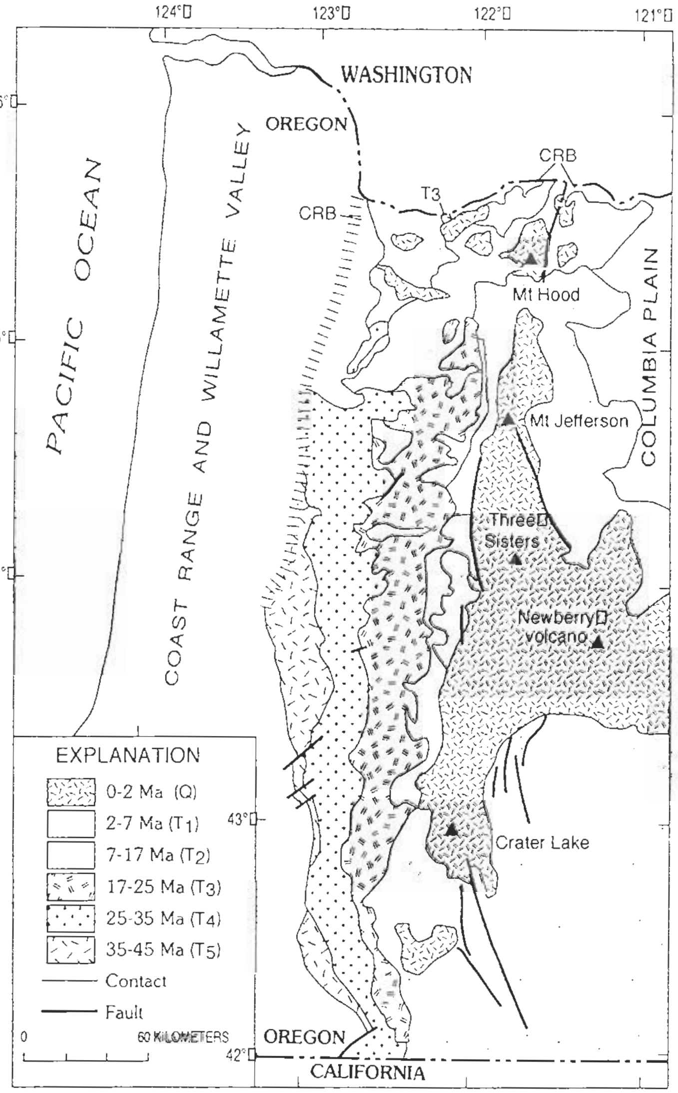


Figure 3. Generalized distribution by age of rock in Cascade Range of Oregon. Hachures on northwest side of patterned area shows limit of mapped area on map sheet 1. CRB, Columbia River Basalt Group; Ma million years before present. Symbology (Q, T_1, T_2, and so on) correspond to broad division of time as discussed in pamphlet.

The past 2 million years (defined as the Quaternary period according to Harland and others, 1982) is subdivided into shorter intervals than is the time period from 45 to 2 million years ago because of the important inverse relation between age and geothermal potential (Smith and Shaw, 1975). However, many Quaternary rocks lack isotopic age determinations. Therefore, thermal remanent magnetization and geomorphic features such as depth of erosion, topographic inversion of intracanyon lava flows, and the relative youthfulness of adjacent volcanoes were used to assign undated younger rocks to particular age divisions. Relative geomorphic youth was used effectively to date Quaternary volcanic rocks, because their volcanic landforms are locally well preserved and adjacent volcanoes of different ages may show sharp geomorphic contrasts.

The intervals chosen and reasons for selecting them are discussed below. The subscript used for each interval corresponds to the subscripts used in the Description of Map Units on map sheet 1.

Q_1, **0 to 12,000 years ago:** This interval includes the entire Holocene and extends back into latest Pleistocene time to the end of the last major glaciation in the Cascade Range (Waitt and Thorson, 1983; Porter and others, 1983). Most Cascade researchers relate young volcanic deposits to glacial stratigraphic successions; thus, the 12,000-yr limit for this map unit is useful. Young volcanic deposits dated by the carbon-14 (^{14}C) method are readily assigned to this unit.

Q_2, **12,000 to 25,000 years ago:** This interval extends from the end of the last major glaciation in the Cascade Range backward to a time for which ^{14}C ages are still fairly easily determined (although few radiometric ages in this interval

133D

PRE-QUATERNARY STRATIGRAPHY OF THE CASCADE RANGE, AND SURROUNDING REGION (FROM SHERROD AND SMITH, 199)

Yonna Formation of former usage (2-7 Ma)					Ts_1
Troutdale Formation (2-7 Ma)					Ts_1
Deschutes Formation (2-7 Ma)	Tb_1		Td_1		Ts_1
Sandy River Formation (2-7 Ma)					Ts_1
Dalles Formation (7-17 Ma)		Ta_2			Ts_2
Rhododendron Formation (7-17 Ma)		Ta_2			
Sardine Formation (7-17 Ma)	Tb_2	Ta_2			
Columbia River Basalt Group	Tcu	(6-13.5 Ma)			
	Tcl	(14.5-17 Ma)			
Breitenbush Tuff (17-25 Ma)	Tb_3	Ta_3			
Colestin Formation (25-35 Ma)	Tb_4		Td_4		Ts_4
Little Butte Volcanics (17-25 Ma)	Tb_3	Ta_3	Td_3	Tr_3	Ts_3
Little Butte Volcanics (35-45 Ma)	Tb_4	Ta_4	Td_4	Tr_4	Ts_4
John Day Formation (17-25 Ma)				Tr_4	Ts_3
Eugene Formation (35-45 Ma)					Ts_5
Fisher Formation (35-45 Ma)	Tb_5	Ta_5			Ts_5
Spencer Formation (35-45 Ma					Ts_5
Clarno Formation (35-45 Ma)		Ta_5			

(SEE GEOLOGIC TIME SCALE ON NEXT PAGE

DECADE OF NORTH AMERICAN GEOLOGY
GEOLOGIC TIME SCALE

DNAG

GEOLOGICAL SOCIETY OF AMERICA

CENOZOIC

PERIOD	EPOCH		AGE	PICKS (Ma)
QUATERNARY	HOLOCENE			0.01
	PLEISTOCENE		CALABRIAN	1.6
TERTIARY – NEOGENE	PLIOCENE	L	PIACENZIAN	3.4
		E	ZANCLEAN	5.3
	MIOCENE	L	MESSINIAN	6.5
			TORTONIAN	11.2
		M	SERRAVALLIAN	15.1
			LANGHIAN	16.6
		E	BURDIGALIAN	21.8
			AQUITANIAN	23.7
TERTIARY – PALEOGENE	OLIGOCENE	L	CHATTIAN	30.0
		E	RUPELIAN	36.6
	EOCENE	L	PRIABONIAN	40.0
		M	BARTONIAN	43.6
			LUTETIAN	52.0
		E	YPRESIAN	57.8
	PALEOCENE	L	SELANDIAN: THANETIAN	60.6
			SELANDIAN: UNNAMED	63.6
		E	DANIAN	66.4

MESOZOIC

PERIOD	EPOCH	AGE	PICKS (Ma)	UNCERT. (m.y.)
CRETACEOUS			66.4	
	LATE	MAASTRICHTIAN	74.5	4
		CAMPANIAN	84.0	4.5
		SANTONIAN	87.5	
		CONIACIAN	88.5	2.5
		TURONIAN	91	
		CENOMANIAN	97.5	2.5
	EARLY	ALBIAN	113	4
		APTIAN	119	9
	NEOCOMIAN	BARREMIAN	124	9
		HAUTERIVIAN	131	8
		VALANGINIAN	138	5
		BERRIASIAN	144	5
JURASSIC	LATE	TITHONIAN	152	12
		KIMMERIDGIAN	156	6
		OXFORDIAN	163	15
	MIDDLE	CALLOVIAN	169	15
		BATHONIAN	176	34
		BAJOCIAN	183	34
		AALENIAN	187	34
	EARLY	TOARCIAN	193	28
		PLIENSBACHIAN	198	32
		SINEMURIAN	204	18
		HETTANGIAN	208	18
TRIASSIC	LATE	NORIAN	225	8
		CARNIAN	230	22
	MIDDLE	LADINIAN	235	10
		ANISIAN	240	22
	EARLY	SCYTHIAN	245	20

RAPID POLARITY CHANGES

PALEOZOIC

PERIOD	EPOCH	AGE	PICKS (Ma)	UNCERT. (m.y.)
PERMIAN			245	20
	LATE	TATARIAN	253	20
		KAZANIAN		
		UFIMIAN	258	24
		KUNGURIAN	263	22
	EARLY	ARTINSKIAN	268	12
		SAKMARIAN		
		ASSELIAN	286	12
CARBONIFEROUS – PENNSYLVANIAN	LATE	GZELIAN (S.)		
		KASIMOVIAN	296	10
		MOSCOVIAN (W.)		
		BASHKIRIAN	315	20
CARBONIFEROUS – MISSISSIPPIAN	EARLY	SERPUKHOVIAN (N.)	320	
			333	22
		VISEAN	352	8
		TOURNAISIAN	360	10
DEVONIAN	LATE	FAMENNIAN	367	12
		FRASNIAN	374	18
	MIDDLE	GIVETIAN	380	18
		EIFELIAN	387	28
	EARLY	EMSIAN	394	22
		SIEGENIAN	401	18
		GEDINNIAN	408	12
SILURIAN	LATE	PRIDOLIAN	414	12
		LUDLOVIAN	421	12
	EARLY	WENLOCKIAN	428	8
		LLANDOVERIAN	438	12
ORDOVICIAN	LATE	ASHGILLIAN	448	12
		CARADOCIAN	458	16
	MIDDLE	LLANDEILAN	468	16
		LLANVIRNIAN	478	16
	EARLY	ARENIGIAN	488	20
		TREMADOCIAN	505	32
CAMBRIAN	LATE	TREMPEALEAUAN		
		FRANCONIAN		
		DRESBACHIAN	523	36
	MIDDLE		540	28
	EARLY		570	

PRECAMBRIAN

EON	ERA	BDY. AGES (Ma)
		570
PROTEROZOIC	LATE	900
	MIDDLE	1600
	EARLY	2500
ARCHEAN	LATE	3000
	MIDDLE	3400
	EARLY	3800?

133F

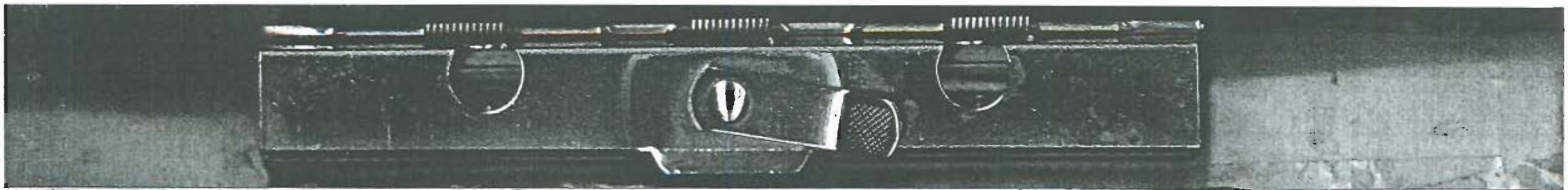


TABLE 2. DIVISIONS OF THE QUATERNARY AND THEIR BOUNDARY DATES AS USED IN THIS VOLUME*

Division		Boundary (top)
		Present
	Holocene (Oxygen-isotope stage 1)	
		10 to 12 ka
Late Pleistocene	Late Wisconsin (Oxygen-isotope stage 2)	
		~28 ka
Late Pleistocene	Middle Wisconsin of Richmond and Fullerton (1986) (O-isotope stages 3 and 4)	
		~71 ka
Late Pleistocene	Late Sangamon (Early Wisconsin and Eowisconsin of Richmond and Fullerton, 1986; O-isotope stages 5a-5d)	
		~115 ka
Late Pleistocene	Sangamon of Richmond and Fullerton (1986) (O-isotope stage 5e)	
		~128 ka†
Middle Pleistocene	Late-Middle Pleistocene (Illinoian of Richmond and Fullerton, 1986; O-isotope stages 6-8)	
		~300 ka
Middle Pleistocene	Middle-Middle Pleistocene of Richmond and Fullerton (1986) (O-isotope stages 9-15)	
		~620 ka§
Middle Pleistocene	Early-Middle Pleistocene (Richmond and Fullerton, 1986) (O-isotope stages 16-19)	
	(Matuyama-Brunhes Chronozone boundary)	750-775 ka**
	Early Pleistocene	
	Upper boundary of Olduvai Subcron	1.65 Ma
	or Gauss-Matuyama Chron boundary	2.48 Ma
	Pliocene	
		5.0-5.5 Ma‡
	Miocene	

OCCULAR HT = 1.68m

PACE 36ft/15 STEPS

Length

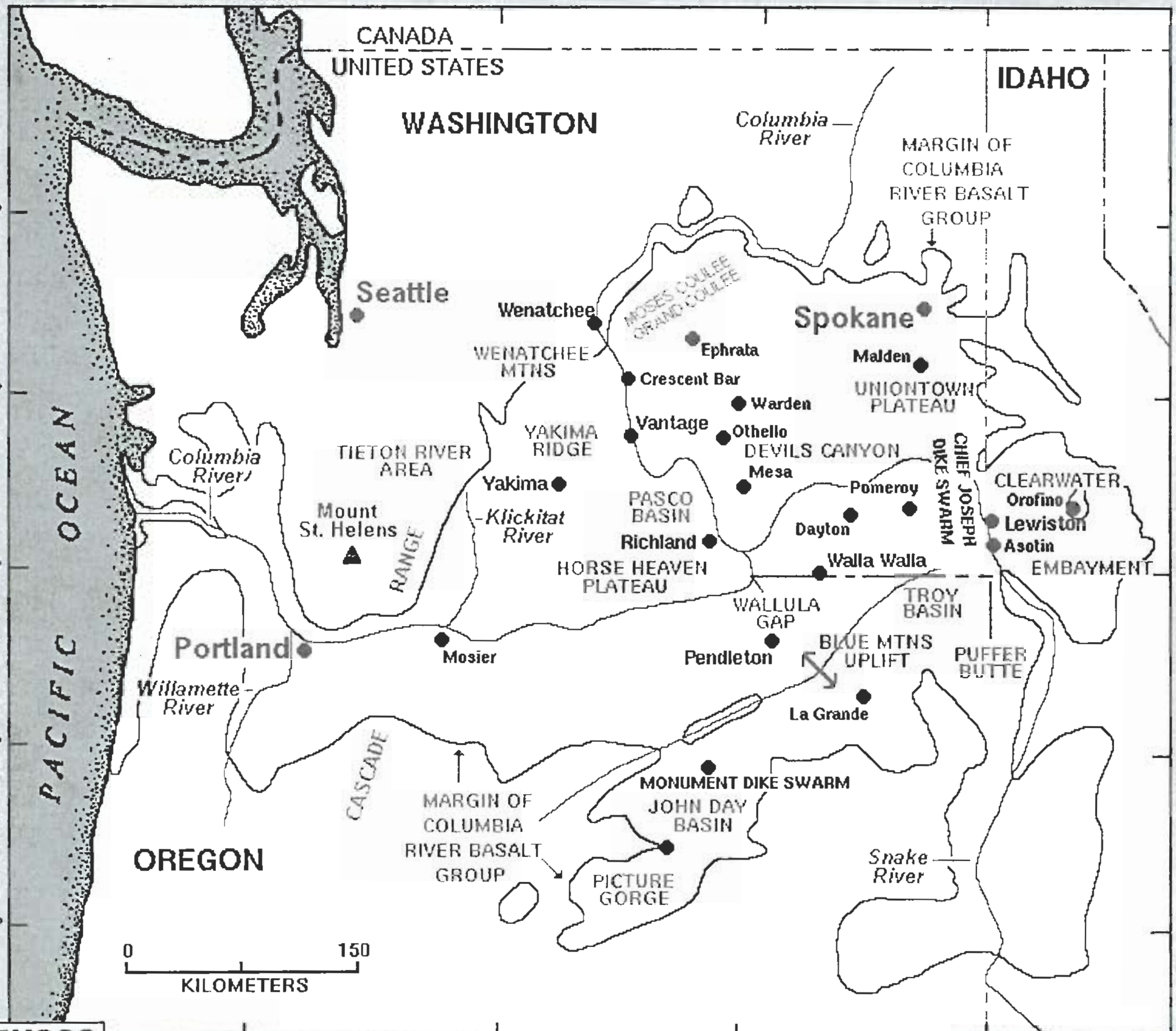
Unit	Equivalent[1,2]					
	millimeters	inches	feet	meters	kilometers	miles
millimeters	1	3.937×10^{-2}	3.281×10^{-3}	1×10^{-3}	1×10^{-6}	6.214×10^{-7}
inches	25.4	1	8.33×10^{-2}	2.54×10^{-2}	2.54×10^{-5}	1.578×10^{-5}
feet	304.8	12	1	0.3048	3.048×10^{-4}	1.894×10^{-4}
meters	1,000	39.37	3.281	1	1×10^{-3}	6.214×10^{-4}
kilometers	1×10^{6}	3.937×10^{4}	3,281	1,000	1	0.6214
miles	1.609×10^{6}	6.336×10^{4}	5,280	1,609	1.609	1

Area

Unit	Equivalent[1,2]						
	square inches	square feet	square meters	acres	hectares	square kilometers	square miles
square inches	1	6.944×10^{-3}	6.452×10^{-4}	1.594×10^{-8}	6.452×10^{-8}	6.452×10^{-10}	2.491×10^{-10}
square feet	144	1	9.29×10^{-2}	2.296×10^{-5}	9.29×10^{-9}	9.29×10^{-8}	3.587×10^{-8}
square meters	1,550	10.76	1	2.471×10^{-4}	1×10^{-4}	1×10^{-6}	3.861×10^{-7}
acres	6.273×10^{6}	4.356×10^{4}	4,047	1	0.4047	4.047×10^{-3}	1.563×10^{-3}
hectares	1.55×10^{7}	1.076×10^{5}	1×10^{4}	2.471	1	0.01	3.861×10^{-3}

133F-1

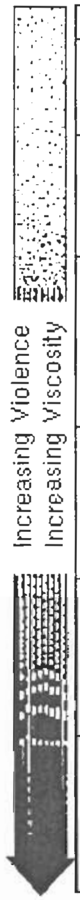
Columbia Plateau Features

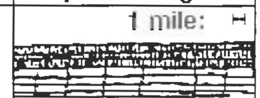
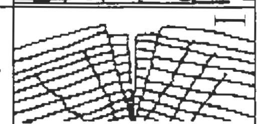
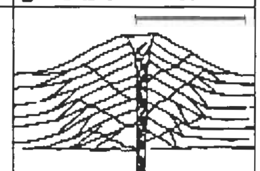
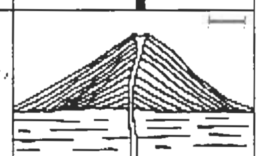
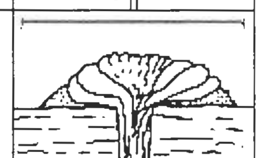
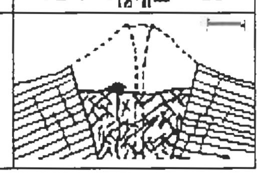


Topinka, USGS/CVO, 1997 and 2003; basemap modified from Swanson and Wright, 1981, USGS Circular 838; basalt coverage generalized from Swanson and Wright, 1981, and Univ. North Dakota "Volcano World", 2002 (based on Hooper, 1997); named features and places mostly from Swanson and Wright, 1981.

133G

Types of Volcanoes



Volcano Type	Characteristics	Examples	Simplified Diagram
Flood or Plateau Basalt	Very liquid lava; flows very widespread; emitted from fractures	Columbia River Plateau	
Shield Volcano	Liquid lava emitted from a central vent; large; sometimes has a collapse caldera	Larch Mountain, Mount Sylvania, Highland Butte, Hawaiian volcanoes	
Cinder Cone	Explosive liquid lava; small; emitted from a central vent; if continued long enough, may build up a shield volcano	Mount Tabor, Mount Zion, Chamberlain Hill, Pilot Butte, Lava Butte, Craters of the Moon	
Composite or Stratovolcano	More viscous lavas, much explosive (pyroclastic) debris; large, emitted from a central vent	Mount Baker, Mount Rainier, Mount St. Helens, Mount Hood, Mount Shasta	
Volcanic Dome	Very viscous lava; relatively small; can be explosive; commonly occurs adjacent to craters of composite volcanoes	Novarupta, Mount St. Helens Lava Dome, Mount Lassen, Shastina, Mono Craters	
Caldera	Very large composite volcano collapsed after an explosive period; frequently associated with plug domes	Crater Lake, Newberry, Kilauea, Long Valley, Medicine Lake, Yellowstone	

USGS

Topinka, USGS/CVO, 1997, Modified from: Allen, 1975, Volcanoes of the Portland Area, Oregon, Ore-Bin, v.37, no.9

133H

Stratigraphic Subdivision of Columbia River Basalt Group (CRBG)

SERIES		GROUP	SUB-GROUP	FORMATION (Age, Volume, % of CRBG)	MEMBER	MAG*
Miocene	Upper	Columbia River Basalt Group	Yakima Basalt SubGroup	Saddle Mountain Basalt (14–6 Ma, 2,400 km3 volume, 1.5% of CRBG)	Lower Monumental Member	N
					Ice Harbor Member	N,R
					Buford Member	R
	Middle				Elephant Mountain Member	R,T
					Pomona Member	R
					Esquatzel Member	N
					Weissenfels Ridge Member	N
					Asotin Member	N
					Wilbur Creek Member	N
					Umatilla Member	N
				Wanapum Basalt (15.5–14.5 Ma, 10,800 km3 volume, 6.0& of CRBG)	Priest Rapids Member	R3
					Roza Member	T,R
					Frenchman Springs Member	N2
					Eckler Mountain Member	N2
				Grande Ronde Basalt (17–15.5 Ma, 151,700 km3, 87%)		N2
	Lower					R2
				Picture Gorge Basalt		N1
						R1
				Imnaha Basalt (17.5–17 Ma, 9,500 km3 volume, 5.5% of CRBG)		R1
						T
						N0
						R0

* Magnetic Polarity:
N, normal; R, reversed; T, transitional; subscripts denote magnetostratigraphic units

USGS *Topinka, USGS/CVO, 1997, Modified from: Swanson, et.al., 1989, AGU Field Trip Guidebook T106*