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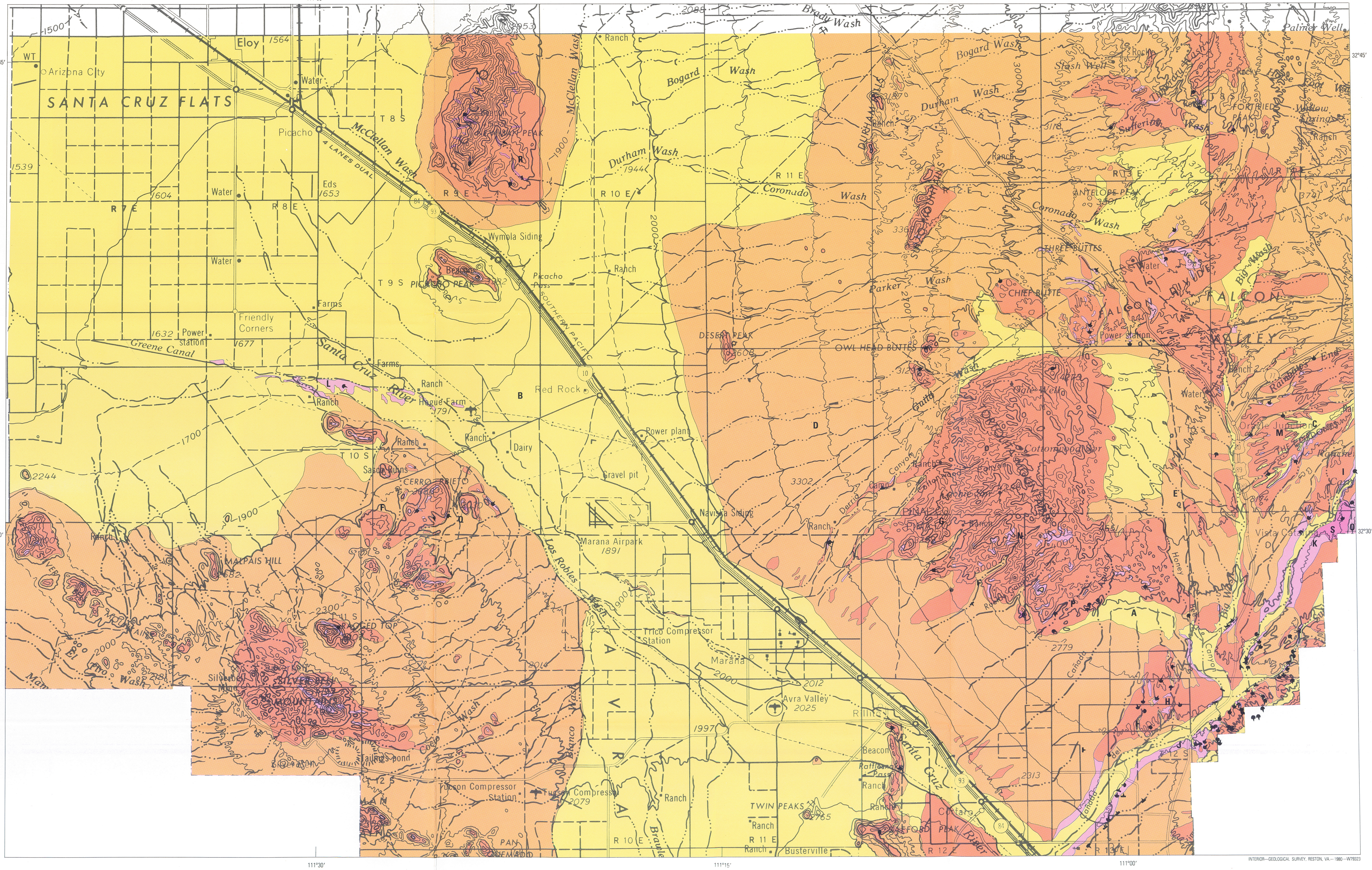


Base from U.S. Geological Survey
Tucson 1:250,000, 1956–69

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA.—1980—W78023

SCALE 1:125 000

5 4 3 2 1 0 5 MILES

5 4 3 2 1 0 5 10 KILOMETERS

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOUR AT 100 FOOT INTERVAL
NATIONAL GEODETIC VERTICAL DATUM OF 1929

MAP SHOWING RELATIVE SLOPE STABILITY, CENTRAL SANTA CRUZ RIVER VALLEY, TUCSON AREA, ARIZONA

By
Bruce J. Murphy and Richard T. Moore
State of Arizona Bureau of Geology and Mineral Technology
1980

DESCRIPTION OF MAP UNITS

[Letters in parentheses (B) indicate type area of described feature]

ZONE 1

Highest stability: Very low probability of downslope movement of material. Nearly flat to moderate slopes (less than 25 percent) developed on bedrock of igneous or metamorphic composition, locally either bare or thinly covered by surficial material (**A**). Flat to nearly flat slopes (less than 3 percent) occurring within flood plains and major drainages (**B**). Areas of thick caliche developed on flat terrace surfaces (**C**)

ZONE 2

High stability: Small probability of downslope movement except in areas adjacent to streams where stream banks are undercut. Flat to gentle slopes (0–5 percent) developed in surficial alluvial deposits dissected by numerous discontinuous streams (**D**). Moderately gentle slopes (5–15 percent) in older, more firmly cemented alluvium, consisting of gravelly sand and clay (**E**). Steep slopes (25–45 percent) underlain by volcanic rocks (**F**)

ZONE 3

Moderate stability: Very steep slopes (45–100 percent) underlain by crystalline rocks (**G**). Steep slopes (25–45 percent) on poorly consolidated, medium- to low-density gravels (**H**). Moderate (15–25 percent) to steep (25–45 percent) slopes on unconsolidated terrace deposits of very coarse gravels overlying moderately cemented alluvium (**I**). These slopes are subject to minor debris slides where material is coarse and well rounded, and to soil slips that occur in the finer-grained deposits. Rock slopes are susceptible to spalling of single blocks, which may travel a considerable distance downslope. Shallow excavations may need sidewall support

ZONE 4

Generally low stability: Steep slopes (25–45 percent) in poorly cemented sandy gravel deposits. Subject to slumping and high soil erosion when saturated with water (**J**). Very steep slopes (45–100 percent) in moderately well-cemented gravel, sand, and silt (**K**). Soil fall in vertical cuts in low-resistant material (**L**). Near-surface (less than 2 feet) soil slumping on steep, well-vegetated slopes producing small terrace-like features (**M**). Very steep to precipitous (65–100 percent) rock slopes with a thin loose deposit of rock rubble and soil-size particles (**N**). Steep to very steep (45–65 percent) slopes on crystalline granite whose surface has weathered into spherical boulders. High probability of downhill movement of rounded boulders when disturbed (**O**). Construction sites in this zone may be subject to problems related to oversteepening and overloading of the natural slopes due to their inherent instability

ZONE 5

Low stability: Very steep to precipitous (65–100 percent) slopes in highly fractured and weathered rock. Subject to debris slides and rock falls, which may produce a large volume of material (**P**). Debris slides common on higher mountain slopes (**Q**). Mudflows or debris slides occur in the higher mountain drainages (**R**). Moderate to moderately steep slopes (25–45 percent) underlain by swelling clays (**S**). Saturation will produce highly unstable conditions

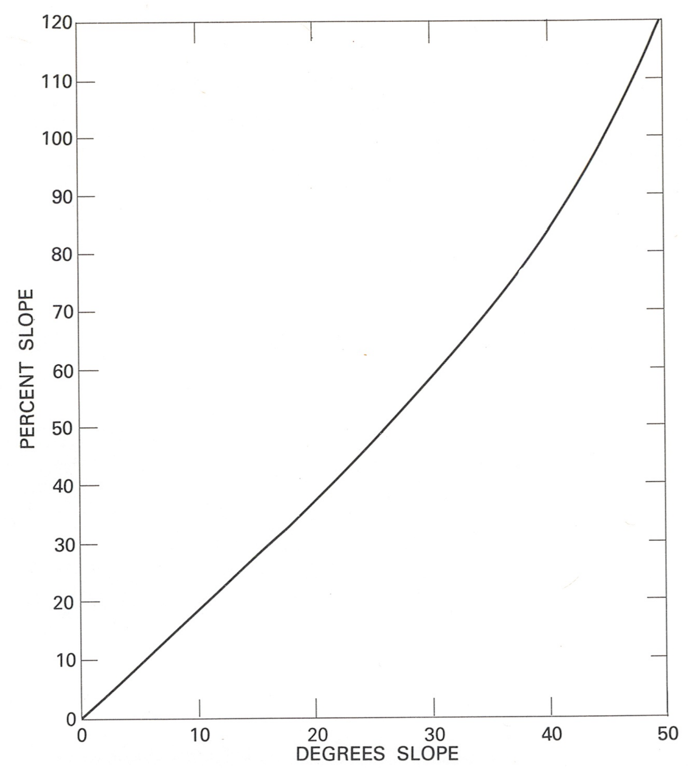
SYMBOLS AND EXPLANATIONS SHOWING TYPES OF POTENTIAL FAILURES WITHIN MAP AREA

Debris slide: Includes all poorly cemented, unconsolidated surficial materials that moved downslope in a relatively dry condition under the force of gravity. The mass may dislocate on an arcuate or mildly undulating surface of failure, or roll downslope on undefined surfaces in the general direction indicated by the arrow. The surface of the deposit is hummocky and irregular and usually very susceptible to erosion. Debris slides are common in two distinct environments: 1) in loose rock rubble in higher mountain drainages that have gradually been oversteepened by deposition, and 2) on very steep (45–65 percent) alluvial slopes of fine-grained, locally clayey material overlain by very coarse, cobbly, lensy gravels. Debris slides generally are small, involving only a few tons of material, although masses of many tons have been observed on similar terrain in adjacent areas. Included in this category, but too numerous and small to map, are areas of debris falls that consist of predominantly coarse, angular, and well-cemented gravel that fell from vertical faces or overhanging cliffs

Mudflow: Mudflows accumulate during rapid downslope movement of wet viscous materials. The occurrence is dependent on 1) abundant but intermittent water supply, 2) sparsity of deep-rooted vegetative cover, 3) unconsolidated or deeply weathered material containing enough clay or silt to aid in lubrication of the mass, and 4) moderately steep slopes (Sharpe, 1938). Mudflows are known to carry huge volumes of material and can transport large boulders onto gentle slopes. They tend to form and move in preexisting drainages, causing natural levees on either side

Soil fall: Soil falls occur in areas where surfaces have been cut back by moving water forming vertical to near vertical faces. Having no horizontal support, these faces often collapse unpredictably

Rockfall or rolling boulders: Rocks prone to this type of instability are frequently deeply weathered and structurally weak. Material falling from a cliff face will usually shatter on the slope below. In some instances, large boulders will roll long distances downhill



RELATIONSHIP BETWEEN PERCENT SLOPE AND DEGREE SLOPE

The relative stability of slopes is based on their probable response to natural processes or manmade activities. Changes in the equilibrium of an existing slope may pose a potential hazard to human activities owing to falling or sliding debris. The danger that results from these mass movements may be relatively inconsequential; on the other hand, catastrophic rockfalls or mudflows pose a serious threat to man's works in their path. It is difficult to accurately predict when and where a slope failure will occur. The map is generalized and on-site investigations by specialists can determine the safety at a specific location.

These stability interpretations are based on previous investigations (Davidson, 1973; Pashley, 1966; Melton, 1965; Terzaghi and Peck, 1967; and Smith, 1938), slope maps prepared by the U.S. Geological Survey, and fieldwork by the authors. All slopes were classified into one of five categories of stability. Rock and soil types were differentiated in the field and assigned relative values according to their inferred strength and ability to resist movement. Massive igneous or metamorphic rock, for instance, possesses greater strength and resistance to movement than does a fine-grained, weakly cemented sand. Similarly, the inclination of the slope from the horizontal was considered and related to the physical characteristics of the material. Generally, the greater the slope, the greater the potential for downslope movement.

Slope instability can be related to several interdependent conditions and various mixes of these conditions will determine the type and severity of the hazard. The erosive effect of moving water may decrease the support at the toe of a slope or deeply dissect a sloping surface throughout its length. This erosion may cause debris slides and mudflows on steeply sloping surfaces, or soil falls in vertically standing sediments. Wetting of poorly consolidated sediments increases the probability of failure both due to the added weight and to the lubrication effect of water. Weakening of rock along structural discontinuities decreases the cohesive strength of the mass and may lead to rockfalls from steep rock faces. Slopes with a veneer of rock and soil (either transported or in place) may fail when the material is saturated with water or oversteepened with further debris. Mudflows are likely to develop in the higher mountain drainages. The overall physical soundness of most crystalline rock in the area, because of its high shear strength, precludes most hazardous, large-scale mass movements. However, spalling of rock material from precipitous slopes or rock faces may result in rolling debris. Boulders of differentially weathered granite lying on moderate slopes may with little difficulty roll downhill if disturbed.

Manmade changes induced in the land can result in overloading and oversteepening slopes, leading to potential instability. The high erodibility of the desert surface when stripped of its vegetative cover may lead to drastic changes in the ability to resist downslope movement. Changes in the shape of a slope may lead to instability in adjacent areas. This is most likely to exist around construction sites.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

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THE ARIZONA BUREAU OF GEOLOGY
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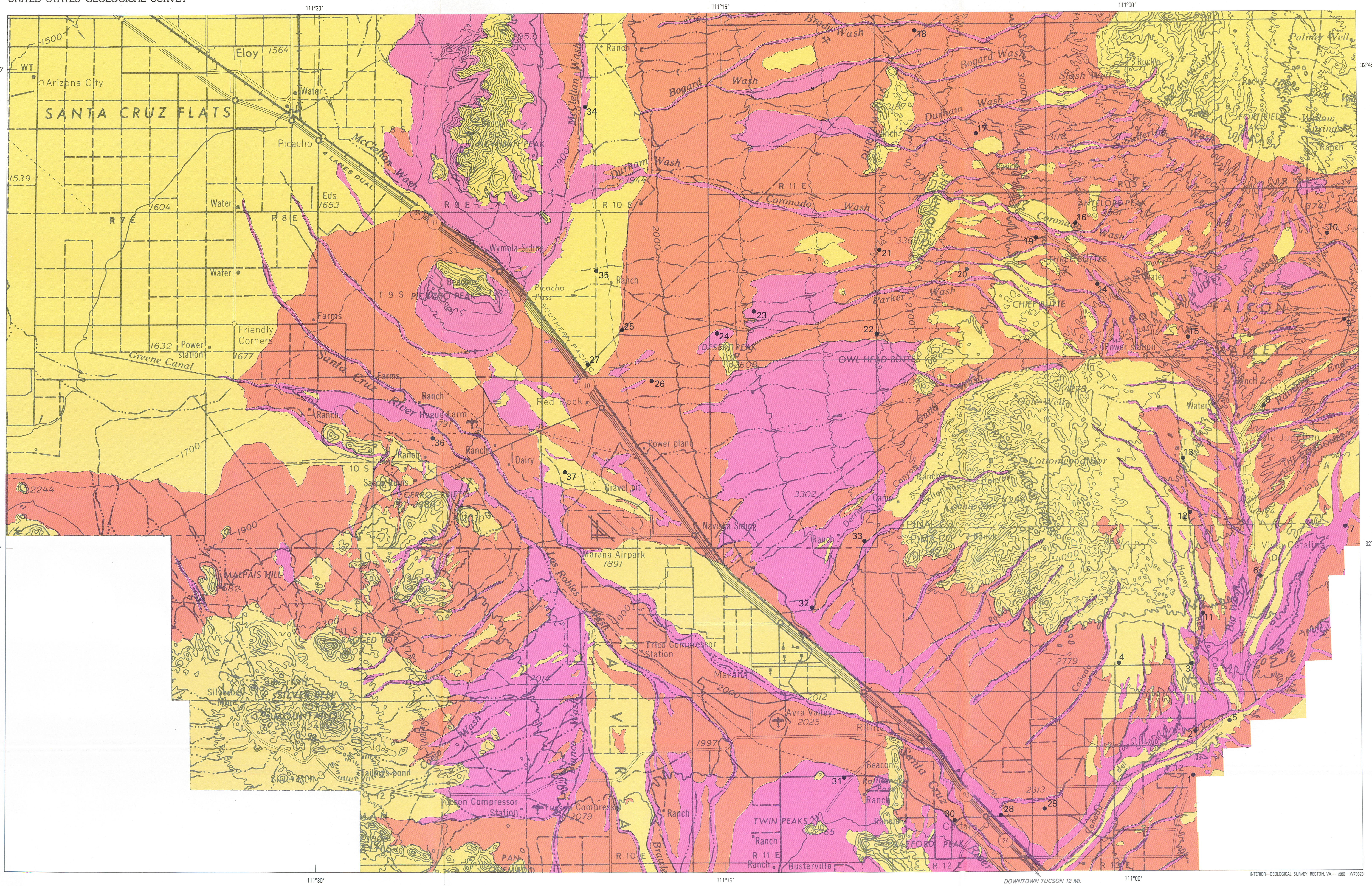
MISCELLANEOUS INVESTIGATIONS SERIES
MAP I-844-O (SHEET 2 OF 2)



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EXPLANATION

RELATIVE EROSION POTENTIAL

[Yellow]

Lowest: The materials are less readily erodible by moving water and the erosion hazard is not significant in the selection of development sites. Slopes are generally flat to moderately gentle (0–10 percent). Surface indicators of erosion, such as gullying and rilling are either scarce or poorly developed, although local areas may be inundated by a few inches of sheet-flow during intense rainfall. Permeability of material is moderate to high (vertical infiltration rate of 0.6–20.0 inches/hour), except where underlain at shallow depth by nearly impermeable caliche or compacted clay. This zone of lowest erosion potential also includes areas of rock outcrop, infrequently inundated flood plains, and alluvial deposits with a rapid infiltration capacity. Vegetation also may reduce erosion in this zone

[Orange]

Moderate: Some development problems may exist that require judicious engineering solutions. Slopes are usually gentle to steep (up to 45 percent). Surface indicators of erosion are prevalent and may be well developed; erosion accomplished through a combination of channeling and sheetflow; permeability of material is generally moderate (vertical infiltration rate of 0.6–2.0 inches/hour), but may show a wide variance. This zone is principally on alluvial valley slopes

[Pink]

Highest: Zone of greatest erosion potential; includes potentially high-risk locations requiring costly remedial measures or special engineering solutions for development. Slope surfaces are variable; surface indicators of erosion are very extensive, and terrain may be nearly impossible to negotiate except on foot; gullies commonly are deeply incised with steep and usually unstable walls; gully walls are deeply cut by side flow; vertical infiltration rate is usually low (less than 0.6 inches/hour) but variable according to the type of material. This zone comprises stream channels, earth water storage, and associated flood plains; steep slopes in fine- to medium-grained silty sand and residual soils and areas that have been subjected to severe misuse through man's activities

•22

Site at which a soil sample was collected and analyzed. Number, 22, is the site number referred to in table

TABLE 1.—*UNIFIED SYSTEM CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES*

Major divisions			Group symbols	Typical names
Coarse-grained soils More than 50% retained on No. 200 sieve	Gravels 50% or more of coarse fraction retained on No. 4 sieve	Clean gravels	GW	Well-graded gravels and gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels and gravel-sand mixtures, little or no fines
		Gravels with fines	GM	Silty gravels, gravel-sand-silt mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	Sands More than 50% of coarse fraction passes No. 4 sieve	Clean sands	SW	Well-graded sands and gravelly sands, little or no fines
			SP	Poorly graded sands and gravelly sands, little or no fines
		Sands with fines	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
Fine-grained soils 50% or more passes No. 200 sieve	Silts and clays liquid limit 50% or less		ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
			OL	Organic silts and organic silty clays of low plasticity
	Silts and clays liquid limit greater than 50%		MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts
			CH	Inorganic clays of high plasticity, fat clays
			OH	Organic clays of medium to high plasticity

In locating urban developments, the physical properties of the surface materials must be considered if maximum safety is to be achieved and the aesthetic value of the land preserved. One such physical property is the relative erodibility of the land—the susceptibility of surficial materials to be worn away and removed by natural or man-induced processes. Moving water is the most significant erosive force in the central Santa Cruz Valley, although winds transport loose, fine-grained sediments, such as those on the Santa Cruz Flats (NW quadrangle area).

The purpose of this map is to show the probable relative response of different surface materials to the action of running water. The erosion zones are generalized and each may contain small areas that are more or less erodible than the general zone. Within these general zones, specialists can determine site-specific erosion potential and plan a suitable mitigation program.

Areas of active erosion were determined by a comparison of aerial photographs taken in 1956 and 1973. Four basic soil indices were determined for 37 sample locations using standard procedures as outlined in the Unified Soil Classification of the American Society of Testing Materials. The classification and group symbols are shown on table 1, the results for the 37 samples are shown in table 2. Areas that exhibit or possess the potential for similar responses to erosion were delineated in three categories, ranging from lowest to highest potential for erosion, on the basis of the inferred and probable response to the action of running water. These ratings do not imply that all materials in a designated zone will erode at the same rate, but that materials in that zone will exhibit similar erosional characteristics.

Generally, many physical properties influence erodibility, and changes in one or more of the properties will change the erodibility even though the remaining properties, such as type of soil, are not changed. Physical and engineering properties that determine erodibility are slope length and inclination, type and structural characteristics of geologic material, cementing or binding agent, compaction, rain intensity, exposure, and vegetative cover. Materials were classified according to the relative potential severity of the cumulative response to erosion at a site, considering each of the above criteria. For example, areas with slopes from 10–15 percent of loosely packed, fine- to medium-grained sandy silt (soil types SM and ML in table 2) show extensive erosion and are in the highest erosion zone. Flat-lying sandy materials (SP and SM) with a high infiltration rate are less affected and are in the zone of lowest erosion potential. A correlation also exists between the age of the sediment and erodibility. Generally, the older materials contain more clay (SC, CL, and CH) and cement binder and hence are more erosion resistant at a given slope angle than younger materials; recently deposited alluvium is more loosely packed on flood plains or slopes and will be removed relatively faster than older deposits. Very old crystalline rocks cropping out at the surface are the most resistant to erosion. Laboratory tests on selected samples (see table 2) indicate a probable correlation between the proportion of silt-clay fraction of soils and the potential of erosion in that material. Nonplastic to slightly plastic fines are common in alluvial materials that have highest erosion potential. Clays of low to medium plasticity have a higher resistance to erosion.

Cattle grazing has increased erodibility in some areas by differentially compacting the surface and by overgrazing, which exposes poorly cemented sediment to extensive gullying. Erosion is also accelerated at construction sites where surfaces are stripped. The runoff in these areas is increased and the steeper slopes in the area are subject to greater erosion than before development. Foundations, fill pads, and roads may be exposed to scouring due to a change in overland flow or slope design.

Acknowledgment: Work was performed under Grant No. 14–08–0001–G–203 from the U.S. Geological Survey.

TABLE 2.—*BASIC SOIL INDICES CALCULATED FROM LABORATORY TESTS PERFORMED IN ACCORDANCE WITH THE ASTM DESIGNATIONS D421–58, D423–66, AND D424–59*

Site number	Zone designation (see explanation)	Soil type[2] (Unified soil classification)	Percent passing 200 mesh (0.074 mm)	Liquid limit (LL)	Plastic limit (PL)	Plasticity index (PI=LL−PL)
1	B	SP	4.5	Non-plastic	Non-plastic	—
2	B	GP-SP	7.5	Non-plastic	Non-plastic	—
3	A	SC	26.3	27	19	8
4	A	SM	23.0	23	20	3
5	A	SM	12.4	Non-plastic	Non-plastic	—
6	B	SC	18.2	48	27	21
7	C	SP	3.5	Non-plastic	Non-plastic	—
8	A	SM, CL-ML	11.1	22	18	4
9	B	SC	17.8	35	23	12
10	B	SC	13.4	40	27	13
11	B	SM	16.6	Non-plastic	Non-plastic	—
12	B	SC	13.2	31	22	9
13	A	SM-ML	32.3	22	18	3
14	B	SM, ML-CL	9.5	30	24	6
15	B	SP	14.7	Non-plastic	Non-plastic	—
16	B	SC	12.3	30	19	11
17	B	SM	12.0	21	18	3
18	B	SM	22.3	Non-plastic	Non-plastic	—
19	B	SM	17.2	22	18	4
20	B	SM	12.4	Non-plastic	Non-plastic	—
21	B	SM	15.6	Non-plastic	Non-plastic	—
22	B	SM	21.7	Non-plastic	Non-plastic	—
23	C	SM-ML	33.0	Non-plastic	Non-plastic	—
24	C	SM-ML	26.3	Non-plastic	Non-plastic	—
25	B	SM-ML	33.6	Non-plastic	Non-plastic	—
26	B	SM	23.2	23	19	4
27	A	SM-ML	26.0	28	25	3
28	C	SC	20.0	40	25	15
29	B	GP-SP	5.2	Non-plastic	Non-plastic	—
30	B	SP	13.4	Non-plastic	Non-plastic	—
31	C	SP	19.7	Non-plastic	Non-plastic	—
32	C	SM, ML-CL	32.4	27	21	6
33	B	GM-SM	6.7	24	20	4
34	C	ML	52.7	Non-plastic	Non-plastic	—
35	A	ML	55.4	Non-plastic	Non-plastic	—
36	B	SM	17.0	26	24	2
37	A	SM-ML	37.2	Non-plastic	Non-plastic	—

[1]The liquid limit LL is the water content in percent of the dry weight at which two sections of a pat of soil barely touch each other but do not flow together when subjected in a cup to the impact of 25 sharp blows from below.
[2]The plastic limit PL is the water content at which the soil begins to crumble when rolled out into thin threads.

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