CHAPTER 8

INDICATORS OF SUBSURFACE BASIN GEOMETRY IN NEVADA

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INTRODUCTION

The state of Nevada extends across most of the western and central parts of the Great Basin, the most extensive and tectonically active region within the Basin and Range geomorphic province. The topography of this region is dominated by elongate, generally north-northwest- to north-northeast-trending alluviated basins separated by high mountain ranges of similar plan form and orientation. About 60% of Nevada is occupied by piedmonts and basins that are covered by surficial deposits of late Cenozoic age; however, relatively little is known about the geometry or stratigraphy of these intermontane areas.

Plate 8-1 combines regional geologic, geomorphic, geophysical, and well-log data which, when brought together, enable a general interpretation of the subsurface geometry of these fault-bounded basins. These data include: (1) regionally consistent photogeologic maps of young faults, pediments, and areas of thin alluvial cover that provide a general tectonogeomorphic context for interpreting basin geometry; (2) digital analyses of a statewide compilation of gravity data (isostatic residual values interpolated to a 2-km by 2-km grid) to approximate depths to dense, generally pre-Tertiary and/or crystalline basement; (3) compilation of generalized oil and gas-, geothermal-, and water-well data to provide calibration for the gravity interpretations; and (4) a digital version of Stewart and Carlson's (1977) geologic map of Nevada.

These data sets were developed to support mineral resource assessments of alluviated areas. They provide (in a comprehensible and regionally comparable format) an objective basis for interpreting subsurface basin geometry. Therefore, the data presented are as objective, reproducible, and regionally consistent as possible and, for the most part, they are unmodified by qualitative interpretation.

Analysis of these data provides several general insights that are potentially useful for mineral resource assessment of covered areas in the Basin and Range province.

1. Deep basins (more than 1 km) are limited in extent (constituting about 16% of Nevada) and approximately 42% of the State is covered with basin-fill deposits that are less than 1 km thick.
2. Young faults (showing Quaternary and/or latest Tertiary offset) are more abundant and widely distributed than previously mapped. Moreover, basin-fill deposits are likely cut by large numbers of unmapped young faults; however, most of these intrabasin faults are probably either short lived or characterized by long recurrence intervals.
3. Basin fills are predominantly water-borne terrigenous sediments; however, interbedded volcanic rocks and landslide deposits are locally significant. In many areas the bulk of these basin-filling deposits are probably older than latest Miocene. Late Miocene deposits lie at or immediately below the surface in many basins; and large parts of the Great Basin landscape, particularly in middle and upper piedmont areas, have changed only superficially during the past several million years.
4. Significant variations in basin depth, subsurface shape, and basin-fill stratigraphy are likely related to variations in the timing, intensity, and style of neotectonic activity across the region. Basin area, depth, and continuity are all generally less in areas adjacent to the boundaries of neotectonic domains, within 'transverse accommodation zones' (the diffuse boundaries separating regions of consistent tilt direction that transect the Great Basin), within most areas of the Walker Lane belt (which forms the transitional margin between the Great Basin and the Sierra Nevada), and along the southern margin of the region (throughout the nonmagnetic zone of southern Nevada and further south). Elsewhere, basins are typically large, elongate, continuous, and deep.

DATA COMPILATION AND ANALYSIS

Map Components

Plate 8-1 is a combination of several diverse components: young faults, piedmont/range-front boundaries, pediment areas with exposed bedrock (identified as to general lithologic types), and 0.5- and 1.0-km contours of the estimated thickness of Cenozoic cover including both sedimentary and volcanic deposits. Most of these components are derived from other maps in this report. The young faults (shown in red) include all of the latest Tertiary and Quaternary faults mapped by Dohrenwend and others (chapter 9) except those cutting late Tertiary volcanic rocks. The piedmont/range-front boundary (shown as black borders around the light gray areas that designate the ranges) was delineated from analysis of small- scale vertical aerial photographs. Piedmont areas with exposed bedrock include all of those areas mapped as bedrock on Stewart and Carlson's 1977 geologic map of Nevada that lie basinward of the piedmont/range-front boundary. The 0.5- and 1.0-km contours of the estimated thickness of Cenozoic sedimentary and volcanic deposits are extracted from chapter 2.

Young Faults

Young faults are herein defined as those faults with clear geomorphic expression that have undergone Quaternary and/or latest Tertiary (in some cases possibly as old as latest Miocene) offset. In aggregate, previous mapping of young faulting in the region covers nearly 50% of Nevada; however, this previous mapping varies significantly in definition, style, and scope. To develop a regionally consistent picture of young faulting, a reconnaissance photogeologic analysis was carried out for the entire State (chapter 9) for a complete description of young fault mapping procedures). Young faults are, of course, a fundamental structural determinant of the location, shape, and size of young fault-bounded basins. However, the geomorphic expression of faults developed in many varieties of volcanic rock may remain relatively undegraded for several million years. Indeed, in many areas underlain by thick accumulations of late Tertiary flow rocks and welded tuffs, many if not most of the faults mapped as possible young faults may be synvolcanic in origin. These faults have not been included on plate 8-1.

Pediment Areas with Exposed Bedrock and Thin Alluvial Cover

To achieve an accurate and regionally consistent depiction of piedmont/range-front boundaries throughout Nevada, photogeologic mapping of this fundamental geomorphic transition was carried out for the entire State. Three different types and scales of aerial photography were used for this analysis (fig. 8-1). Nearly 80% of the State was mapped using National High Altitude Program (NHAP), 1:58,000 nominal-scale, color infrared photography, and approximately 15% was mapped using Army Map Service 1:60,000 and 1:63,000 nominal-scale, panchromatic photography. The detail of mapping in these areas is relatively consistent. Mapping of the remaining areas (using NASA U-2, 1:115,000 to 1:124,000 scale, color infrared transparencies) is somewhat less precise. This mapping was transferred directly to 1/2° by 1° topographic maps that had been enlarged to the scale of the photographs. These maps were then reduced to 1:250,000 scale and digitized.

For plate 8-1, pediment areas with exposed bedrock were delineated via a digital comparison of the piedmont/range-front boundary map with Stewart and Carlson’s 1977 geologic map of Nevada. All areas mapped as bedrock and located on piedmonts are considered to be predominantly pediments where bedrock is exposed or immediately underlies a very thin (less than 10 m) alluvial cover. Areas immediately adjacent to pediments or between them and the nearest range front are, in most cases, very likely to have a thin (less than 100 m) alluvial cover.

ESTIMATED THICKNESSES OF CENOZOIC BASIN FILL

One-half-kilometer and one-kilometer contours of the estimated thickness of Cenozoic cover were extracted from chapter 2 and truncated by the piedmont/range-front boundary or by pediments on pre-Cenozoic bedrock to provide a first order approximation of the general locations, sizes, and shapes of alluviated basin areas.

To calculate the estimated thicknesses of Cenozoic cover, the isostatic residual gravity values of Saltus’ (1988) statewide compilation were transformed to a 2-km by 2-km grid. Measurements on outcrops of pre-Tertiary rocks and on Tertiary granitic rocks were used to define an initial approximation for the "basement" gravity field, which was subtracted from the overall isostatic residual gravity field to yield a secondary residual field reflecting the presence of low-density Cenozoic sedimentary and volcanic deposits. A four-layer density model for these deposits was applied to this secondary residual field to estimate Cenozoic cover thickness. Because the effects of deep basins tend to lower observed gravity values on nearby basement outcrops, this initial estimate of cover thickness was used to calculate a basin correction to the initial approximation of the "basement" gravity field. The entire process was then repeated through a sufficient number of iterations to ensure that the basin effects were removed from the "basement" gravity field (see chapter 2 for a complete discussion of this method).

As discussed in chapter 2, this method has some unavoidable limitations that must be understood before attempting to interpret its results. Two limitations are particularly significant regarding the 0.5-km and 1.0-km thickness contours. These arise from the uneven distribution of gravity data and the grid spacing used for computational analysis. Because the gravity data are distributed unevenly, the reliability of cover thickness estimates varies from place to place. Ideally for a 1:1,000,000-scale map, gravity data points are needed at 2- to 3-km spacing in covered areas and at somewhat wider spacing in areas of "basement" outcrop. These conditions are not satisfied in several areas (see fig. 2-1). Because a grid with 2-km spacing was used for all computations, features with characteristic dimensions less than about 6 km are not faithfully portrayed. For example, basin margins bounded by large-displacement high-angle faults are portrayed as more gentle features by the cover-thickness contours. See chapter 2 for a more complete discussion of these and other limitations.

These limitations notwithstanding, comparison with subsurface data compiled from oil and gas-, geothermal-, and water-well logs indicates that these gravity-based estimates of Cenozoic cover thickness are generally accurate to within approximately ± 0.25 km (chapter 2). Well data were selected from records of water and geothermal wells on file at the U.S. Geological Survey Water Resources Division office in Carson City, Nevada and from general lithologic logs of oil and gas wells compiled by the Nevada Bureau of Mines and Geology. Selected wells (1) are located in basin or piedmont areas and (2) either penetrate bedrock or are more than 150 m deep. These well logs were interpreted to infer approximate depths to five general lithologic types: post Oligocene sedimentary basin fill, Tertiary basaltic rocks, Tertiary tuffaceous rocks, pre-Tertiary sedimentary or metamorphic rocks, and plutonic rocks (primarily Tertiary granitic rocks). These data were compiled on 1:250,000 scale maps for comparison with, and calibration of, the gravity-derived estimates of Cenozoic cover thickness.

SUBSURFACE GEOMETRY OF LATE CENOZOIC BASINS

Piedmont and basin areas in Nevada occupy approximately 164,500 km^2, 58% of the area of State (see table 8-1). Of this total, 20,000 to 30,000 km^2 (7-10.5% of Nevada) are pediment areas with exposed bedrock or thin alluvial cover. An additional 45,000 to 55,000 km^2 (16-19% of Nevada) are

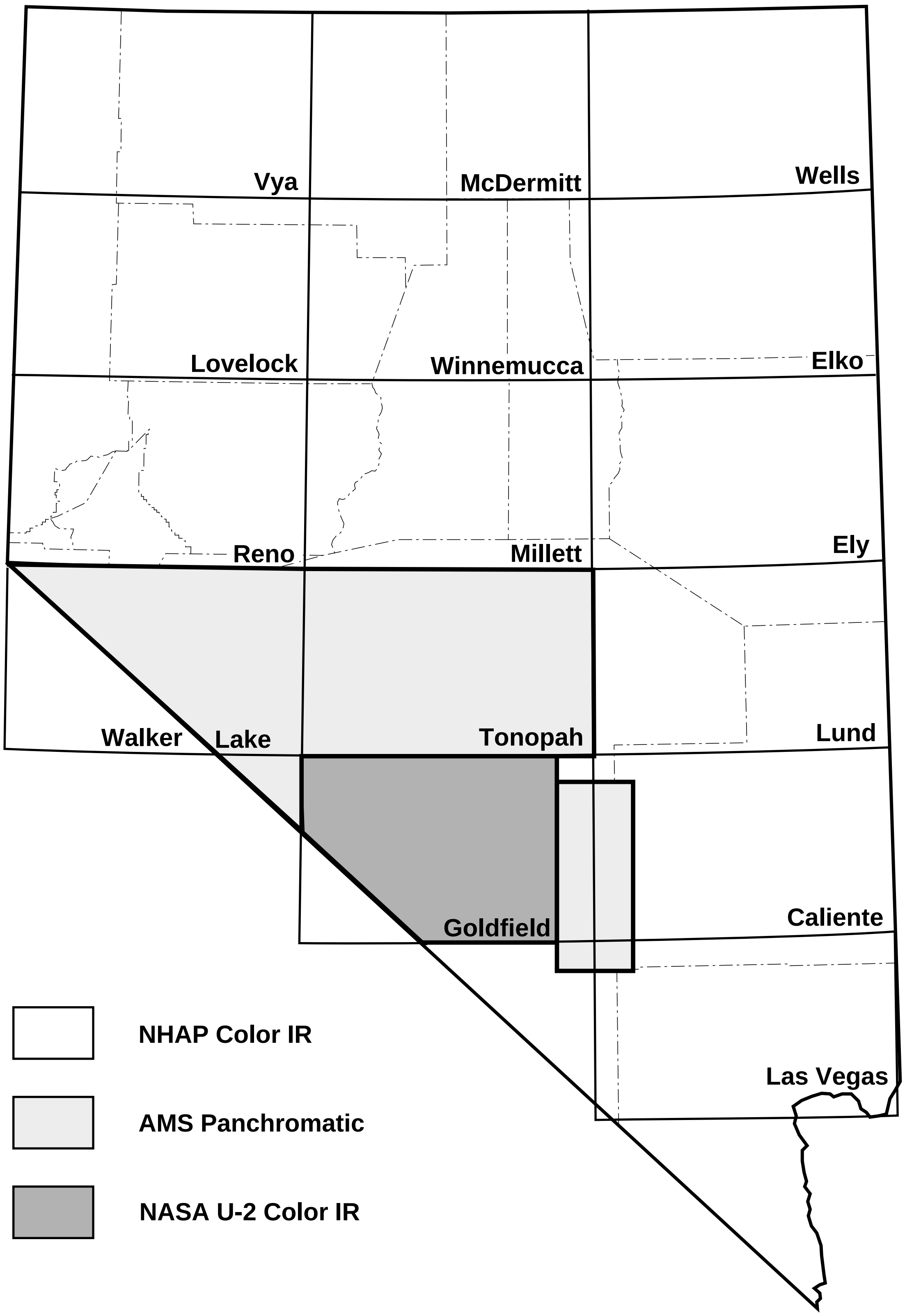

Figure 8-1. Areas covered by the three types of aerial photography used for preparation of this map: unshaded areas indicate coverage by National High Altitude Program (NHAP) 1:58,000 scale (nominal) color infra-red photography; light gray areas indicate coverage by Army Map Service 1:60,000 scale (nominal) panchromatic photography; and dark gray areas indicate coverage by NASA U2 1:115,000 to 1:124,000 scale color infra-red photography.

areas where piedmont and basin-fill deposits (sedimentary and/or volcanic) are less than 0.5 km thick. Only 45,000 km^2 are covered by basin-fill deposits with thicknesses greater than 1.0 km.

Distribution of Pediments

Pediments are defined as gently inclined erosion surfaces cut on bedrock. Typically, pediments form in proximal piedmont areas immediately adjacent to the range front; however, they may extend from the range front to the basin axis. Pediments are commonly mantled by fluvial gravels, but discontinuously exposed bedrock and veneers of residual colluvium are typical of many proximal pediment areas. It is generally held that pediments form under conditions where erosional and depositional processes have been approximately balanced for long periods of time, and the pediments of the Basin and Range are, at least in part, relics of considerable age (Dohrenwend, 1987a and b). Ubiquitous deep weathering beneath extensive pediments in the Mojave desert suggests at least pre-Quaternary ages for the original surfaces of these pediments. Moreover, local burial of piedmonts along the Reveille, Pancake, and Quinn Canyon Ranges by late Miocene to early Pleistocene basaltic lava flows provides convincing evidence for a long period of piedmont stability in at least one area of the central Great Basin (Dohrenwend and others, 1985).

Pediment distribution in Nevada does not appear to be closely related to lithologic variation. The relative abundances of exposed bedrock pediments underlain by specific rock types accords well with the relative abundances of those same rock types within the upland areas of the region (table 8-2, fig. 8-2). Thus, it would appear that pediment development in Nevada has been controlled primarily by spatial and temporal variations in late Cenozoic tectonic activity.

Table 8-1. Areas of piedmonts, basins, and ranges in Nevada

Terrain	Area (km^2)	Area (%)
Pediments and areas of thin alluvial cover << 0.5 km basin fill	20,00-30,00	7-10.5
Piedmonts and basins <0.5 km basin fill	78,500	28
Piedmonts and basins 0.5-1.0 km basin fill	41,000	14
Piedmonts and basins >1.0 km basin fill	45,000	16
Total area of	164,500	58
Total area of ranges	119,000	42
Total area of Nevada	283,400	100

Within the tectonically active Great Basin, pediments are preferentially developed in local settings of relative landscape stability. These favorable geomorphic settings include proximal piedmonts, range embayments, and narrow gaps between ranges. Such settings are particularly well suited for pediment development if they are also situated on the backtilted flanks of large asymmetrically tilted range blocks or around the peripheries of gently upwarped structural highs (Dohrenwend, 1982).

The most extensive and continuous areas of exposed bedrock pediments and associated areas of thin alluvial cover are present in areas that have apparently undergone relatively little post-Miocene vertical tectonic movement. These include: (1) the Lovelock-Gerlach area of northwestern Nevada, an area of relatively low ranges and small basins which lies between the Carson Sink and the Black Rock Desert, (2) transverse accommodation zones, the diffuse west- and northwest-trending transitional zones that separate regions of opposing tilt direction within the central Great Basin (Stewart, 1980; Thenhaus and Barnhard, 1989), (3) strike-slip/oblique-slip fault domains within the northern and central parts of the Walker Lane belt, (4) the Goldfield Hills-Cactus Range area of south-central Nevada, an area of low ranges and broad basins along the northeast margin of the Walker Lane belt north of the late Miocene volcanic centers of Pahute Mesa, and (5) the large late-Miocene volcanic centers of southern Nevada.

The smallest and most widely scattered areas of exposed bedrock pediments are found within those portions of the central Great Basin outside of the transverse accommodation zones. The central Great Basin includes some of the most tectonically active areas of the state and contains most of the longer, more continuous young fault zones and the larger, deeper, and more continuous Cenozoic basins within the state. Pediments are also small and widely scattered throughout the nonmagnetic zone of southern Nevada (a 100-km wide, west-southwest-trending zone with virtually no shallow magnetic sources that transects the state between lat **35°40'N** and 37° 15'N; Blakely, chapter 3). This latter region is geomorphically anomalous; although it is cut by numerous young faults, most of its basins are small and shallow.

Subsurface Basin Geometry

About 16% (45,000 km^2) of Nevada is occupied by deep (greater than 1.0 km) alleviated basins (table 8-l). The subsurface geometry of these deep basins is generally reflected by the surface geomorphology of the adjacent ranges. Basin orientations accord closely with the orientations of adjacent ranges. Moreover, the larger, deeper, more continuous basins are commonly associated with the larger, higher ranges that are bounded by the longer, more continuous young faults. For example, the larger deep basins of the central Great Basin (those greater than 100 **km^2)** average approximately 40 km long, 9 km wide and 2.0 km deep. In comparison, the larger deep basins of the Walker Lane belt, the Lovelock-Gerlach area, and the transverse accommodation zones of the central Great Basin average about 25 km long, 8 km wide and 1.7 km deep. Basin dimensions in areas around the eastern and

Table 8-2. Relative abundance of exposed bedrock pediments by rock type.

Map Unit*	Bedrock Area (km ^{2})	Pediment Area (km ^{2})	Bedrock Area Total Bedrock Area (percent)	Pediment Area Total Pediment Area (percent)	Pediment Area Upland Area (percent)
Cc	3140	412	2.54	1.99	15.10
Ch	309	18	0.25	0.09	6.19
Ct	350	43	0.28	0.21	14.01
Czq	1789	167	1.45	0.81	10.30
Czs	617	99	0.50	0.48	19.11
DC	4183	550	3.38	2.66	15.14
Dcc	497	80	0.40	0.39	19.18
Dsl	280	30	0.23	0.15	12.00
Jgr	1736	183	1.40	0.89	11.78
JTRs	3069	549	2.48	2.66	21.79
JTRsv	1185	168	0.96	0.81	16.52
Kgr	4622	747	3.74	3.61	19.28
KJim	852	41	0.69	0.20	5.06
MDmc	655	92	0.53	0.45	16.34
MDs	3031	654	2.45	3.16	27.51
MZgr	931	124	0.75	0.60	15.37
Oc	3073	346	2.48	1.67	12.69
Occ	252	61	0.20	0.30	31.94
OCt	426	41	0.34	0.20	10.65
0s	1772	184	1.43	0.89	11.59
Osv	1869	136	1.51	0.66	7.85
Pc	1601	267	1.29	1.29	20.01
PMc	428	22	0.35	0.11	5.42
PMh	1540	151	1.24	0.73	10.87
PPC	3398	602	2.75	2.91	21.53
PPcd	469	94	0.38	0.45	25.07
Psc	2203	350	1.78	1.69	18.89
Qta	264	27	0.21	0.13	11.39
Qtb	1620	231	1.31	1.12	16.63
Sc	571	107	0.46	0.52	23.06
Soc	444	34	0.36	0.16	8.29
St	272	14	0.22	0.07	5.43
Tal	2140	291	1.73	1.41	15.74
Ta2	3393	794	2.74	3.84	30.55
Ta3	4577	686	3.70	3.32	17.63
Tba	7156	1414	5.78	6.84	24.63
Tgr	978	241	0.79	1.17	32.70
TKs	253	91	0.20	0.44	56.17
Trl	1644	362	1.33	1.75	28.24
Tr2	1228	206	0.99	1.00	20.16
Tr3	9130	999	7.38	4.83	12.29
TRc	945	86	0.76	0.42	10.01
Tri	281	58	0.23	0.28	26.01
TRk	421	27	0.34	0.13	6.85
TRmt	655	228	0.53	1.10	53.40
TRPvs	585	85	0.47	0.41	17.00
Trt	384	109	0.31	0.53	39.64
Tsl	574	173	0.46	0.84	43.14
Ts2	288	115	0.23	0.56	66.47
Ttl	1558	248	1.26	1.20	18.93
Tt2	18891	3838	15.27	18.57	25.50
Tt3	13633	1643	11.02	7.95	13.70
Tts	2728	1261	2.20	6.10	85.96
Xrn	987	221	0.80	1.07	28.85
Zqs	373	43	0.30	0.21	13.03
Other	3478	827	2.81	4.00	31.20
Total	123728	20670	100.00	100.00	

* units from Stewart and Carlson, 1977

Pediment Area/Upland Area (Mean) 20.06

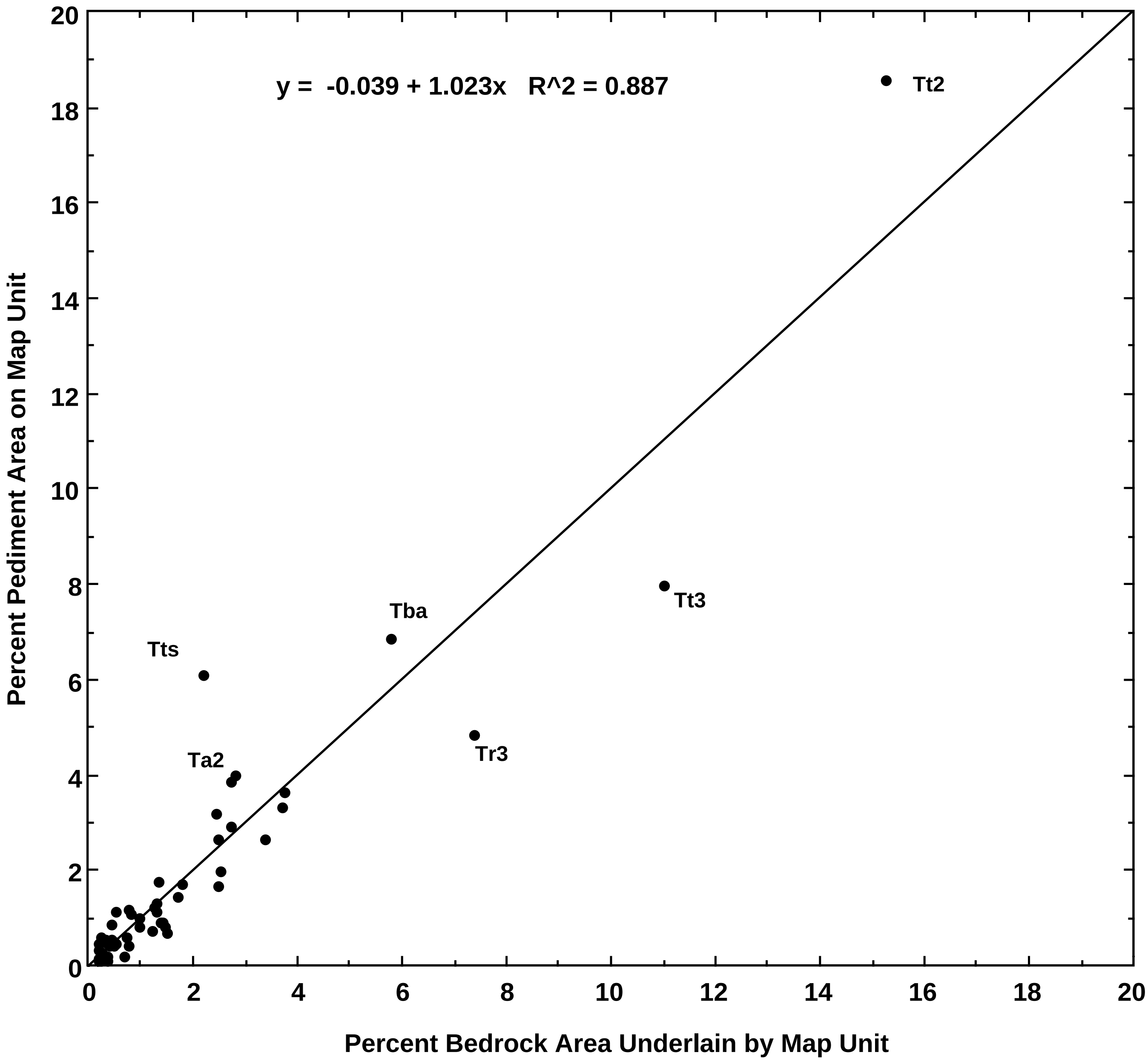

Figure 8-2. Graph comparing the relative extent of exposed bedrock pediments versus the relative abundance of bedrock in upland areas for each bedrock unit (with total surface exposures greater than $100 km^2$) on the geologic map of Nevada (Stewart and Carlson, 1977). In essentially all cases, the relative abundance of exposed bedrock pediments underlain by a specific rock type accords well with the relative abundance of that same rock type within the upland areas of the region. Thus, it would appear that pediments development in Nevada has not been strongly influenced by lithologic distribution.

northern margins of the central Great Basin are, on average, intermediate between these two extremes. It follows, therefore, that the spatial distributions of pediments and deep basins are inversely related (that is, regions with small, shallow, discontinuous basins are also characterized by extensive areas of pediments and thin alluvial cover, whereas regions with large, deep, continuous basins are characterized by small, discontinuous pediments and areas of thin alluvial cover).

One conspicuous exception to these general relations between surface geomorphology and subsurface basin geometry is the region of the nonmagnetic zone of southern Nevada. This area is characterized by both large and small basins. Although many of the ranges in this area are bounded by continuous fault zones and pediments are generally small and sparsely scattered, the ranges are generally closely spaced and many of the intervening basins are small and shallow. However, the few broad valleys of the area (Virgin River Valley, Las Vegas basin, and Pahrump Valley) are underlain by large deep basins.

Estimated Average Rates of Basin Filling and Range Denudation

The total volume of Cenozoic basin fill in Nevada can be estimated using the approximate areas for each piedmont/basin depth category listed in table 8-1. Although this estimate (table 8-3) is very approximate at best and does not attempt to differentiate sedimentary and volcanic deposits, it can be used to make some general observations regarding average rates of range denudation and basin deposition in the Great Basin. For example, production of a total sedimentary basin fill volume of 178,000 km^3 would require an average depth of denudation of 1.33 km over all upland areas (assuming a closed erosional-depositional system with negligible losses due to either fluvial or eolian transport out of the region and relatively minor contributions from volcanic sources). At average rates of erosion for the late Cenozoic (about 25 to 50 meters per million years for upland areas in the Basin and Range, Dohrenwend, 1987a), this amount of erosion would require from 27 to 53 million years. By comparison, the entire extensional history of the Basin and Range is approximately 40 million years (Christiansen and McKee, 1978; Eaton, 1982; Stewart, 1983). Therefore, it would seem likely that erosion rates were substantially greater at some time during the past, and/or volcanic deposits comprise a large proportion of most basin-filling deposits in the Great Basin. Whatever the case, it is very likely that post-Miocene basin-fill deposits are less than 200 m thick throughout much of the region.

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Table 8-3. Estimate of total volume of late Cenozoic basin fill deposits in Nevada.

Basin depth range (km)	Average depth (1) (km)	Area (2) (km2)	Basin-fill volume (km3)	Density factor (3)	Equivalent bedrock vol 4) (km3)
0.0-0.01	0.01	30,000 (2)	300	0.75	225
0.01 -0.5	0.25	48,500	12,125	0.78	9,450
0.5- 1.0	0.75	41,000	30,750	0.85	26,125
>1.0	3.00	45,000	135,000	0.90	21,500
Total			178,175		58,300

(1) average depth is assumed to equal the mean value of the depth range

(2) total area of pediment and thin alluvial cover is estimated to equal all areas mapped as bedrock that lie in pediment areas (on the basin side of the range-front/piedmont contact)

(3) density factor is estimated from the four-layer density model presented in Jachens and others (this volume) - for example 2.1 gm/cc (alluvium)/2.67m/cc (bedrock) = 0.75

(4) equivalent bedrock volume is calculated as the product of basin-fill volume and density factor