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SOME IMPORTANT ASPECTS OF THE MORPHOLOGICAL PROCESSES IN THE SOUTHWESTERN UNITED STATES

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ABSTRACT

This paper considers some processes which are important for the development of macro-relief. Parts of the Basin and Range-Section and of the Colorado Plateaux are compared. In both regions the development of plains is dominant, originating from peneplanation processes in the former region and from modification by scarp recession in the latter.

Key words: Basin and range-structure, plateaux, peneplanation, scarp recession, structural geomorphology.

ALGUNOS ASPECTOS IMPORTANTES DE LOS PROCESOS MORFOLOGICOS EN EL SUROESTE DE LOS ESTADOS UNIDOS

RESUMEN

En este trabajo se estudian algunos procesos importantes en el desarrollo del macro-relieve. Se comparan partes de la sección de 'basins and ranges' y de las plataformas de Colorado. En las dos regiones el desarrollo de las llanuras es importante, resultando de procesos de aplanación en la primera región y de la modificación por recesión de escarpes en la segunda.

Palabras clave: Estructura de 'basin and range', plataformas, aplanación, recesión de escarpes, geomorfología estructural.

EINIGE ASPEKTE VON MORPHOLOGISCHEN PROZESSEN IM SÜDWESTEN DER VEREINIGTEN STAATEN

ZUSAMMENFASSUNG

Diese Arbeit behandelt einige wichtige Prozesse für die Formung des Makroreliefs. Teile der Basin and Range-Sektion und der Colorado Plateaus werden verglichen. In beiden Gebieten dominiert Flächenbildung, die im ersteren Gebiet durch Pedimentationsprozesse und im zweiten Gebiet durch Schichtstufenrückschreitung stattfindet.

Schüsselbegriffe: Basin und Range-Struktur, Plateaus, Flächenbildung, Schichtstufen, strukturelle Geomorphologie.

1. Geographical situation

Up to now there has not been a definite agreement on the term 'American Southwest'. Most authors, however, include the states of Arizona and New Mexico (W. Zelinsky, 1980; National Geographic Magazine, 1982; F. Kottlowski, M. Cooley, R. Ruhe, 1965). This paper sticks to the definition of 'Southwest' of F. Kottlowski et al. (1965, p. 287), because it applies best to the geological and morphological situations. The other essays generally base their concept of 'Southwest' on cultural and historic traits. According to F. Kottlowski et al. (ibid) the following sections may be distinguished (fig. 1):

a. *The Basin and Range-Section,* subdivided into

aa. The Great Basin, which includes the whole state of Nevada and the western portion of Utah (This sub-

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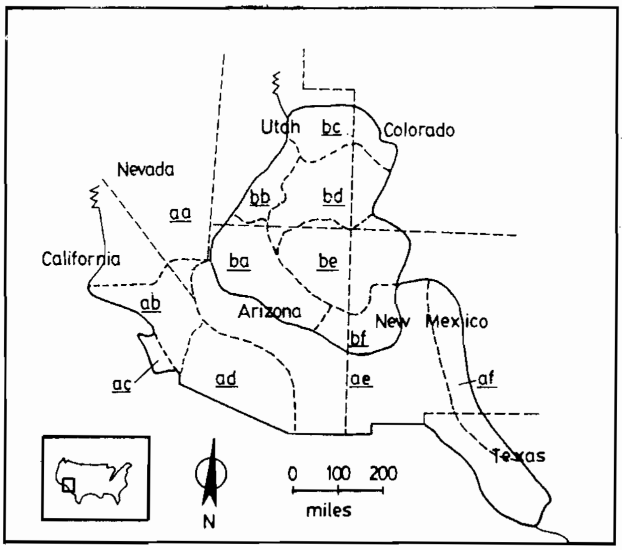

Fig. 1.—Sections of the American Southwest (explanation see text). Source: F. Kottlowski et al. (1965, p. 287); N. M. Fenneman (1931, p. 277).

division will not be dealt with in this paper). Morphologically this region differs from the southern parts of the Basin and Range-Section only to a limited extent. There is, however, a difference in vegetation. The Great Basin is characterised by the sagebrush-landscape of the Great Basin Desert [1], whereas the Mohave Desert to the south is characterised by Joshua tree-landscape (P. Farb, 1963, p. 239),

ab. the Mohave Desert,
ac. the Salton Trough or Imperial Valley,
ad. the Sonora Desert in the south,
ae. the Arizona Highland (or Mexican Highland),
af. the Sacramento Section to the east.

The orientation of the mountain ranges in sections ab. to af. is different from the Great Basin (Great Basin: South-North, ab. to af.: irregular, NW-SE dominant).

b. *The Colorado Plateaux,* subdivided into

ba. Grand Canyon-Section, characterised by the incision of the Colorado River and its tributaries,
bb. High Plateaux of Utah, characterised by high altitudes and separating faults,
bc. the Uinta Basin in the north,
bd. Canyon Lands-Section, with deeply incised canyons, folds, and laccolithic mountains,
be. Navajo Section, similar to the Canyon Lands but less incised,
bf. Datil Section in the southeast, characterised, by ancient volcanism and vast lava plateaux.

Whereas there is general agreement on the section-scheme of the Colorado Plateaux, established by N. M. Fenneman (1931, p. 277), opinions about the scheme of the Basin and Range-Sections diverge. The given list provides one of the best subdivisions of the area. According to C. L. White, E. J. Foscue, and T. L. Mc Knight (1964), both the Basin and Range-Section and the Colorado Plateaux form part of the intermontane plateaux and basin landscapes, where evapotranspiration values exceed precipitation values. Furthermore it has to be added that the southern limit of the region is not a geological or morphological unit but a political frontier. Therefore the features and processes described in this paper must not be seen in isolation, but in connection to the intensely related physiography of Northern Mexico.

2. General characteristics of climate

Considering the climate classification of Köppen-Geiger (A. Hanle, 1978, p. 67), the following types of climate can be distinguished:

BWh (hot desert climate) applies to the western portion of the Basin and Range-Section, consisting of the Mohave and Sonoran Deserts and the basins of the Arizona Highland plus the Sacramento Section.

BSh (hot steppe climate) applies to the higher parts of the Arizona Highland and to the summit regions of most mountain ranges.

From this it can be seen that the Basin and Range-Section is dominated by high temperatures and low precipitation values all year round.

BSk (cold steppe climate) applies to most parts of the Colorado Plateaux, all situated at considerable altitude (occasional orographic anomalies, e.g. the bottom of the Grand Canyon: BWh).

Dfb or even Dfc (snow-woodland climate) apply to the marginal parts of the southern and western plateaux situated at high altitudes (e.g. Aquarius Plateau, approximately 3000 m).

So the Colorado Plateaux are dominated by cold winters and precipitation values somewhat higher than those of the Basin and Range-Section due to a higher tendency to convectional rains.

The climate ranges from aridity to semi-aridity in the Basin and Range-Section and from semi-aridity to semi-humidity in the Colorado Plateaux. Altitude and topographic location are decisive factors in determining the character of the climate. The pattern of precipitation is greatly influenced by the continental nature of the region, which is reinforced by the intermontane topography. Annual precipitation is highly variable as is typical for semi-arid regions. Most rains fall as short, heavy showers, which is a major factor in the shaping of relief.

1 The American expression of 'desert' refers to many arid and semi-arid and also semi-humid regions (in the U.S.A. to large parts of the west as a whole), whereas the German expression 'Wüste' and the Spanish expression 'desierto' only include fully arid regions.

3. Some aspects of geology

Geological structures are a determining factor in the formation of relief in the American Southwest. The Basin and Range-Section and the Colorado Plateaux show interesting contrasts. Whereas the geology of the former region is dominated by structures of 'basins' and 'ranges', the latter is characterised by the folding of more or less even layers of rocks and by volcanic intrusions.

The monotonous topography of basins and ranges is based on very different rock formations and structures: Layers of Palaeozoic, Mesozoic, and Cenozoic rocks have been removed by erosion. Precambrian igneous rocks, metamorphic and younger intrusive rocks and thick series of volcanic rocks united with clastic sediments are abundant. This development has been caused by continuous tectonic movements (uplift) of the whole area, which shows considerable age.

The ranges are considered to be tilted blocks ('horst'), and the intermittent basins to be 'graben'-units. C. B. Hunt (1974, p. 488) describes the development of basins and ranges as follows: 'Primarily a Palaeozoic geosyncline existed, which was later folded and overlapped by an early Mesozoic geosyncline. During the middle and late Mesozoicum folding and thrust faulting occurred, then late Mesozoic and early Tertiary stocks and laccoliths intruded. During middle and late Cenozoicum block faulting, volcanic action and deposition of sediments in the basins were the dominant agents'.

It is very important to stress the Cretaceous uplift of the Arizona Highland, which contributed to the deposition of sediments on the sea floor, which then covered today's Colorado Plateaux. The Arizona Highland unit did not fall below the level of the plateaux before the Tertiary. Due to intense thrust and block faulting as well as to volcanic action, the Basin and Range-Region is an unstable area. Earthquakes and relatively fresh facetted spurs, which prove persistent tectonic movements along the fault lines, are abundant.

The geology of the Colorado Plateaux differs from the former. Folded Precambrian rocks form the base for a 'pile of saucers' of sedimentary rocks which were deposited during the Palaeozoicum and Mesozoicum, when the plateaux functioned as a continental shelf. Above all the carbonaceous series reached considerable thicknesses (in contrast to the Basin and Range-Section). This 'pile of saucers' is smoothly inclined to the NE. As a result of erosion Palaeozoic rocks are exposed in the southwestern plateaux, whereas younger rocks (tertiary) are mainly exposed in the northeastern parts.

Volcanic action and intrusions took place during the Miocene, the results of which can be seen in the forms of batholiths, laccoliths, volcanic buttes, dykes, and vast lava plateaux (C. B. Hunt, 1974, p. 429).

In spite of this endogenic impact the Colorado Plateaux have always been a region of much higher stability than the basins and ranges. Major faulting only occurred in the western plateaux, which presents a transitional region to the Great Basin. Vast parts of the plateaux have not been disturbed by faulting, rock strata are arranged horizontally and form scarps or smoothly inclined cuestas. Important tectonic action was reduced to the production of folds, upwarps, tertiary volcanism, and only feeble faulting. According to D. Barsch (1983) the whole complex of the Colorado Plateaux has been uplifted to its present height from the Pliocene and this process is still continuing. This persistent uplift has had a major influence on the shaping of the present relief (e. g. incision of the canyon of the Colorado River and many others).

4. Morphogenetic aspects of the macro-relief

As stated in the preceding chapter there are striking differences in the geological development of the Basin and Range-Section on one hand and of the Colorado Plateaux on the other hand. In this chapter, the processes which have created the present macro-relief shall be analysed and contrasted.

a) *The Basin and Range-Section*

In this region, the morphological processes are highly dominated by the complex history of the endogenic impact. One example of this impact already alluded to is the existence of triangular facetted spurs. Now more examples will be given. The facetted spurs are united to recent fault scarps. Furthermore there is a discordance of relief and geological structure. If the ranges were remnants only originating from a longer period of erosion, the topographic situation would have to coincide with the geological structures. This is not the case, as can be seen from valley formation. This has been dominated by endogenic agents, too. Many river-beds are steep, V-shaped, and the valley slopes are convex, which indicate the continuing downcutting of the base level. Also, the abundance of hot springs and earthquakes proves the existence of recent tectonic movements. In addition to this, N. M. Fenneman (1931, p. 338) also writes about the existence of tilted peneplains, consisting of lava-beds, which provide evidence for fault dynamics ('first cycle'). All these statements stress the importance of the tectonic history of the region for present morphological processes.

With reference to the fault scarps, N. M. Fenneman (ibid.) adds, however, that their existence can easily lead to misinterpretations. According to his hypothesis of a 'second cycle of erosion', many fault scarps are, properly spoken, fault-line scarps. This means that the original morphological effects of faulting have been modified by erosion, causing a sort of 'relief inversion'. It is not known exactly which of todays basins and ranges have been formed mainly by fault dynamics (i. e. separated by fault scarps), and which of them have been modified by a 'second erosional cycle' (i. e. fault dynamics and following modification by erosion leading to the development of fault-line scarps). W. D. Thornbury (1965, p. 479 f.) also stresses the complex nature of any one of the ranges by indicating the existence of fault scarps, fault-line scarps and faults which have no expression in the actual topography. It can easily be noticed that there is an especially strong interaction of endogenic and exogenic processes in the region.

The arid-morphodynamic processes result in the following morphological units: linear mountain ranges, pediments and glacis, elongated basins (bolsons or playas).

The development of mountainous relief in an arid environment has been dealt with by many authors (L. Waibel, 1928; N. M. Fenneman, 1931; H. Mensching, 1958; D. Warnke, 1969; J. Büdel, 1970).

First, a look at the area ratios will be given: The areas of basins and ranges in the region are supposed to have had a ratio of approximately 40:60 (e. g. in the Great Basin still today). This ratio is different, however, in the southern parts of the Basin and Range-Section (Arizona Highland 60:40, Mohave and Sonoran Deserts 85:15). Due to these differences in area ratios it may be assumed that the regions are subject to different stages in development (referring to mountainous relief), resulting in erosion of the ranges and the formation of vast peneplains.

In the Arizona highland we find narrow elongated sierras with wide rockplains and talus slopes ending in elongated flats. In the Mohave and Sonora Deserts mountain ranges have been reduced to smaller dome-shaped remnants of the former sierras. Rock plains, talus slopes, and flats reach enormous dimensions.

According to J. Büdel (1970, p. 41) primarily the front slopes recede by pedimentation. Valleys with steep slopes exist within the ranges. Consequently the process of pedimentation proceeds from the front slopes into the outer valleys. So-called pediment tips ('Pediment-Spitzen') are developed. Linear erosion and passive slope development in the valleys cease and are replaced by active slope recession resulting from pedimentation. Therefore the valleys widen more and more, and pediments develop in the inner parts of the range as well. Increased widening of the valleys within the ranges also occurs in places, and where gullies unite, 'headwater basins' (L. Waibel, 1928, p. 59) are formed. In the course of time valleys unite from both sides of the ranges and form pediment passes (divides). After widening the valleys and forming pediment passes, the process of pedimentation continues by reducing the mountainous areas from all sides. Finally the widened valleys become broader basins called pediment lanes ('Pediment-Gassen') between the by now very reduced mountainous areas. These remnants ('Restberge') are dome-shaped, low hills surrounded by wide areas of pediments and glacis (fig. 2). If these remnants are removed, too, the result will be a gently undulating peneplain ('Pediment-Scheitelfläche'). This kind of 'passively' developed plain is then a convergence form to the 'actively' developed peneplain of the savannah climate (J. Büdel, ibid.).

All these dynamics require long periods of unchanging

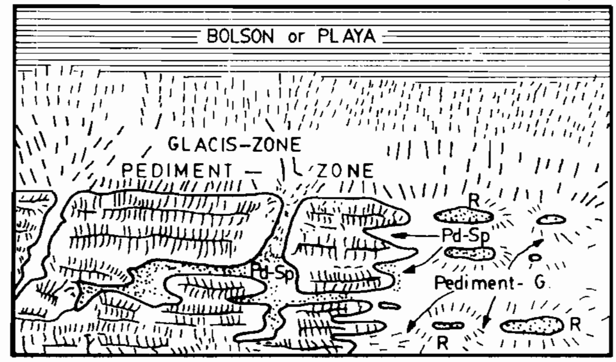

Fig. 2.—Valley widening and formation of remnant mountains Pd-Sp = Pediment-Spitzen; R = Restberge; Source: J. Büdel (1970, p. 40, modified).

climate and a certain degree of tectonic stability, therefore the final form of 'Pediment-Scheitelfläche' has not developed in the Basin and Range-Section of the American Southwest, due to both tectonic instability and climatic change with a more humid climate in the Pleistocene.

D. Warnke (1969, p. 388) proposes a possible scheme of description for the different stages of relief development:

a. Initial phase, which is the period between final uplift and the development of larger embayments in the front slopes. This status applies to many sierras of the Great Basin.
b. Middle phase, which is the period of embayments, widened valleys, pedimentation and pediment passes developing. This status applies to the sierras of the Arizona Highland.
c. Advanced phase, when 'panfans' and desert domes are developed. This status applies to larger parts of the Mohave and Sonora Deserts.
d. Final phase, which is the development of a larger, undulating peneplain. It is not represented in the area.

Figure 3 (after N. M. Fenneman, 1931, p. 320) distinguishes between six phases of peneplanation.

According to these theories it is concluded that the relief of the Mohave and Sonora Deserts (Nr. 5) has reached a stage more advanced than that of the Arizona Highland (Nrs. 4,3) or the Great Basin (Nrs. 2,1). The final stage (Nr. 6) has not been developed in the area.

It was also stated that relief development in the region is dependent on climatic changes (D. Barsch and C. Royse, 1972). Therefore both palaeoclimatic and structural arguments (Y. Tuan, 1962; D. Warnke, 1969) must be considered. For the regions which show considerable tectonic instability, structural features proved to be the controlling agent, whereas more stable regions proved to be dependent on palaeoclimatic and climatic characteristcs. None of the regions treated in this paper, however, is completely dependent on *one* single controlling feature (see also D. Barsch and C. Royse, 1972).

Fig. 3.—Phases of peneplanation (explanation see text). Source: N. M. Fenneman (1931, p. 320).

b) *The Colorado Plateaux*

The main endogenic factor is the continuous uplift of the plateaux as a whole. The first movements occured in the late Cretaceous age and the actual uplift began in the Pliocene (D. Barsch, 1983). The speed of the uplift is somewhat higher in the southwestern part of the plateaux than in the northeast, therefore Tertiary rocks are scarce in the former part and abundant in the latter.

In contrast to the Basin and Range-Section, the Colorado Plateaux have always been a relatively stable area as a whole, only affected by folding, upwarping, diapirismn and Miocene volcanism. The macro-relief is not dominated by faults dynamics, but, nevertheless, the geological (stratigraphical) structures control morphological processes. Enormous parts of the plateaux (Grand Canyon, the 'scarp-staircase' from the rim of the Grand Canyon to the Bryce Canyon, Monument Valley and its surroundings and many more) have almost horizontal rock strata. Anomalies in relief occur, where stocks, dykes, laccoliths, and batholiths intruded into the country rock, have since been removed by erosion (W. D. Thornbury, 1965, p. 412).

All the plateaux are dominated by weathering and fluvial erosion, two agents, which uncover, and, in the course of time, stress the given stratigraphy.

The dominant agent of erosion is the process of scarp recession, which has been studied intensely in this region (S. A. Schumm and R. J. Chorley, 1966; H. Dongus, 1970; H. Blume, 1971; H. Barth and H. Blume, 1973; K. H. Schmidt, 1980). This process is found in all parts of the plateaux. As typical for semi-arid and arid regions (compared to humid regions), scarp slopes are steep. The lower scarp slope is normally concave and adjoins pediments or glacis. Valley systems are more irregular in areas with horizontal rock strata (mesas) than in area with smoothly inclined strata, cuestas, or hogbacks, the inclination of which was supposed to re-

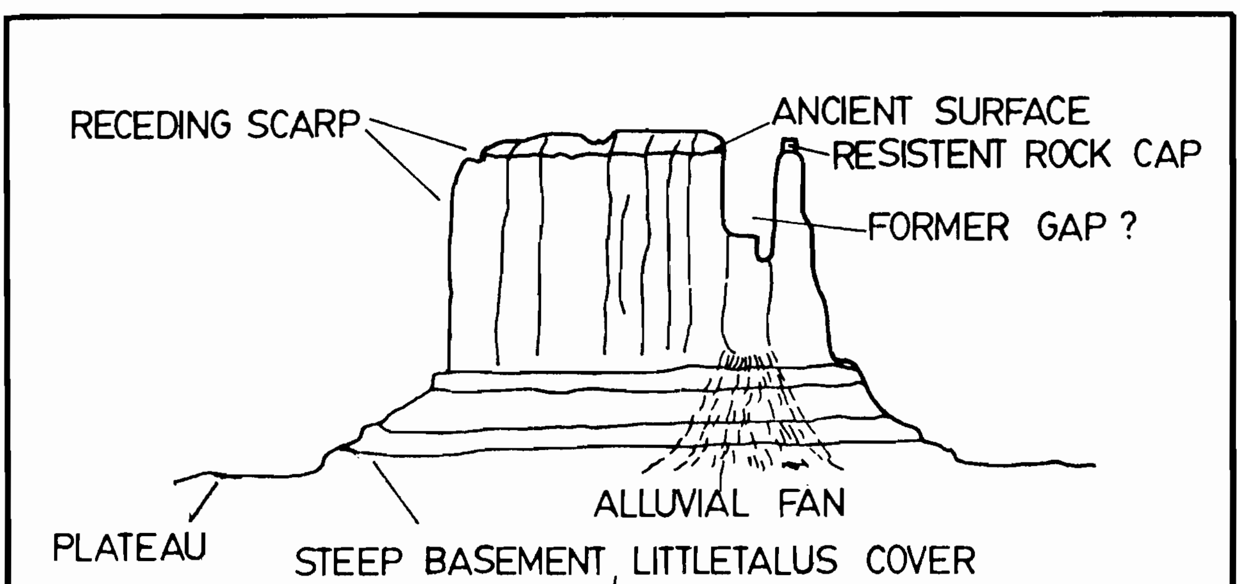

Fig. 4.—West Mitten Butte, Monument Valley, Utah. Source: Photography of the author.

sult from folding and upwarping (H. Blume, 1971, p. 53). Remnants of plateaux (buttes, Zeugenberge) are assumed to be more resistent to erosion because of their situation away from intense erosion or because of induration of rock strata, caused by endogenic or exogenic agents.

According to H. Dongus (1970, p. 51) the process of scarp recession does not occur by falling or gliding (gravitative) agents of the upper (harder) strata (sandstone in most cases), but by undercutting and gullying of the underlying strata. S. A. Schumm and R. J. Chorley (1966, p. 28) remark that the size of the material found on the scree slope does not depend on climatic influences but on the characteristics of the material itself, as does talus weathering at the base of the scarps. The authors prove this by stating that in regions with the same climate different sorts of talus size occur. Thick talus slopes are scarce, because the abundant sandstone strata crack up into tiny pieces and are weathered rapidly. This fact can be observed in Monument Valley: the underlying strata of vertically walled buttes (fig. 4) only show thin layers of talus and the strata of the scarp basement are exposed in many places.

S. A. Schumm and R. J. Chorley (1966, p. 28) tried to find a mathematical expression to describe the production of talus (p) and the degree of talus weathering (d): If

$$p : d = 1$$

then the coarse talus on the slope of the scarp basement will not be very thick. But if

$$p : d < 1$$

then weathering occurs more rapidly and coarse talus on the slope base does not exist. According to the authors, the latter ratio is common in most parts of the Colorado Plateaux.

The factors which influence scarp recession have also been dealt with by K. H. Schmidt (1980), who examined the embayments of scarps. He postulates that scarps react differently to inclination and thickness of rock strata. Two more factors in the formation of embayments are the ratio of the thickness of the scarp-forming stratum and the distance to the channel. But the author stresses that structural and lithological factors are most important (rate of approximately 60%).

Many of the given arguments about arid-morphodynamic processes (which have been going on since younger Tertiary), have been summed up by H. Barth and H. Blume (1973, p. 91) in basic investigations concerning the relief of the plateaux. Primarily they state that the processes are very different from one region to the other. The processes are dependent on:

a. the degree of aridity,
b. differences in resistance between scarp-forming strata, i. e. the greater the differences in resistance, the more effective are the processes,
c. the relationship between the thickness of the scarp-forming strata and the underlying strata (as stated by K. H. Schmidt, 1980, p. 245 in his study on embayment rates), i. e. the thicker the strata of the basement are, the more intense is the efficiency of erosional processes,
d. relief energy and base level, i. e. the stronger relief energy and the nearer the base level, the higher are erosional values.

This does not mean that these facts have to coincide everywhere in the same region. There are scarps with and without recent processes of formation. All stages of transitional states are possible. Active and passive portions can exist in one single scarp. These minor oscillations could also be caused climatically. Because of the gradual variations in relief formation it is very important to differentiate among minor landscape units.

Once again the importance of geological structure in the geomorphology of the Colorado Plateaux is stressed. If, for example, a resistant scarp-forming stratum is finally removed by erosion, a less resistant underlying stratum will be subject to arid-erosional processes of ernormous dimensions which may lead to a positive erosional feedback, i. e. to a sort of an 'autocatalytic principle' (H. Barth and H. Blume, 1973, p. 87).

5. Comparison between the processes producing the macro-relief in both regions

In the preceding chapters a short survey of some of the most important aspects of morphological processes in the Basin and Range-Section and in the Colorado Plateaux were outlined according to the literature and to some personal observations [2].

The existence and formation of plains are most significant in the regions. But whereas the plains are actually formed in the Basin and Range-Section (peneplanation), they are only subject to modification and changes in the Colorado Plateaux (scarp recession). Consequently, a list is presented (table 1) which tries to point out some of the most important contrasts in the morphology of both regions.

This list cannot be complete due to lack of space, but it illustrates the morphological contrasts between two regions with similar climates but with different structural geology.

6. Some relations between the morphology of the semi-arid American Southwest and the semi-arid regions of southeast Spain

Both the American Southwest and southeast Spain show interesting similarities, namely the semi-arid cli-

2 This paper sums up some aspects of relief-formation in the American Southwest, which were dealt with on a larger scale in an unpublished minor thesis written by the author for the achievement of the B. Sc. degree under the direction of Prof. Dr. Heinz Slupetzky (Institute of Geography, University of Salzburg, Austria). This minor thesis is based on literature work and a sojourn of six weeks in the western United States (June-July 1982).

TABLE 1
Morphological contrasts in the American Southwest

BASIN AND RANGE-SECTION	COLORADO PLATEAUX
CLIMATE	
arid to semi-arid (BWh, BSh)	semi-arid to semi-humid (BSk, Dfb)
GEOLOGY	
Stratigraphy	
igneous rocks	(neritic) sediments dominant
metamorphic rocks	intrusive rocks
intrusive rocks	volcanic rocks
volcanic rocks and clastic sediments	
Tectonics	
thrust and block faulting	continuous uplift as a whole
folding	folding, upwarping
volcanic action	volcanic action
	minor faulting
continuing movement along the faults	continuing uplift of unfaulted block
tectonic instability	relative tectonic stability
GEOMORPHOLOGY	
Structure and processes	
dependence on tectonics	dependence on stratigraphy
basin and range dynamics	plateau formation
altitude differences along fault scarps or fault-line scarps	altitude differences along the lines of scarp recession
rock strata irregular	rock strata horizontal
dependence on fluviatile erosion	dependence on fluviatile erosion
major part connected to a peripheral drainage system	major part connected to a peripheral drainage system
peneplanation processes	scarp recession
	incision of canyons
front slope development dependent on peneplanation	front slope development dependent on scarp recession
hillslopes smoothly inclined	scarp basements steep-sloped
much talus cover	little talus cover
underlying structures covered	underlying structures often exposed
Forms	
mountain ranges (sierras)	plateaux, scarps, hogbacks, cuestas
remnant mountains (buttes, inselbergs)	remnant mountains (buttes, no inselbergs!), mesas
pediments and glacis	
alluvial fans (bajadas)	
elongated depressions (bolsons)	canyons
dry lakes (playas)	
V-shaped valleys within the ranges	
vertical dimensions of the landscape still dominant in some regions	horizontal dimensions of the landscape dominant
easy accessibility due to separated mountain ranges	difficult accessibility due to high scarps and canyons interrupting the plateaus ('mountain ranges upside down')

TABLE 2
Precipitation and climate

STATION		PRECIPITATION/YR (mm)	CLIMATE	
Alicante	(82m)	328	BSh	*Southeast Spain*
Murcia	(44m)	304	BSh	
Almería	(7m)	232	BSh	
Albacete	(697m)	393	BSk	
Yuma, Ariz.	(47m)	83	BWh	*American Southwest*
Tucson, Ariz.	(739m)	293	BSh	
Nogales, Ariz.	(1.280m)	354	BSh	
Cuba, N. Mex.	(2.100m)	<375	BSk	

Source: M. Müller (1980), C. B. Hunt (1974, p. 509 f.).

mate, the vegetation, and the actual arid-morphodynamical agents. Precipitation is low and concentrated to a short 'wet' season (table 2). Furthermore the annual variability is high.

In spite of the differences in altitude, the climatic characteristics are similar.

The geological situations differ, but Quaternary geomorphological processes show major similarities. Considering morphology, some authors have already stated close relations between the regions, for example A. Harvey (1978, p. 179) in an essay on alluvial fans (which are abundant in both of them), writing that 'fans of central California occur where modern and Pleistocene climates are not markedly different from those of southeast Spain'.

Also recent morphological processes are related, partly influenced by anthropogene factors: Both areas are subject to heavy soil erosion. According to the World Map of Desertification Hazards (H. Mensching, 1978, p. 101) the hazard of desertification is 'high' to 'very high'. Due to these recent hazards and challenges, both the American Southwest and southeastern Spain represent regions of intense studies concerning geomorphological dynamics in arid and semi-arid environments.

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