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GROUND-SQUIRREL MOUNDS AND RELATED PATTERNED GROUND ALONG THE SAN ANDREAS FAULT IN CENTRAL CALIFORNIA

by

Robert E. Wallace

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U. S. Geological Survey

ABSTRACT

Extensive areas of mound topography and related patterned ground, apparently derived from the mounds of the California Ground Squirrel (Spermophilus beecheyi beecheyi), are in central California. The relation of patterned ground to the San Andreas fault west of Bakersfield may provide insight into the timing of deformation along the fault as well as the history of ground squirrels. Mound topography appears to have evolved through several stages from scattered mounds currently being constructed on newly deposited alluvial surfaces, to saturation of areas by mounds, followed by coalescence, elongation and lineation of the mounds. Elongation, coalescence and modification of the mounds has been primarily by wind, but to a lesser extent by drainage and solifluction. A time frame including ages of 4,000, 10,500, 29,000, and 73,000 years BP is derived by relating the patterns to slip on the San Andreas fault. Further relating of the patterns to faulting, tilting and warping may illuminate details of the rates and history of deformation. Similarly, relating the patterns to the history of ground squirrel activity may help answer such problems as rates of dispersal and limits on population density.

KEY WORDS

San Andreas fault; Patterned ground; California Ground Squirrel; Mima-like mounds.

INTRODUCTION

Extensive areas of patterned ground apparently derived from the mounds of the California Ground Squirrel (Spermophilus beecheyi beecheyi) were found and studied during investigations of the San Andreas fault in central California between 1965 and 1968. Some of the data and findings were reported orally at the Conference on Geologic Problems of San Andreas Fault System held at Stanford University in May, 1968 (Dickinson and Grantz, 1968). None of the material, however, was prepared for publication in the proceedings volume of the conference. This paper records, belatedly and briefly, some of the more significant findings and describes some of the problems, both geologic and biologic, that deserve attention.

Almost certainly, I will never be able to follow even some of the most obvious and interesting lines of investigation, so I present this to intrigue others to pursue these fascinating problems.

Patterned ground has received much attention by investigators, but, as Washburn (1956, p.823) states, "The origin of patterned ground is far from satisfactorily explained". Washburn also cites nineteen hypotheses that have been suggested to explain various types of patterned ground, and his review and extensive bibliography are excellent. Washburn (1988) provides a modern review and evaluation of the proposed origins of Mima-like mounds. Washburn notes that the hypothesis of Mima-like mounds being developed primarily by fossorial rodents "was primarily developed by Dalquist and Scheffer (1942)" and "has been vigorously supported by Price (1949, 1950)" and by Cox (1984). Malde (1964) provides some excellent insight into many of the problems of patterned ground. Pewe (1983) reviews periglacial environments and patterned ground characteristic of these environments. Interest in patterned ground accelerated in the late 1940s with attention paid to permafrost and related problems of ice wedges and polygonal ground. In the early 1950s the Mima mounds of Washington state were described by Newcomb (1952) and Ritchie (1953) and since then many of the patterns have been loosely referred to as Mima mounds. Several papers suggest that pocket gophers are a dominant agent, for example, Arkley and Brown (1954, p.199) state that "..it is clear that the pocket gopher is responsible for the mounds", and Cox and Allen (1987) suggest that pocket gophers create and maintain sorted stone circles in the Columbia Plateau region. Hallet (1990) discusses the more general thesis of self-organization in geomorphology, using patterned ground as an example. White and Wiegand (1989) speculate that sand mounds in Texas are derived from river bars enhanced by vegetation which traps aeolian sand from flood plains.

Important potential findings that might come from further study of the problems here discussed lie in the areas of terrain dating, paleoclimatology, rates of geomorphic and faulting-folding processes, soils development and in the community dynamics of the ubiquitous California Ground Squirrel, including that of dispersal.

LOCATION

The area of mound topography studied is in a strip about 4 km wide by 40 km long along the San Andreas fault northwest and southeast of 35° 10'N., 119° 37'W. The area is east of Paso Robles and west of Bakersfield (fig. 1, see also map of San Andreas fault by Vedder and Wallace, 1970).

DESCRIPTION OF MOUND PATTERNS

The patterns of ground apparently derived from ground-squirrel mounds are here discussed under three major categories: 1) areas containing only scattered mounds; 2) areas saturated with mounds; 3) areas containing highly-modified, especially elongate mounds arranged in lineated patterns of preferred orientation (figs. 2, 3, 4, 8, 9, 10). Gradations are found between all three types.

1.- Areas of scattered mounds:

On many areas of recently deposited alluvium, ground squirrels are actively building mounds. The individual mounds are widely scattered (fig. 3, 6). but, as other mounds are built, the density of mounds on a given area of land increases.

The mounds are crudely circular and range in diameter principally between 2 and 15 m, averaging in different areas between 7 and 10 meters. Mounds generally are between 30 and 100 cm. high. Material dug from burrows on hill slopes slides downhill producing elongate mounds and later solifluction can change the shapes. No significant sorting of coarse and fine materials has been noted in any of the mounds.

2.- Areas saturated with mounds:

Mounds are densely developed across areas many tens of square kilometers in extent (fig. 2). The mounds do not merge or coalesce into a blanket of bioturbated ground; rather, each mound maintains a high degree of integrity and is separated from nearby mounds by undisturbed ground in moat-like troughs where vegetation grows. Mounds may constitute from 40 to 80 percent of large areas of land; the undisturbed intermound areas make up the remainder. On air photos the mounds invariably appear lighter than the intermound areas. In the growing season the intermound areas are green in comparison to the light buff color of the mounds. The development of soil in the intermound moat areas where vegetation grows makes the moats appear browner or darker long after the mounds become inactive. Even after a mound-saturated area is cultivated repeatedly over many seasons, the pattern of light and dark remains.

3.- Areas of elongate mounds and lineated patterns:

After mounds have saturated a land area, modifications by water and wind erosion become apparent (figs. 2, 3). For example, drainage eventually develops along the intermound areas, although in early stages local intermound areas are isolated and undrained. The drainage channels tend to separate the otherwise evenly-distributed mounds into rows of mounds. Tectonic warping and tilting of the land surface in this very active tectonic environment near the San Andreas fault has controlled the direction of drainage flow and, thus, the orientation of many gullies.

A lineated pattern of elongate mounds composed of coalesced individual mounds dominates large areas (fig. 3). The width of the elongate mounds is about 10 m., the same as individual mound diameters, but the lengths range between 50 and 100 m and in extreme cases are more than 200 m.

Regionally, the elongate mounds have a preferred orientation between N. 10° and 30° E. (figs. 4, 5). This linear pattern maintains the northeast orientation over hills and valleys, strongly suggesting that prevailing winds was the modifying agent. Lineated mounds are absent in a band just northeast of the crest of the Panorama Hills (fig. , see letter "D"), suggesting that that area was the lee side of the hill, and that the prevailing wind direction was from the southwest. In some places the lineaments bow around prominent topographic features as in the center of section 28, figure 4. Few other agents conceivably could cause such a pattern to develop across varied topography.

Down-slope movement of mound material also changes both shape and orientation of elongate mounds. In many places channels formed by down-slope drainage are at a distinct angle to the lineated pattern of mounds (fig. 3). Differential tectonic warping of the land surfaces seems to have taken place after the lineated pattern developed. All the processes interact at different rates to produce variations of the main patterns.

BOUNDARIES BETWEEN AREAS

Many boundaries between the different patterns are margins of alluvial deposits which have been laid across areas of elongate mounds and related lineated patterns. Later the newer alluvial surfaces have become populated with mounds. This overlap relation is well displayed on the southwest side of the San Andreas fault where drainage cutting through the pressure ridges along the fault tends to spew sediments in the form of relatively young fans with apices at the gap in the ridge. Triangular areas representing alluvial fans are also clear on the lower slopes of the Panorama Hills northeast of the San Andreas fault. These fans are deposited across areas of elongate/lineated mounds and have apices at the downhill ends of major channels eroded into the flanks of the Panorama Hills. Characteristically the lower parts of the fans have well-developed mound patterns, but the density of mounds decreases toward the apices where fan deposits are youngest; there mounds may be absent altogether.

In addition to distinct fan forms, the downhill wash of sediments continuously builds up a blanket over areas of lineated patterns in the lower reaches of the hill slopes. New mounds seem to be continuously forming on these developing surfaces. For areas to become saturated with mounds the rate of dispersal of mounds must be faster than the development of new alluvial surfaces. Perhaps from place to place, and time to time, either the rate of mound dispersal or the formation of new alluvial surfaces might win out. In the lower reaches of the flanks of the hills, adjacent to the ridge zone along the San Andreas fault, distinct alluvial fans are to be found, and the fans broaden and spread out as ponding increases just uphill of the pressure ridge and faulted zone. Many of these fans and ponded surfaces have little or no population of mounds.

As discussed later, faults and folds, which are superimposed across the patterned ground, separate various areas of patterned ground.

INTERIOR OF MOUNDS

The third dimension of mounds was examined only in a few places where channels had been cut across mounds (fig. 7). The mounds themselves are a shield-shaped layer of sand and silty material tapering from thin at the edges to between 30 and 100 cm. at the center. The mound material is derived from original strata below the mound. Below those mounds examined the original strata were bedded alluvial material including silt, sand and gravel. The Ground Squirrels burrow along the less resistant layers, commonly just beneath a layer of more indurated sand or gravel which provides good roof strength, and from there they carry the material to the surface. Several levels of burrows at vertical intervals of 30 to 60 cm appeared to be active, and under some mounds as many as six burrow levels one above the other were found. The squirrels developed paths between portals along ledges on the near-vertical wall of the gully.

MOUNDS AND GROUND-SQUIRREL ACTIVITY ELSEWHERE

A comparison of the distribution of Spermophilus beechi and mound topography in some of the western states is shown in figure 11. I have examined only a few areas outside of the San Andreas-fault study area. One site in the San Joaquin valley on the Stoddard ranch, about seven miles southeast of Merced, consists of 140 acres of ranch land that has never been levelled, according to Herbert Stoddard. There ground-squirrel mounds were found to be similar in dimensions to those in the San Andreas-fault study area. Squirrels were very active in late November, 1990 when the site was visited. Mr. Stoddard told me that the squirrels had been killed with poisoned bait in the period between 1947 and 1952, but that the pasture had been completely reoccupied within about three years.

Another site examined is on Stanford University land near the large radio telescope west of the campus. There ground squirrels were very active during the winter of 1990 and 1991. The mounds were not well developed; they were of low relief and had indistinct boundaries. I found this of interest, because I have no good answer as to why. Perhaps, as Arkley and Brown (1954) report that mounds can be correlated very closely with soil types. The Stanford site is on a colluvial cover of bedrock, and very likely burrows do not go very deep. In contrast, the San Andreas and Stoddard sites are on deep alluvium where there would be no soil constraint on depth of burrowing.

Arkley and Brown (1994, p.195), however, attribute "the mounds to the work of pocket gophers (genera Thomomys, Goemys and Cratogeomys", and dismiss the work of ground squirrels. They state (p.197) that "The ground squirrel is widespread ... however, he is a gregarious animal, and develops colonies that are often honeycombed with holes. Wherever ground squirrels are active the mounds are of indiscriminate shape, and there seems to be no tendency toward domal mound formation". My findings strongly contradict those of Arkeley and Brown. As I found on the Stanford land, however, in some areas Ground Squirrels do not create mounds that are very distinctive.

Ground squirrels tend to select easy-to-dig sites for burrows, e. g. dirt bladed off roads. Well known to many field geologists is the fact that ground-squirrel diggings are common in faulted materials which is soft and easily excavated.

AGES OF PATTERNED GROUND

As land surfaces, the three types of patterned areas must grade in age from youngest to oldest. Areas of scattered, active mounds are the youngest; areas of elongate mounds and lineated patterns are the oldest. Many different lines of research are worthy of following to determine the ages of the pattern types. Here a suggestion of age is derived by relating the patterned areas to the rate of slip on the San Andreas fault.

The regional pattern is such that the San Andreas fault and related pressure ridges and grabens markedly truncate the pattern of elongated mounds, for example, on the southwest side of the fault and ridge band (fig. 3). The elongate mounds and lineated patterns do not bow or change orientation near the fault, rather they end abruptly at the fault.

On the northeast side of the fault-ridge band relatively new, young alluvium, which collects there because of relative damming, grades up hill through areas saturated by mounds to areas of elongate mounds and lineated patterns on the higher flanks of the Panorama Hills and Temblor Range. This pattern suggests that the elongate mounds and lineated pattern was regionally extensive and predates the uplift developed in the vicinity of the San Andreas fault.

A minimum date for the beginning of significant uplift and warping along the San Andreas fault in this reach of the fault can be derived from the rate of fault slip at Wallace Creek (Sieh and Jahns, 1984, and Sieh and Wallace, 1989) combined with the length of the longest entrenched reaches of stream channels along the fault. A rate of fault slip of 3.4 cm/year has been well documented at Wallace Creek. The longest entrenched stream offset along the San Andreas Fault in the vicinity is approximately 1 km long, and lies in sec. 19, T. 32 S., R. 21 E. along the Elkhorn Scarp. The original head of this same stream may be 2.5 km southeast of its outlet across the San Andreas fault. Entrenchment of this offset reach of the stream could not have been achieved until significant uplift had occurred. Given 1 km of slip at a rate of 3.4 cm/yr, the stream must have been entrenched for no less than 29,000 years. If 2.5 km is assumed, an age of 73,000 yrs is indicated. It would follow that accepting the 29,000 yr age, that age would also be a minimum age of the ridge structure that developed across the regionally-extensive, elongate/lineated patten. In turn it would be a minimum age of the elongate/lineated pattern itself. The pattern, however, might be considerable older than 73,000 years.

A caveat must be noted. Although a slip rate of 3.4 cm/yr is used above, observed displacement on some segments of the fault ranges from large near the segment midpoint to very little near the ends. Overall, however, the value of 3.4 cm/yr is believed to be a valid average.

An age of 73,000 years for the elongate mounds and lineated pattern would be consistent with calculations by Hanks and others (1984) that fault scarps a meter high in Nevada would still be discernable after about 100,000 years. Although the features are different, each is of the order of one meter high. The distinctiveness of the mounds pattern, however, owes its longevity at least in part to the contrast between the darker soil surrounding each mound.

Slip rates on the San Andreas fault also provide suggestions of the rates at which mounds are created on newly formed land, and the length of time required for mounds to saturate an area. Several streams that flow across the ridge-fault zone erode a notch through the ridge and deposit fans on the southwest side of the ridge and fault. The erosion notch shifts with slip on the fault providing a source of fan material that shifts continuously southeast relative to the older apices of fans. The older fans, thus, gradually become beheaded. One example is shown in figure 8.

In figure 8 the three types of mound areas are represented and labeled 1, 2, and 3. Displacement of the boundary between the area of saturated mounds (2) and the area of elongate/lineated mounds (3), indicated by the length of the arrow along the San Andreas fault (A to C) is 360 m. At a rate of slip of 3.4 cm/yr, that boundary represents fault slip over about 10,500 years. Within 400 m of the fault, the boundary is fairly distinct, but west (bottom of photo) of that types 2 and 3 are smoothly gradational. In the same figure, the contact between areas 1b and 2 is possibly offset as much as, but no more than, 138 m, representing about 4,000 years of slip. Area 1b grades imperceptibly into area 1a, and area 1a has few mounds developed on it. The very light area (1) is the surface of an alluvial fan formed during the rainy season of 1965-66 before January 13, 1966, when the photo was taken.

From the above crude measurements and assumed rate of slip on the fault, I conclude that: 1) Mounds may be developed to a point of saturating an area in less than 4,000 years, and perhaps in as few as hundreds of years; 2) Some mounds became elongate and lineated in a time period bracketing 10,000 years ago, but full development may have been achieved only in the period between 10,500 and 73,000 BP.

The two ages derived above, which pertain to the elonate mounds and lineated patterns, are neither mutually exclusive nor incompatible. The argument, indeed, can be made that the climatic conditions causing the winds that elongated the mounds was present as short a time ago as 10,500 years. But the period of wind may have continued for periods of the order of 70,000 years, and possibly much longer, so that the elongate/lineated pattern was regionally developed prior to 70,000 when the pressure ridges and uplift along the fault zone became significant. Without a doubt, both wind velocity and years duration are important considerations. Even today sand and silt can be seen moving in strong winds.

PUZZLES ABOUT EVOLUTION OF MOUNDS AND PATTERNS

The clear gradation from very recent alluvium just being invaded by active ground-squirrel mounds to mound-saturated areas argues strongly that the patterned ground, indeed, does originate from ground-squirrel activity. The evolution of the patterns through the various stages, however, poses several questions, and further confirmation is needed that all of the present patterns do start as ground-squirrel mounds. Perhaps some periglacial process, such as produced the Mima mounds may have created the older patterns, and then those mounds were later occupied by ground squirrels. To my knowledge, however, no one has suggested that patterned ground at such low latitudes and low elevations was created by ice wedging and permafrost, albeit that is a major cause in higher latitudes. Saturation of an area by mounds as recently as a few hundred to, at most, a few thousand years ago would argue against a periglacial climate. Excavation of mounds and dating of squirrel remains might cast light on the problem.

Perhaps a sedimentary process on alluvial fans, modified by vegetation, as described by White and Wiegand (1989) might be responsible for some patterns.

In the early stage, where only scattered ground-swuirrel mounds are present, I have puzzled about what factor controls the maximum size of the mounds. This becomes critical when the area reaches saturation, because as reported above, the mounds do not coalesce, but are separated by an undisturbed, grassy moat between mounds. I have not explored the habits of the California ground squirrel adequately, but, thanks to the help of Professor David Regnery of Stanford University, I can offer a few ideas reported in the literature.

During a single year in the life of a California ground-squirrel mound, the females and her young apparently dominate a colony, as "more young males disperse from their natal colony than young females" (Dobson, 1979, p. 1108), and Fitch (1948) suggests that young males disperse every year. David Regnery (personal communication, 1990) reports that soon after breeding, males leave the mounds. Dobson also reports that "Adult females may have excluded some immigrant young." (p. 1108).

For some period, thus, one mound seems to be primarily the domain of one female and her young, and little incentive may exist to enlarge the diameter of a mound beyond approximately 10 m. For a period of decades, however, during which a mound seems to change little in shape or size, one must wonder what the sequence of family units is to result is so little change in a mound. Considering millennia, the puzzle grows.

Ground squirrels, of course, do disperse and start new mounds at some distance from their natal colonies or mounds. Significant in this process may be the habit of a limited range of movement by individuals. Linsdale (1946, p.44) reports that 68.8 percent of individuals in one study ranged no more than 150 yards, and that only 1.4 percent ranged 1,200 or more yards.

Considering the density of mounds in some large areas, I question the ability of the area to provide sufficient food for a ground-squirrel population active in all mounds. Only the intermound moat areas are available for the growth of abundant grasses and seeds, and this would seem to be scarcely enough. Perhaps as the land area becomes saturated with mounds, only a fraction of the mounds are active at one time. The pattern of dispersal and development of additional mounds awaits further study.

Important questions surround the stage of abandonment of mounds by the squirrels. Squirrels have a tendency to reoccupy existing mounds and burrows (Dobson, 1979). Conceivably, a mound might become abandoned and dead, only to become the site of a later dispersal event, including a new cycle of burrow digging.

In February, 1991 I spent a few hours examining several mounds that appear in aerial photographs taken in 1966. Remarkably, after 25 years, the mounds had retained almost their identical shapes and sizes as in 1966. How could this be, when active burrowing apparently has continued unabated, and moderate winds were moving sand and silt during the brief examination? Many generations of squirrels must have used these mounds. I wonder for how many millennia these mounds have been continuously occupied.

SOME REMAINING QUESTIONS AND COMMENTS

Geomorphology, Tectonics, and Paleoclimatology

1. Is the patterned ground described actually derived from ground squirrel mounds, as I believe it is, or are the saturated patterns primarily derived from some other process, and the squirrels merely occupy the mounds and modify them through burrowing? Excavation of older mounds and dating of burrow material could cast light on these problems. A comparison and further study of the distribution of mound topography to the distribution of the California ground squirrel (Spermophilus sp.) would be significant (see figure 11).

2. Can better dates be found to bracket the ages of the types of patterned ground? What is the oldest date of intense wind that elongated the mounds? What wind velociites and duration are required?

3. The wide-spread distribution of the patterned ground should make it useful in interpreting the timing and rates of deformation in the Panorama and Elkhorn Hills, and perhaps elsewhere.

4. Elements of paleoclimatology, especially the history of wind strength and direction, and possibly some periglacial processes, should become clearer from the study of changes in patterned ground derived from ground-squirrel mounds.

Ground Squirrels:

1. At what stage of development of the patterned ground do the ground squirrels cease to reside in the mounds? Do the squirrels reoccupy ancient mounds that have been highly modified by wind and other erosion? How long is an individual dwelling kept continuously active?

2. If the mounds are active after an area becomes saturated with mounds, where does the food crop grow? Only in the intermound areas, which may constitute as little as 20% of the land, does vegetation flourish; the mound areas are continually bioturbated. Can this limited area provide sufficient food? Perhaps, only a limited number of mounds in a saturated area are active at one time?

3. Why do ground squirrels build mounds of significant height and limited diameter in some regions of California, whereas mounds elsewhere are less-well defined. Very likely soil thickness and type are factors, but, specifically, what are they and why do they control ground-squirrel activity?

4. Do the ages suggested for the patterned ground provide any answers for the problem of dispersal, or about the long-term history of the ground squirrel community?

5. Over a broader region, how extensive are mounds that are clearly the product of ground-squirrel activity, both in modern and prehistoric times?

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FIGURE CAPTIONS

Figure 1.- Index map of California showing location of study area of mound topography and patterned ground along the San Andreas fault .

Figure 2.- Aerial photograph showing an area saturated with ground squirrel mounds. In places a faint lineation shows; some appears to be related to intermound, downhill drainage. (Photo by Water Resources Division, U. S. Geological Survey, Series 50-6, nr. 0287, 1/13/66, scale 1:6,000)

Figure 3.- Aerial photograph showing elongate mounds and lineated pattern in triangular area bordered on the northeast by the San Andreas fault. The fault is the linear feature extending from the left to right margin about one third the way from the top of the frame. The elongate mounds and lineated pattern are sharply truncated at the fault. Note that drainage channels flowing down slope are at a distinct angle to the orientation of lineation. The very light area in the lower left is new alluvium deposited in the winter of 1965-1966. An area saturated with mounds is northeast of the San Andreas fault, and ponded alluvium forms an arcuate area along the northeast flank of the saturated area. (Photo by Water Resources Division, U. S. Geological Survey, Series 50-6, nr.0417, 1/13/66, scale 1:6,000)

Figure 4.- Aerial photo, scale about 1:21,000, showing regional relation of some patterned ground areas. The San Andreas fault is the linear feature extending from right to left margin. The Panorama Hills are in the upper part of the frame and the Carrizo Plain is in the lower part. Areas A, B, and C display examples of elongate mounds and lineated patterns. The lineations in A and B are sharply truncated at the San Andreas fault. Alluvial fans, the apices of which are at the San Andreas, are between areas A and B and to the right of area A. Offset of the fan between A and B was used to estimate ages from slip rates on the fault. Area D on the northeast slope of the Panorama Hills is largely devoid of elongate mounds suggesting that it was the lee side of the hills when the wind blew to elongate the mounds. (Photo source unknown, except that the photographs were taken during an infrared-imaging project in 1965.)

Figure 5.- Map of a part of the area studied to illustrate the prominent northeast orientation of lineations on patterned ground in ten areas. Many areas other than those shown on map also display similar orientations of the lineated pattern.

Figure 6.- Ground-squirrel mound approximately one meter high, showing burrow entrances. Stadia rod standing in burrow is marked in feet and at base in tenths of a foot.

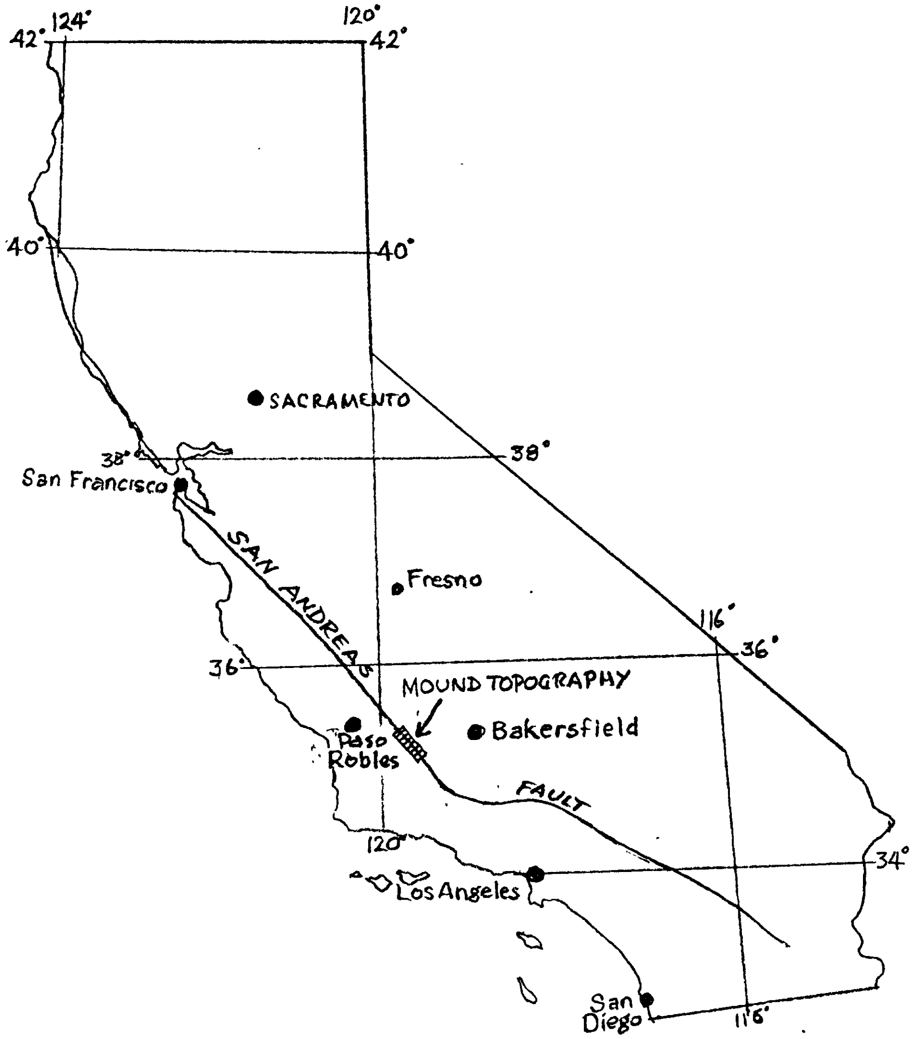
Figure 7.- Photograph of a section through a ground-squirrel mound and burrows exposed in the bank of a gulch. The geologic pick, about 30 cm long, is for scale. Note the several levels of burrow development below the mound, and the strategraphy beneath the mound. Mound material lies above this cut but doesnot show in the photograph.

Figure 8.- Aerial photograph of areas of patterned ground off-set by slip along the San Andreas fault (the linear feature extending from right to left margin). See section regarding "ages" in text for discussion. (Photograph by Water Resources Division, U. S. Geological Survey, series 50-6, nr. 0419, 1/13/66, scale 1:6,000).

Figure 9.- Oblique aerial photograph of part of area in figure 8 near "3". Note size of mounds relative to power poles along road. Note that mound pattern shows clearly despite plowing of fields.

Figure 10.- Oblique aerial photograph of mounds in vicinity of graben on crest of Elkhorn Hills, sec. 34, T.32 S., R.22 E. View southeast.

Figure 11.- Maps showing: (A) distribution of mound regions in the western states (from Washburn, 1988, quoting Cox, 1984) and, (B) distribution of the California ground squirrel (Spermophilus beecheyi) in California, Oregon and Washington, and Mexico (from Hall, 1981).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Fresno
116°
36°
36°
MOUND TOPOGRAPHY
Bakersfield
Paso Robles
FAULT
120°
34°
Los Angeles
San Diego
116°

FIG. 1

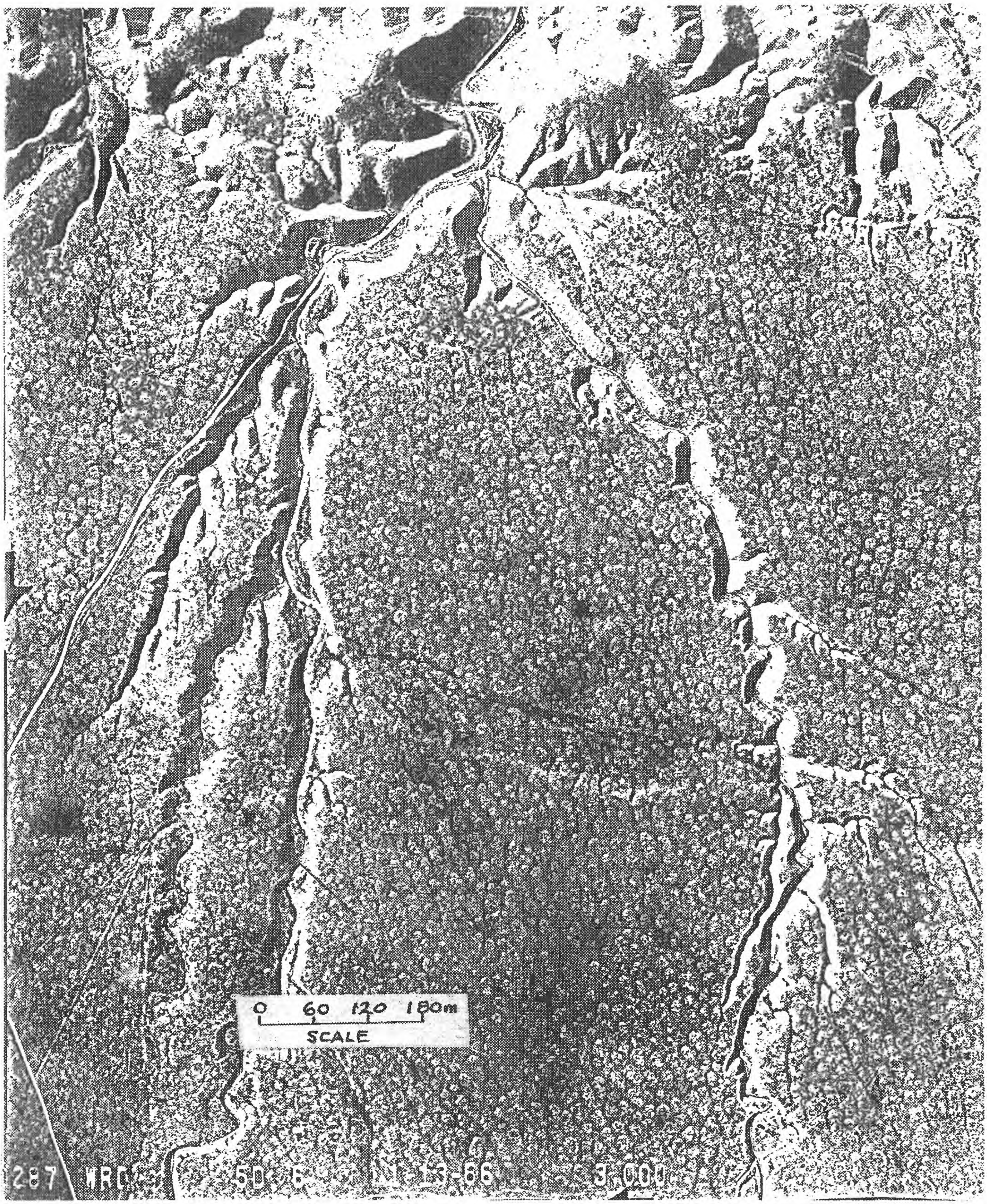


FIG. 2

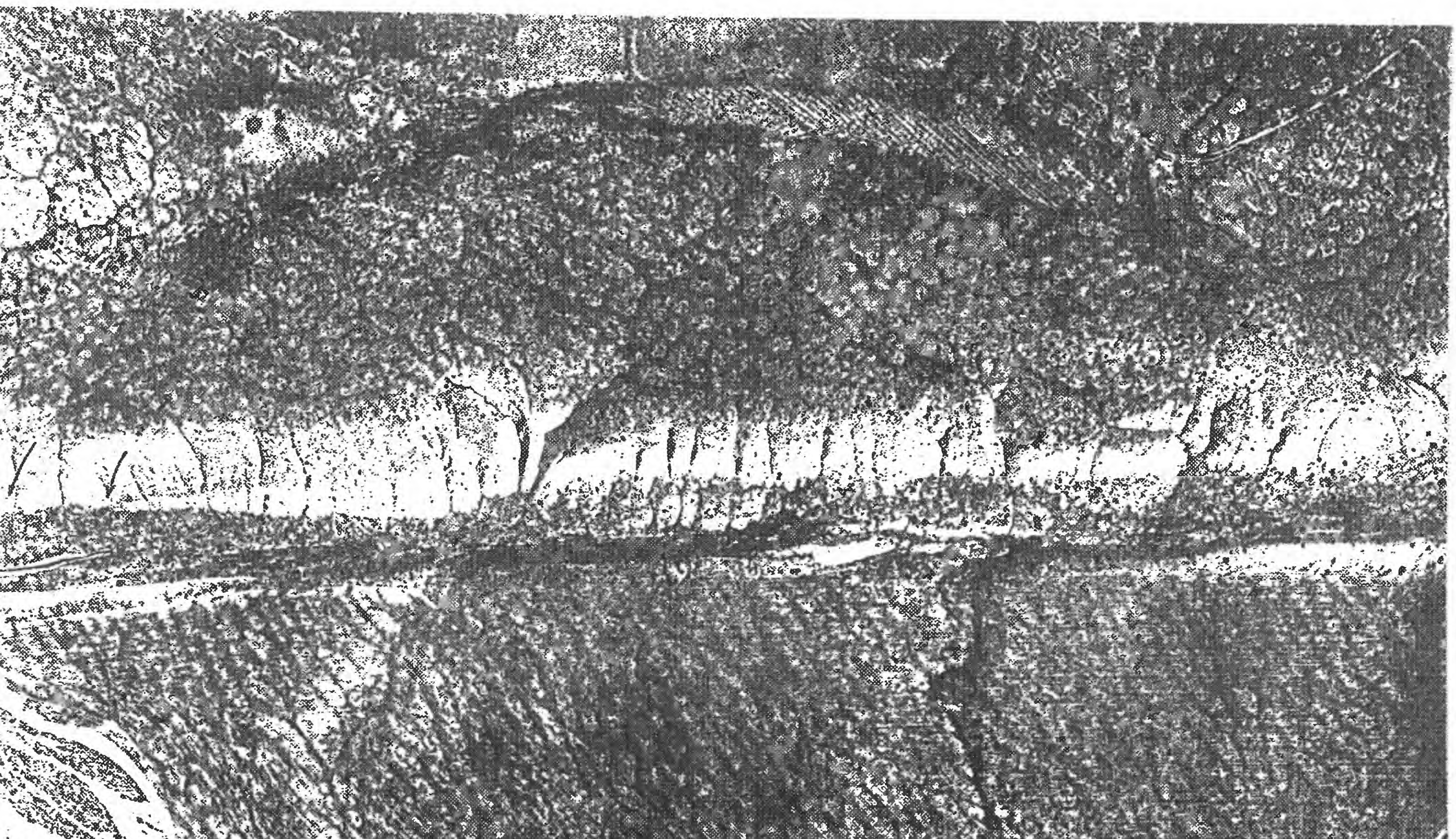


FIG. 3

PHOTO 0417 URD

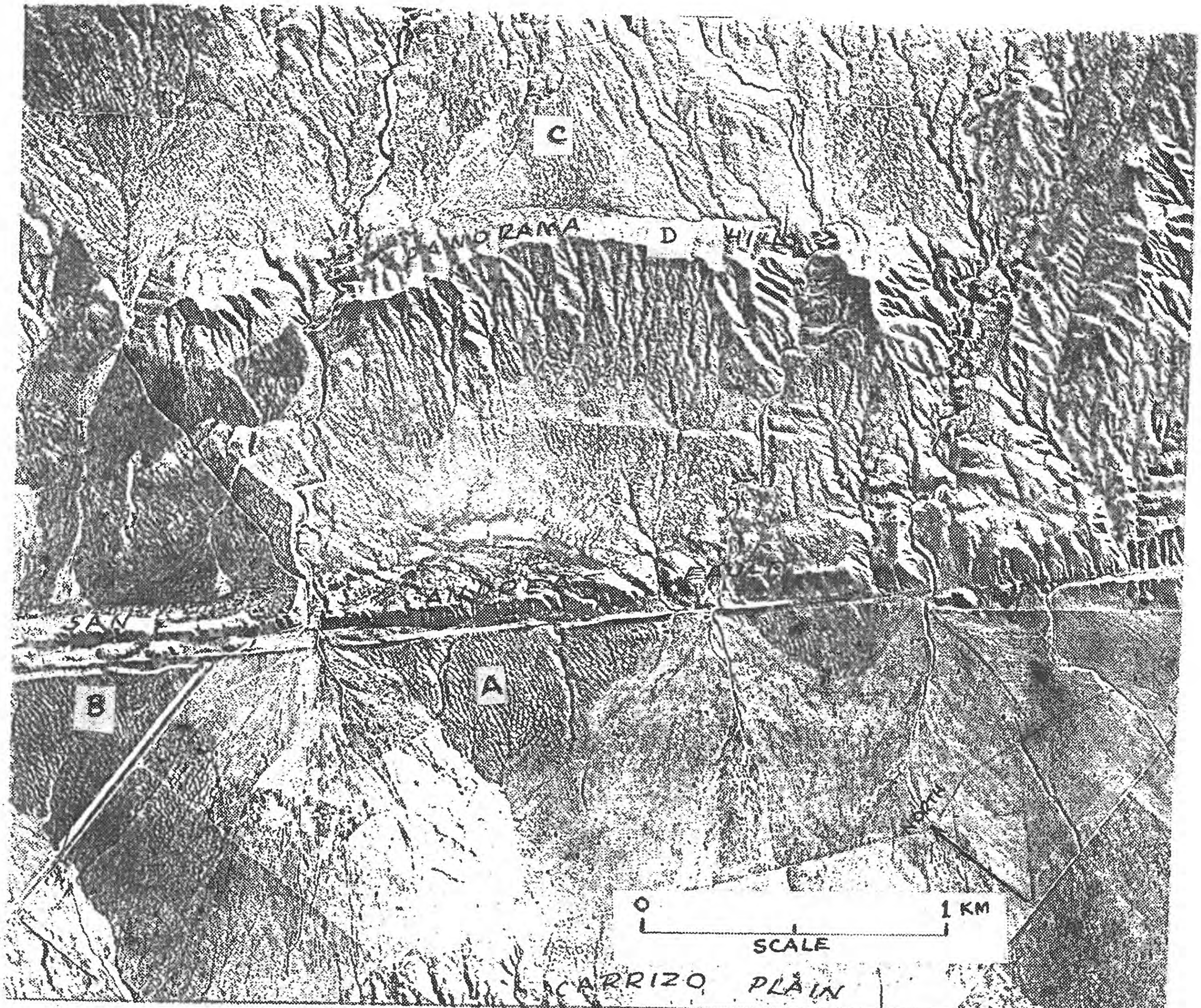
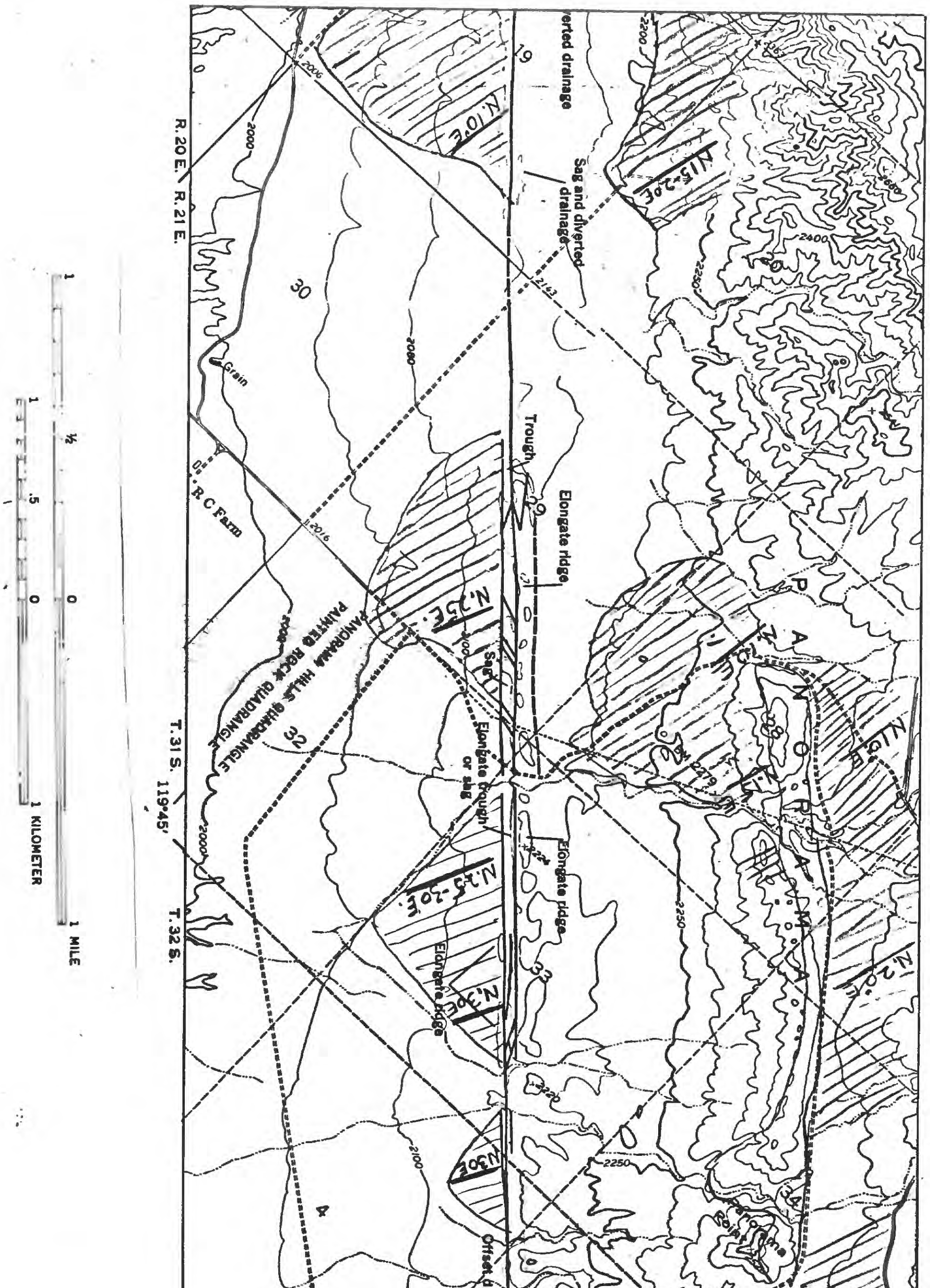


Fig. 4



Sag and diverted drainage
Diverted drainage
Trough
Elongate ridge
Sag
Elongate trough or sag
Elongate ridge
Elongate ridge
Offset drainage
N.10°E.
N.15-20°E.
N.25°E.
N.15-20°E.
N.30°E.
N.30°E.
N.10°E.
N.20°E.
PANORAMA HILLS
PANORAMA HILLS QUADRANGLE
PAINTED ROCK QUADRANGLE
R. 20 E.
R. 21 E.
T. 31 S.
T. 32 S.
119°45'
Grain
R C Farm
1 MILE
1 KILOMETER

FIG. 5

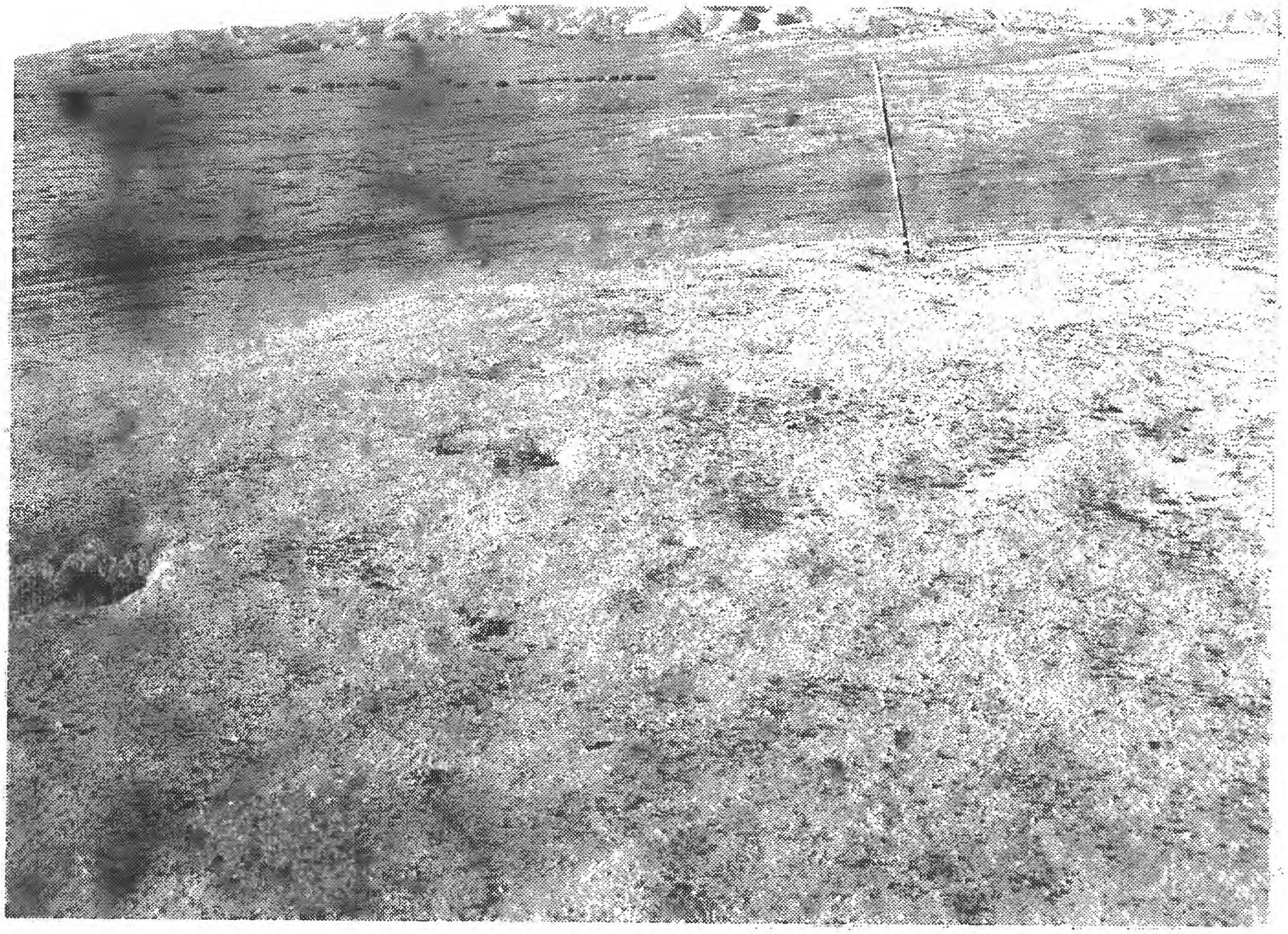


FIG. 6

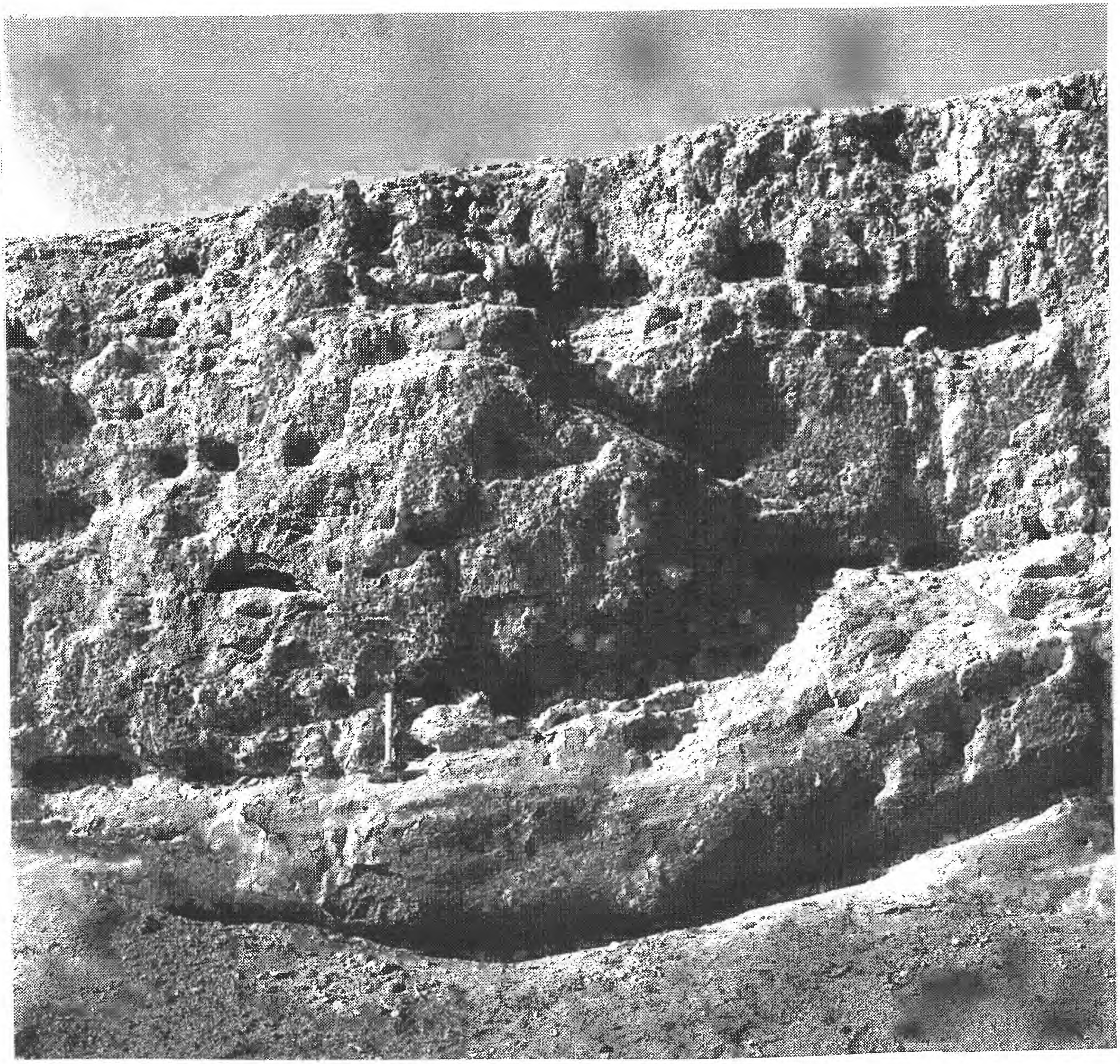


FIG. 7

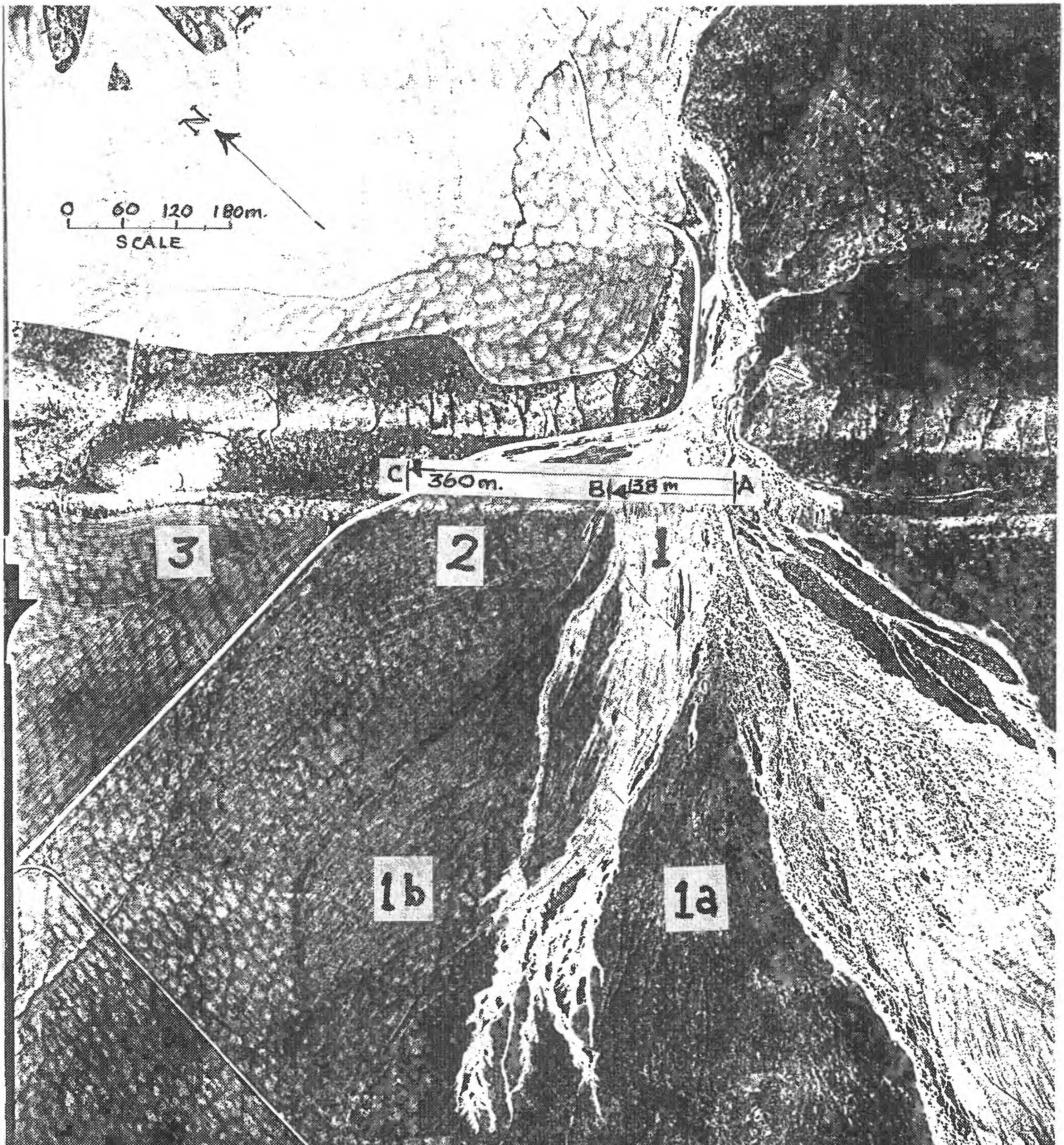

N
0 60 120 180m.
SCALE
C
360m.
B
138 m
A
3
2
1
1b
1a
419 WRD 5D. 6 1-13-66 3.000

FIG. 8

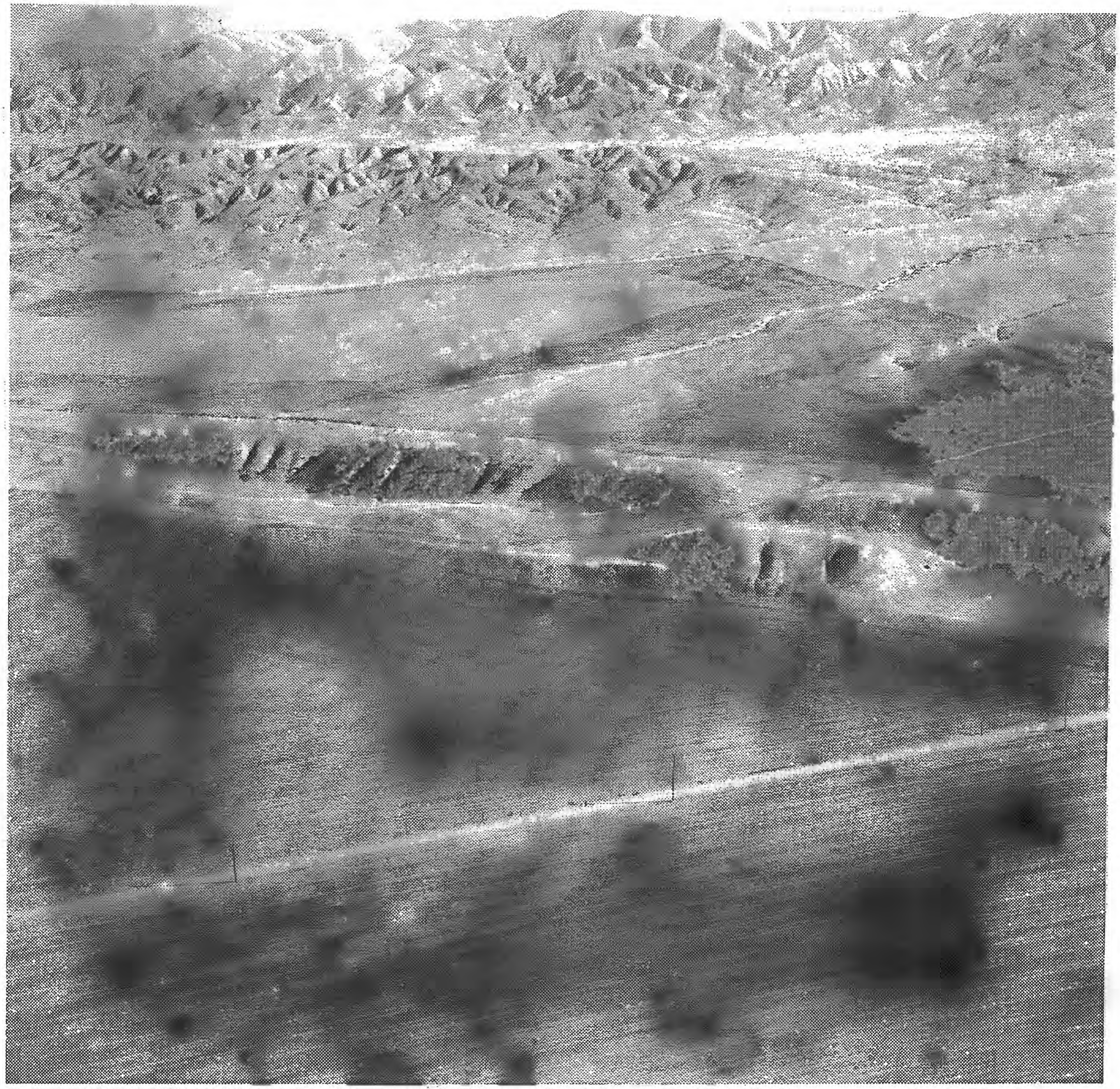


FIG. 9

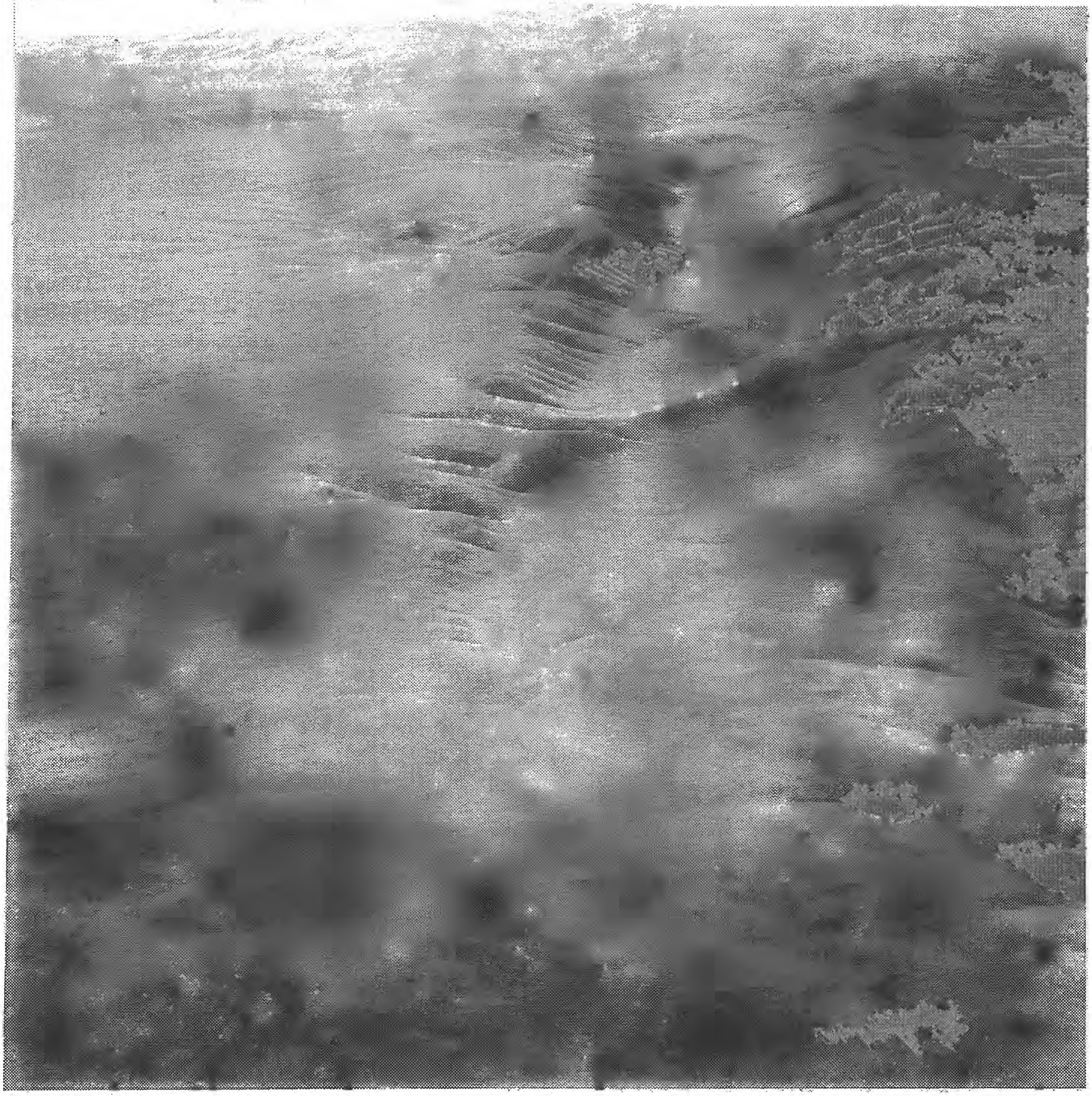
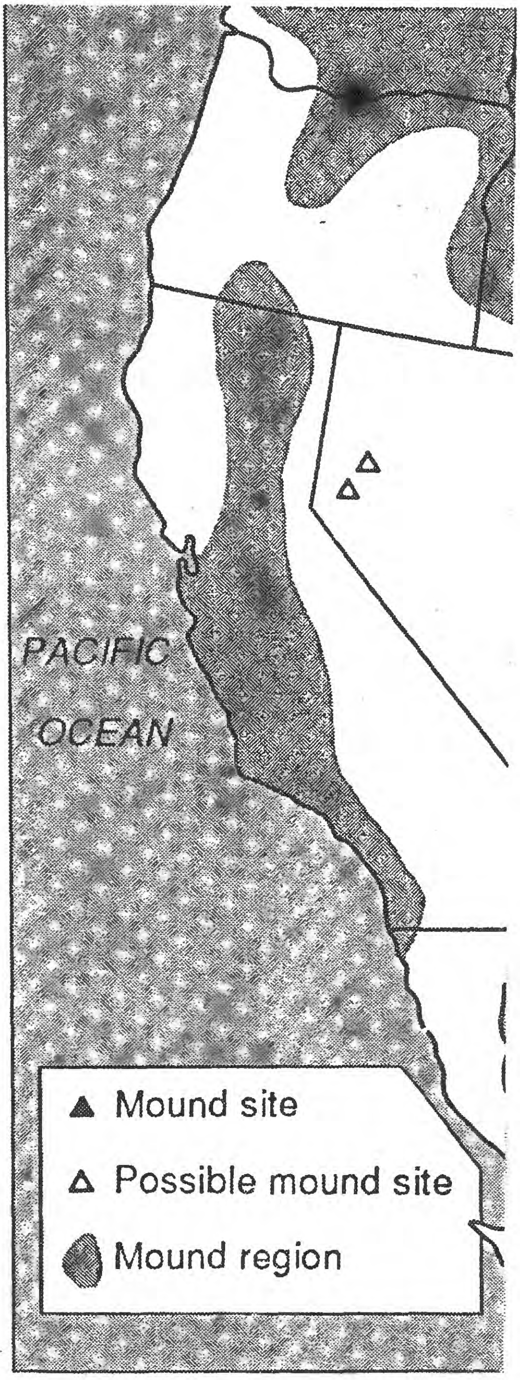
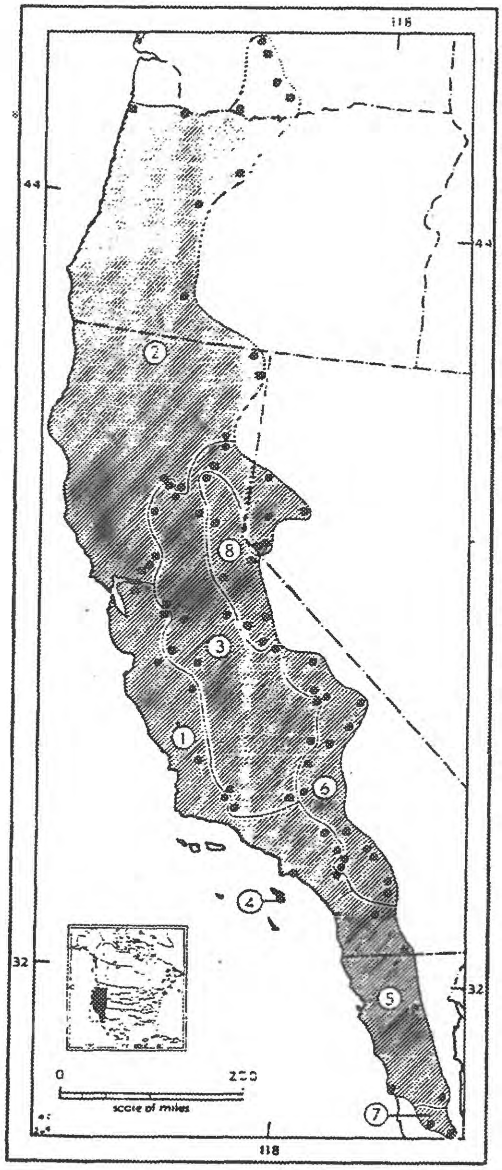


FIG. 10



A.



Map 269. *Spermophilus beecheyi.*

1. *S. b. beecheyi*
2. *S. b. douglasii*
3. *S. b. fisheri*
4. *S. b. nesioticus*
5. *S. b. nudipes*
6. *S. b. parvulus*
7. *S. b. rupinarum*
8. *S. b. sierrae*

B.

FIG. 11