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GEOLOGY OF LITTLE SAN PASQUAL MOUNTAIN

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Little San Pasqual Mountain is in the Rio Grande Valley approximately 13 airline miles south of San Antonio, New Mexico, and one mile east of the Rio Grande. The mountain lies within the Bosque del Apache National Wildlife Refuge and constitutes the extreme north central portion of the Val Verde 15-minute quadrangle (see fig. 1). Methods used

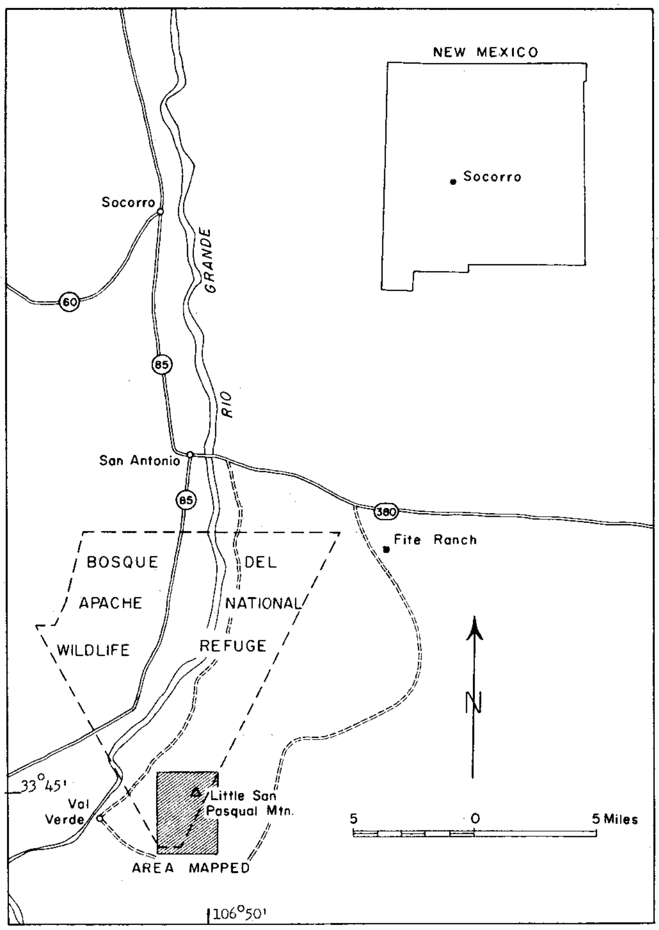

FIGURE 1

in this investigation were both geological and geophysical. Surface mapping determined the exposed structural relations of the area and provided partial subsurface control for a subsequent gravity survey.

STRATIGRAPHY

The sedimentary rocks exposed in the area mapped range in age from Pennsylvanian to Tertiary with most of the section assigned to the Paleozoic. Little San Pasqual Mountain is composed entirely of Pennsylvanian sediments with fringes on the west, east, southeast, and south of Permian rocks. On the north and northwest the Pennsylvanian rocks are in contact with the Tertiary Santa Fe Formation (fig. 2). Included within the Santa Fe Formation is an andesitic lava (pre-Santa Fe according to Weber and Kottlowski) which forms a purple soil cover and locally occurs as badly weathered outcrops. To the northwest, two dark reddish brown mesas are present which are composed of the Tertiary Baca Formation. One small block of sandstone contained in the Santa Fe was tentatively identified as being derived from the Cretaceous Dakota Sandstone.

PENNSYLVANIAN SYSTEM

The Pennsylvanian System in New Mexico consists largely of marine limestones and is quite varied and widespread. The fact that the sequence is predominantly limy somewhat complicates mapping since it is difficult to identify a given bed within a group of limestones. For this work the nomenclature of Thompson (1942) was originally adopted; however, it met with little success. The Pennsylvanian limestones in the mapped area in general can not be correlated with Thompson's sections in the Oscura Mountains on a lithological basis. However, three of Thompson's units, the Coane Limestone, the Adobe Formation, and the Council Spring Limestone, have been recognized. Most of Thompson's units are based an paleontological data and the requisite collections for evalution were not made in the Little San Pasqual area.

Thompson (1942) defines four series for the Pennsylvanian system in New Mexico on a paleontological basis. These four series are, from oldest to youngest, Derryan, Desmoinesian, Missourian, and Virgilian. On Little San Pasqual Mountain, the Pennsylvanian was divided into four mappable units which here are designated units 1, 2, 3, and 4. On a general lithological basis, it is believed that these units correspond quite closely to the series units of Thompson.

The basal Derryan is the most clastic of the four series described by Thompson. Unit 1 of this report

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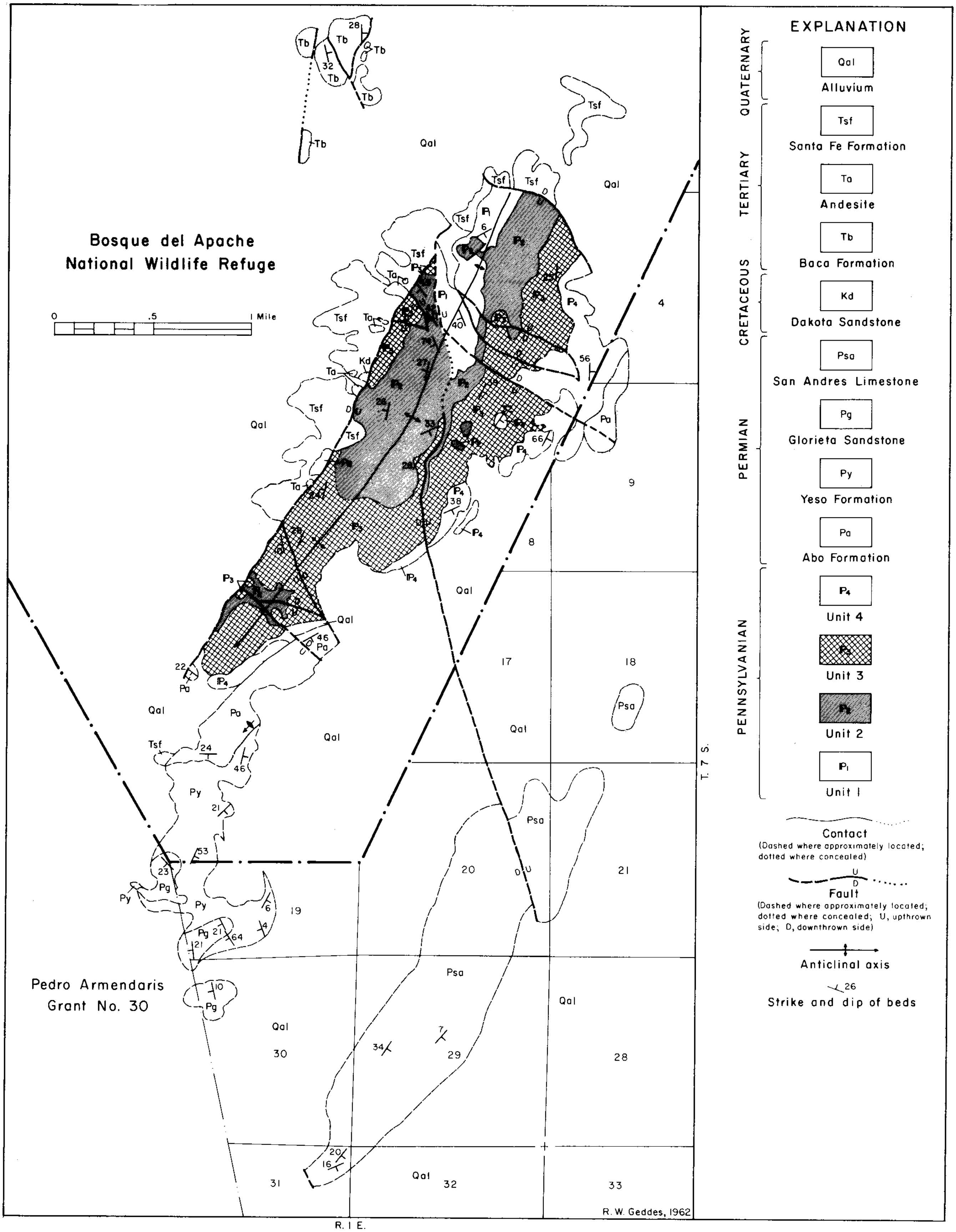

FIGURE 2
Geology of Little San Pasqual Mountain.

is also highly clastic, composed largely of sandstones and shales. The top of unit 1 is placed at an angular unconformity of about 10 degrees magnitude. This unconformity is believed to be the Derryan–Desmoinesian contact of Thompson. In Whiskey Canyon, northern Mud Springs Mountains, where Thompson described Derryan and Desmoinesian rocks, an unconformity is indicated by a faunal break. The clastic nature of unit 1 and the pronounced unconformity at its top suggests that unit 1 is probably the Derryan equivalent. Measured thickness of unit 1 is 572 feet; however, the base is not exposed.

Unit 2 consists predominantly of very cherty limestones which are characteristic of the Desmoinesian in New Mexico. The chert is dark brown or black and generally occurs as bands or layers of chert lenses or as continuous thin beds. The lenses vary in size with the largest being approximately six inches long and one inch in thickness. The colors of the rocks of unit 2 become darker as the top of the section is approached and are almost black at the very top of the unit. Fossils are not common; however, crinoid stems, corals, and a few fusulinids can be found scattered throughout the sequence. The base of unit 2 is the angular unconformity discussed above, the top is at the base of what has been tentatively identified as the Coane Limestone. The upper contact is everywhere covered. Total thickness of unit 2 is 414 feet.

Unit 3 consists almost entirely of limestones. The limestones of unit 3 are generally more massive than those of the underlying unit 2. The basal member of unit 3, the Coane Limestone, was tentatively identified by its massive cliff-forming nature and its sequential relationship to an overlying massive but somewhat thinner cliff-forming limestone tentatively identified as the Council Spring Limestone. The Coane Limestone contains very little chert and forms two almost vertical cliffs, the upper cliff being only one half as thick as the lower cliff. The top of the Council Spring Limestone is extremely silicified, locally becoming agatelike with pale blue, milky white, and black layered bands up to a quarter inch in thickness. These beds (except for silicification) resemble those described by both Thompson (1942) and Kottlowski (1960). The identification of the Adobe Formation follows since this unit separates the Council Spring Limestone from the Coane Limestone. From the top of the Council Spring Limestone upward to the top of unit 3, the beds are only partially exposed. Where exposed, they usually consist of thin- to thick-bedded limestones with beds up to 6 feet in thickness. Approximately 50 feet above the top of unit 3 in NW¼SE¼, sec. 8, T. 7 S., R. 1 E. (the General Land Office survey projected through the wildlife refuge), a lenticular quartz and limestone pebble conglomerate occurs. Maximum thickness is 18 feet; however, both the base and top are covered. Southward from the exposure the conglomerate thins rapidly and disappears beneath a soil cover. To the north, the bed thins to 2 feet within a distance of 30 feet from the thickest part of the outcrops, then continues northward for 200 feet before it disappears under cover. This conglomerate is absent in all other areas where unit 3 is exposed. It is believed that this bed could possibly represent deposition upon a karst surface and that a period of emergence from the sea occurred during unit 3 time.

The entire unit is a light gray to light brown in color with the upper half locally weathering bright orange to reddish brown. Fossils are more abundant in unit 3 than in unit 2, consisting for the most part of brachiopods and crinoid stems. Fusulinids were found only in the extreme upper part of the Coane Limestone.

The upper boundary of unit 3 was placed at the base of greenish gray, alternating thin-bedded limestones and shales which provided an excellent marker bed. The equivalency of the unit 3–unit 4 boundary to the Missourian–Virgilian boundary of Thompson is not known. Thompson's section in the Oscura Mountains contains no such unit described above, so an estimate cannot be made as to the actual boundary relationships. Total thickness of unit 3 is 350 feet.

Unit 4 consists of limestones in the lower part and grades upward into red clastics. The base of unit 4 consists of 35 feet of alternating greenish gray calcareous shales and greenish gray limestones with no individual bed being greater than 2 inches in thickness. Overlying this sequence are dark gray, thin- to thick-bedded limestones which grade upward into a series of alternating gray limestones and red to purple shales. The thickness of the beds in unit 4 becomes greater upward from the base until the interbedded red clastics are reached, with the maximum thickness being 20 feet. The interbedded limestones and red clastics of the upper portion of unit 4 range greatly in thickness, with one red shale bed being 51 feet thick. Fossils, where present, consist almost entirely of crinoid stems. Scattered fusulinids are found in the middle of the sequence with one massive limestone containing abundant fusulinids in the basal 2 feet.

The unit 4–Permian contact was arbitrarily placed at the top of the uppermost limestone just below a continuous series of red shales and fine-grained sandstones. It appears that unit 4 actually is gradational into the Permian Abo Formation and that no unconformity exists between the two units. Total thickness of unit 4 is 268 feet.

PERMIAN SYSTEM

The Permian System is best exposed in the southern part of the mapped area. The Permian rocks delineated during the mapping are Abo Formation, Yeso Formation, Glorieta Sandstone, and San Andres Limestone. The transitional Bursum Formation, if present, was included with the Abo Formation for mapping purposes.

Abo Formation. The Abo Formation consists of bright red to maroon and dark reddish brown fine-grained sandstones and shales. A considerable thickness of the Abo is covered with sand dunes and could not be described in detail. In the Little San Pasqual area the Abo Formation is 753 feet thick. The top of the Abo was placed at the base of a thick limestone with overlying red mudstones which are here considered correlatives of the Yeso Formation.

Yeso Formation. The Yeso Formation is poorly exposed in the southern part of the mapped area. The Yeso consists primarily of red, yellow, and brown mudstones and shales with a smaller amount of light gray limestone and an occasional red or brown sandstone. The Yeso for the most part is covered with soil. The limestones generally form good outcrops while the remaining beds are only locally exposed in the numerous gullies that cross the area. No gypsum was found to occur in the Yeso Formation in this area.

The Yeso Formation has apparently acted as an incompetent unit during folding and is quite brecciated. Local dip reversals are common and on the western margin of the Yeso outcrop area, where the Yeso is best exposed, numerous slump faults occur. Because of these complications, the measured thickness of the Yeso Formation is doubtful. The thickness of the Yeso is approximately 900 feet.

Glorieta Sandstone. The Glorieta Sandstone caps three low hills in the extreme southern part of the mapped area. Lithologically, the Glorieta is somewhat variable. On the westernmost of these three hills, the Glorieta is an extremely hard and dense dark brown quartzite. The Glorieta that caps the remaining two hills is a well-indurated, fine-grained, well-rounded, light brown quartz sandstone, quite different in appearance from the quartzite facies just described. The thickness of this unit is 31 feet.

San Andres Limestone. The San Andres Limestone occurs as two low, parallel ridges southeast of Little San Pasqual Mountain. These two ridges trend northeast, are about 3 miles long, and have a total relief of about 40 feet. Outcrops are very poor except at the southernmost boundary of the unit where for a distance of about 200 feet a thin section of the San Andres is well exposed. The San Andres was identified as such by its stratigraphic relationship to the other rocks occurring in the area.

The San Andres where exposed is a thick-bedded, granular, gray, very sparsely fossiliferous limestone, which weathers to a corroded surface. The thickness of this unit was calculated from map data as 743 feet.

TERTIARY SYSTEM

Baca Formation. A large exposure of rocks in the area has been identified as the Baca Formation. The original identification was made by Dane and Bachman (1961) and was used here.

The Baca Formation occurs in the northwestern part of the area as two steep-sided mesas. It consists of red and reddish brown sandstones with a conglomerate unit at the top. The sandstone is quite friable and in general is quite well sorted.

An angular unconformity occurs near the top of the Baca section which probably reflects intermittent faulting that is believed to have occurred in this area.

The Baca Formation is, at least in part, considered to be Eocene in age (Johnson and Read, 1952). The measured Baca thickness is 419 feet; however, both the base and top are covered.

Santa Fe Formation. The Santa Fe Formation is exposed in the northern part of the area and along the northwest-facing front of Little San Pasqual Mountain. The Santa Fe beds dip very gently westward and are lithologically variable. The rocks consist of thin, cross-bedded, water-laid sandstones and muds containing large limestone fragments. The beds are not well indurated and are generally covered by sand dunes. The exposed Santa Fe measures only 100 feet in thickness; however, the base is not exposed and is known from other evidence to be deeply buried, so a total thickness of several thousand feet is probable.

A small block of medium- to fine-grained quartz sandstone occurs within the Santa Fe Formation and has been tentatively identified as Dakota Sandstone. This block is approximately 100 feet long and 9 feet in thickness. The sandstone, which is quite pure, extremely cross-bedded, and badly brecciated, is probably a large slump block. It crops out along the western margin of the Pennsylvanian System outcrops.

Quaternary System

The remainder of the mapped area is covered by recent alluvium and sand dunes.

STRUCTURE

Folding

Structurally, Little San Pasqual Mountain is a gently arcuate anticline, concave westward and trending north-northeast. The western limb of the anticline has been more deeply eroded than the eastern limb which leaves a steep scarp facing to the west. In the southern part of the area, the anticline plunges 65 degrees to the south. Map data indicate that at the north end of the area, the anticlinal limbs start to converge and plunge to the north; however, a northwest-striking fault cuts off the Paleozoic rocks and forms the northern boundary of the exposed anticline.

On the eastern flank of the anticline is a monoclinal flexure. Rocks of unit 4 change abruptly in dip from approximately 35 to 75 degrees within a distance of 200 feet. The flexure apparently flattens out rapidly beneath the alluvium of the Jornada del Muerto, since gravity data do not indicate an easterly extension. If the rather flat-lying San Andres Limestone in the southeastern portion of the area is projected northeastward with the same attitude, it can be seen that the flexure must flatten out in a short distance to accommodate the rest of the stratigraphic section.

A small anticline occurs in the Abo Formation in the southeastern part of the area just below the Abo–Yeso contact. It disappears under sand dunes to the north and dies out rapidly to the south. The anticline is no more than 100 feet in width and is a very local structural feature.

Faulting

Numerous faults cross the anticline, most of which are approximately perpendicular to the trend of the fold. One normal fault, however, strikes approximately parallel to the axial trace of the fold. To the west of this fault the western limb of the anticline has been down-dropped, forming part of the Rio Grande trough. Almost everywhere along this fault Santa Fe or alluvium rests against Pennsylvanian rocks. In one area, however, Abo is exposed opposite the basal beds of unit 3. The stratigraphic position of this part of the Abo is unknown; therefore, the displacement along this fault can only be given within a certain range. The total displacement is somewhere between 1100 and 2400 feet as determined graphically. Stratigraphic displacement ranges from 600 to 1350 feet.

Another large normal fault trends diagonally across the anticline. This fault is observed in the San Andres Limestone and can be traced north-northwestward through the area to where it disappears beneath the Santa Fe. The displacement along this fault where easily observed is approximately 200 feet.

At both the north and south ends of the anticline, normal faults cut off the Paleozoic rocks. The fault to the north is quite clear while the southern boundary fault is for the most part covered. Only at the southern end of the San Andres outcrop can this fault be observed. Displacements for these faults cannot be determined.

Several other faults strike northwest through the area; one has apparent reverse movement, while the remainder has apparent normal displacement. Displacements on these smaller faults range from 15 to 40 feet. The Baca Formation, which forms two small mesas to the northwest of the mountain, is also cut by normal faults. No faults were observed within the Santa Fe Formation. No obvious joint patterns were discernible.

Gravity Interpretation

The gravity survey was conducted to aid in interpreting the relationship of Little San Pasqual Mountain to the Rio Grande trough to the west. Figure 3 shows the gravity traverse in relation to Little San Pasqual Mountain.

The Bouguer anomaly obtained during this work was 28.8 mg. Interpretation of the anomaly was made using the method of Hubbert (1948). (For a complete discussion of this method as applied to this problem, *see* Geddes, 1963.)

The interpretation indicated that the faulted northern part of the anticline is shallowly buried beneath the Santa Fe Formation and that Permian rocks are the youngest remaining rocks involved in the folding. To the west of the fold, there are at least two large normal faults bounding the eastern margin of the Rio Grande trough, and the center of the valley contains a minimum of 7500 feet of the Santa Fe Formation. Alternate interpretations are possible; however, the close geologic control used in interpreting the results indicates that this is the most probable structural interpretation and any changes would be those of dimensions and not of basic structure.

Structural History

The anticlinal Little San Pasqual Mountain is probably Laramide in age. The thrusts and overturns of the Caballo and Fra Cristobal mountains to the

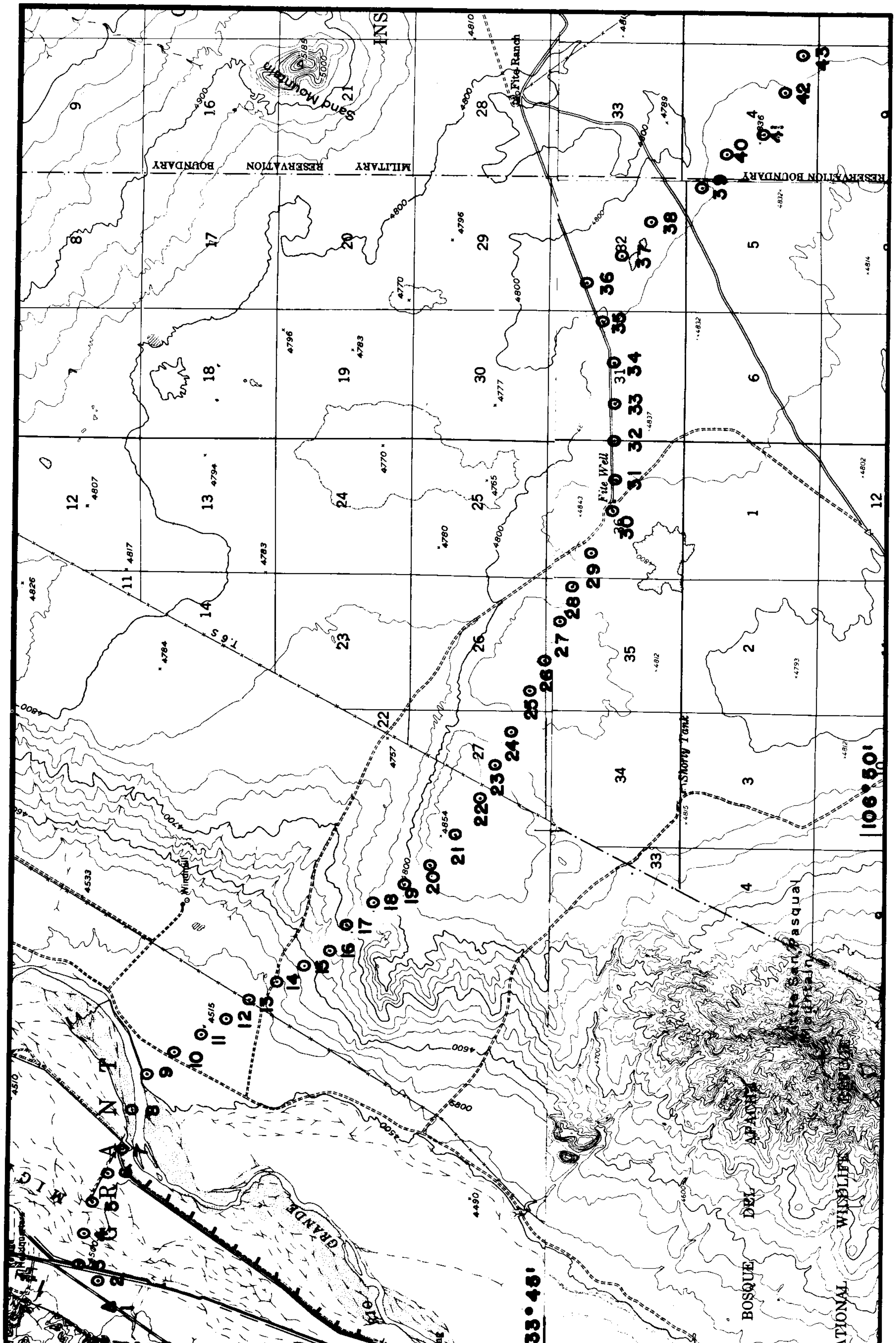

FIGURE 3

Map showing the location of gravity stations to the north of Little San Pasqual Mountain.

south and of the Joyita Hills and Manzano and Sandia mountains to the north, all either in or bordering the Rio Grande Valley, are considered to be Laramide structures (Wilpolt et al, 1946; Kelley and Silver, 1952). It is quite possible that the forces responsible for the deformation of the areas named above were also responsible for the folding of Little San Pasqual Mountain, although to a lesser degree. The steepening of dip on the eastern limb of the anticline could indicate the beginning of overturning and had the stresses continued for a greater length of time, Little San Pasqual Mountain would have also become an overturned structure associated with thrust faulting.

The stresses that created the fold also caused joints to form, some of which later became the normal faults which cross the area, generally in a northwest direction. The formation of the west-bounding, northeast-trending fault is probably due to a more general and deep-seated unknown cause.

The time of formation of the large fault to the west of the mountain is not known; however, movement had begun no sooner than early Eocene. Movement occurred at least during the Eocene, as evidenced by an angular unconformity near the top of the measured Baca Formation and by the tilted and faulted nature of the Baca beds. As faulting progressed, the Rio Grande trough was continually receiving debris from surrounding elevated areas.

A younger limit can be placed on the movement occurring along this large fault. The Santa Fe Formation along this fault is in depositional contact with the older, folded Pennsylvanian sediments. Since the Santa Fe Formation is considered Miocene–Pliocene in age (Kelley and Silver, 1952), the last movement on this fault occurred prior to deposition of the youngest Santa Fe beds.

Subsequent erosion has stripped the Mesozoic and Permian rocks from the anticline and has deeply eroded the remaining Pennsylvanian sediments. Should the eroded section be restored, Little San Pasqual Mountain would be 4000 feet higher than its present elevation.

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