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THE RIGHT-RELAYED RIO GRANDE RIFT, TAOS TO HATCH, NEW MEXICO

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INTRODUCTION

The Rio Grande rift contains the course of the Rio Grande which heads in southern Colorado and flows southward through New Mexico, eventually emptying into the Gulf of Mexico. The northern end of the rift is bounded by the Colorado Plateau and by the New Mexico and Colorado Rockies and High Plains. The southern part of the rift lies in the Basin and Range province of southern New Mexico. The rift has also been considered to be a part of the orogenic Rockies (Eardley, 1962, p. 390) because of its bordering uplifts. Bryan (1938) was the principal early worker to recognize the rift with his term "Rio Grande depressions." The rift and its borders have been extensively mapped since the work of Bryan and his students. The portion of the rift considered here is about 435 km in length. It consists of a double right echelon (series of parallel right-echelon offsets) of uplifts, ramps, benches, and synclines between faults arranged in overlapping or relay patterns (fig. 1).

STRUCTURE

Introduction

The overall trend of the Rio Grande from Taos to Hatch is about N20°E, but the uplifts and the major bounding faults trend more nearly north (fig. 1). The uplifts occur in right echelons (Kelley, 1952) on both sides of the rift, but they are most pronounced on the eastern side. The right echelon is developed by down-ramping of uplifts, benches, or plunging synclines between faults arranged in relays (see fig. 2; Goguel, 1962; Kelley, 1979a). Eight northerly descending ramps occur along the eastern side of the rift; and eight southerly descending ramps occur along the western side of the rift. Opposing this general pattern, several ramps are nearly flat or descend away from the rift. The double echeloning of the uplifts produced right echeloning of the linked basins which form the rift. The northern basins, Albuquerque, Espanola, and San Luis, are larger, deeper, and better defined than the southern basins. The irregular nature of the southern basins is due largely to Basin and Range faulting which has led some writers (Hamilton, 1981) to terminate the rift at about Socorro. The Rio Grande rift is simply a part of the Basin and Range province. There are numerous rifts within the Basin and Range of Utah and Nevada where linking of basins, as in the Rio Grande, justify the concept of rift or trench, as was pointed out by Eardley (1962) and Cook (1965). The right echeloning and marked disruptions along the Rio Grande rift as described here are ample reason for extending the rift concept southward at least to Hatch, and it is common usage to extend the term "rift" at least to El Paso, Texas.

East Side Uplifts and Faults

The southern end of the rift, as considered here, begins at the Caballo uplift (CU, fig. 1) which is 40-50 km in length. The Caballo fault dies out northward between the Engle basin and the Cutter Sag (CS, fig. 1), near the southern end of the Fra Cristobal uplift (FC, fig. 1). With practically no overlap, the Fra Cristobal fault takes over. Both uplifts plunge into the Cutter Sag ramp. The ramp is only about 1 km wide owing to the slightly north-northeastern trend of the two faults. North of the Fra Cristobal, the Rio Grande turns north-northeasterly for about 50 km. This change in the river's course is part of a much broader structural belt (Dane and Bachman, 1965) which includes the Jornada del Muerto basin, San Andres Mountains, Tularosa basin, and the northern end of the Sacramento Mountains (Kelley and Thompson, 1964). This structural belt is 40-50 km wide in an easterly direction and about 110 km long. This right-trending curvature (Kelley and Thompson, 1964) of all the structures in the belt is older than the Rio Grande rift, which follows the western margin of the belt. Much older "roots" of this structural belt may be Laramide, late Paleozoic, or Precambrian in age. The rightward curvature of this belt between the Fra Cristobal and Joyita uplifts enhances the ramp's width and increases the spacing of the relaying between the Fra Cristobal, San Pasqual, and Joyita Hills faults (fig. 1). These two ramp areas are covered extensively by Santa Fe beds, Quaternary terraces, slope wash, lava flows, and eolian deposits. The ramp into the San Marcial basin is roughly 10 km wide, and it may be a graben or half graben. The short ramp into the Socorro constriction is only about 6 km wide.

The Joyita Hills uplift is about 50 km long. Its frontal fault dies out into the Albuquerque basin, where the uplift ramps down into the shallow eastern side of the basin which is known as the Hubbell bench (see Kelley, this guidebook). The ramp width and relay offset between the Joyita and Los Pinos (LP, fig. 1) faults is about 15 km.

The Los Pinos and Manzano fault (MF, fig. 1) on the eastern side of the Hubbell bench bounds the western side of a continuous, curving uplift, about 80 km in length, to the Tijeras wrench fault. North of the Tijeras fault is the bold Sandia uplift (SU, fig. 1) with its bounding faults. One of these, the Rincon fault, dies out northward into the rift with its offset transferring to the San Francisco (FF, fig. 1) fault. The northward downwarp of the Sandia uplift is about 11 km wide. This ramp and relay is the best example, in terms of exposure and accessibility, in the entire echelon system. The San Francisco fault transfers offset to the next relay fault, the La Bajada (LF, fig. 1), across the 810 km wide Hagan basin and bench which lie east and northeast of the Sandia uplift. The La Bajada fault curves northwesterly and dies out toward the Jemez Mountain bench and the intrabasin Pajarito fault (PF, fig. 1). The La Bajada fault, in turn, relays 27-30 km across the Cerrillos uplift and the southern end of the Espanola basin to the southern Sangre de Cristo uplift. The Sangre de Cristo uplift extends 70-90 km along the entire eastern side of the Espanola basin. The uplift consists predominantly of Precambrian rocks which descend westward beneath the Santa Fe beds by minor faulting and flexing. On the north, the uplift is bounded by the Embudo fault (EF, fig. 1) and the San Luis basin. The northern part of the uplift is interrupted by the Penasco embayment (PE, fig. 1), and east-west downwarp filled with Santa Fe beds. The northern side of this embayment is a faulted arch of Precambrian rocks known as the Picuris salient (PS, fig. 1). The eastern end of the embayment is downwarped and downfaulted against Pennsylvanian beds in the Sangre de Cristo Mountains.

The Embudo fault is accompanied by downflexing of the Picuris salient along the northern flank of the mountains. This is, in effect, a downramping of part of the Sangre de Cristo uplift. The Picuris-Pecos fault is essentially a relay take-over from the faulted and flexed boundary of the southern part of the Sangre de Cristo uplift. The relay distance is about 20 km. The cumulative eastward relaying of the eastern side

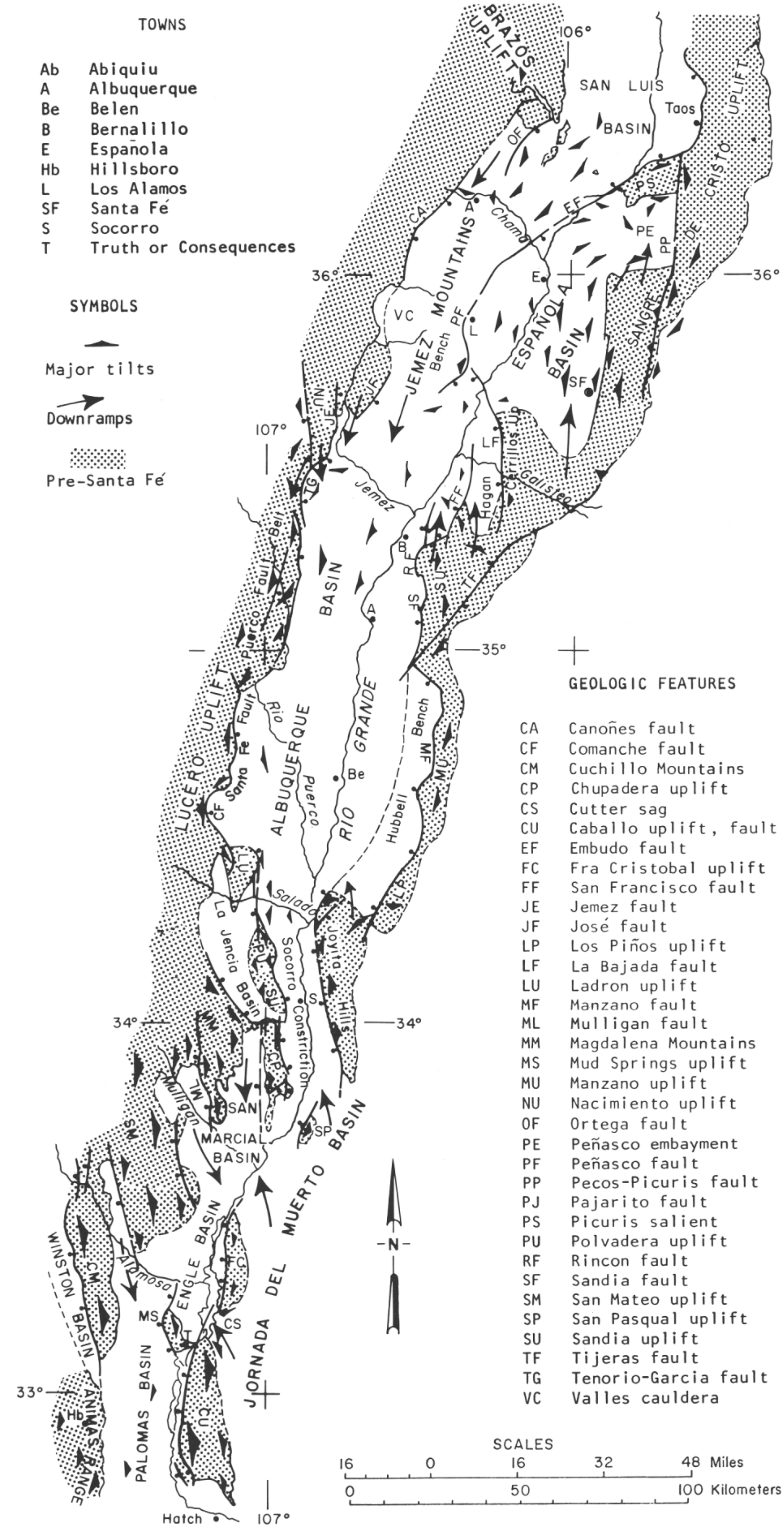

Figure 1. Tectonic map of the central Rio Grande rift.

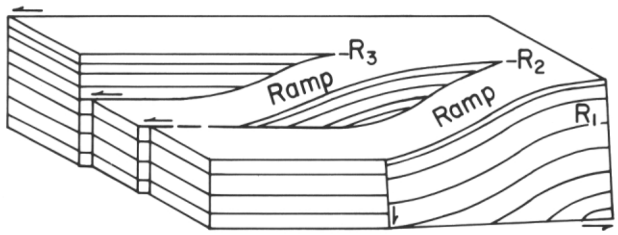

Figure 2. Sketch of relay faults and associated ramps.

of the Rio Grande rift, from the Caballo uplift on the south to the western base of the Sangre de Cristo uplift, is about 145 km.

West Side Uplifts and Faults

The western ramps descend southward, which is opposite to those on the east side of the rift (fig. 1). Right-relaying along the western side is described from north to south in order to follow the direction of downramping. The west-side ramps and relaying differ considerably from those on the eastern side. In the northern part the ramps are much less obvious. In the southwestern part the relaying is clearer than it is on the east side.

The northernmost downramping on the western side occurs south of the Brazos uplift. The ramping trends southwest toward Abiquiu, between the Ortega and Canones faults (OF and CA, respectively, fig. 1). The ramp is about 8 km wide and the relay overlap is quite short. To the south the rift border is largely hidden by the Valles caldera (VC, fig. 1) and associated volcanics of the Jemez Mountains. South of the caldera there is a small ramp and relay between the Jose and Jemez faults (JF and JE, respectively, fig. 1). The ramp narrows southward from about 13 km to 6 km. Just west of the Jemez fault, the Nacimiento uplift (NU, fig. 1) ramps down into the basin across the Tenorio-Garcia fault. From the southern end of the Nacimiento uplift to the northern end of the Lucero uplift, the rift is bounded by the Puerco fault zone. The fault zone consists of a swarm of west-dipping faults roughly parallel to the rift. The beds dip eastward toward the rift. In places, however, they swing eastward in south-dipping monoclines. As a result, the overall structure descends as a ramp some 65 km in length between the Tenorio-Garcia fault on the north and the Santa Fe fault (SF, fig. 1) along the Lucero uplift (Kelley, 1979a). This structural descent from the north to the south is about 1,200 m (Kelley, 1977). South of the Santa Fe fault along the Rio Puerco, the basin-filling Santa Fe beds continue the southward ramping for several kilometers. The projected ramp width is about 10 km. Although the use of the term "ramp" is questionable here, the right relay from the Tenorio-Garcia fault to the Santa Fe and or Comanche fault (CF, fig. 1) is clear.

The curving Comanche fault bounds the eastern side of the Lucero uplift for about 53 km to the semicircular Ladron uplift (LU, fig. 1). The basin edge, however, swings southwesterly to the Magdalena uplift (MM, fig 1) and bounding fault. The relay transfer from the Comanche fault to the Magdalena frontal fault is about 15 km. The Ladron, Polvadera (PV), Socorro (SU), and Chupadera (CP) uplifts (fig. 1) are a string of horsts within the rift which give rise to the La Jencia basin and Socorro constriction.

Proceeding southward, the next relay is between the Magdalena and Mulligan (ML, fig. 1) faults. The relay is 10-15 km in width. The succession of relays from the Magdalena uplift southward involve Basin and Range horsts or half horsts and intervening grabens. The total cumulative right-relay distance of this stretch is about 75-80 km, compared to the total west-side right-relaying of roughly 150 km. In the grabens the beds thicken southward or eastward into the basins. The beds dip eastward or southeastward toward the rift axis.

An important overall aspect of the structure that is not directly related to the echelon pattern is the contrasted major tilt of beds and uplifts along the entire rift. In the southern section, roughly south of Socorro and the Magdalena Mountains, the major tilt of beds is easterly across the entire rift. Along the western side from the Magdalena Mountains (latitude 34°N) northward to the northern end of Lucero uplift, the major tilts are westerly, including the Polvadera-Socorro horst situated within the rift. Tilts switch to easterly in the Puerco fault belt and continue so northward all the way to the Brazos uplift. Along the eastern side of the rift, the major tilts are easterly from the Caballo uplift northward to the northern end of the Cerrillos uplift southwest of Santa Fe. On the eastern side, north of the Cerrillos uplift, the major tilts are westerly in the Espanola basin and southern part of the Sangre de Cristo uplift. In summary, six major tilt segments occur along the rift as follows:

Eastern side

1. Caballo to Cerrillos (easterly),
2. Espanola and southern Sangre de Cristo (westerly), and
3. Northern Sangre de Cristo (easterly).

Western side

1. Animas Range to Magdalena uplift (easterly),
2. Magdalena uplift to Puerco fault belt (westerly), and
3. Puerco fault belt to Brazos uplift (easterly).

Severe twisting and shearing have taken place where the tilts show sudden change. This is particularly evident near Socorro where eastward tilts in the Chupadera and Socorro uplifts suddenly change to westward dips in the Magdalena Mountains. Across this change in tilt, 20°-40° of rotation appear to have occurred. This was first mentioned in 1952 (Kelley) and has been described recently in detail by Chapin and others (1978). Similarly, minor twisting occurs between the Lucero uplift and the Puerco fault belt. Easterly dip lengths along the rift total 800 km and greatly exceed the cumulative length of westerly dips (150 km).

The rift basins also reveal some sharp dip contrasts and twisting action, such as between the Albuquerque and Espanola basins across the La Bajada fault (Kelley, 1979a). There is also considerable pivotal action along the Pajarito-Embudo fault trend, from down-on-the-east for the Pajarito fault to down-on-the-west on the Embudo fault.

It should be realized that the picture described here and illustrated in Figure 1 is generalized and that there are numerous examples of small structures that do not fit into the overall double-echelon pattern. Some of these may be the result of second-order stress fields, others may be due to intrusions, or to remnant attitudes in cauldrons and the Jemez caldera. Additionally, some Laramide structures within the uplifts appear to distort the late Cenozoic picture.

DISCUSSION

The broad pattern of double-right echeloning, relay faults, and associated ramps for this stretch of the Rio Grande is not likely to have formed by simple extensional uplifting and subsidence. Echelon fault patterns are nearly always associated with diagonal stress and rotational action. In the Rio Grande structural belt such action is counterclockwise, and the wrenching between opposite sides of the rift is left. Several left drags, separations, or offsets of regional features are present. Prominent left drag occurs along the northern end of the Caballo, Rincon, and San Francisco faults. Left offset and drag of rock units and fold axes of the Mud Springs uplift at Truth or Consequences are 1.5-2 km (Kelley and Silver, 1952, fig. 2). Left separation of stratigraphic units is about 7 km between the Rincon and the San Francisco faults and is accompanied by steep plunge of drag folds. Similar left separation between the San Francisco and La Bajada faults is about 2 km. Along the western side of the rift near the northern end of the Puerco fault belt, sharp left drag and offset of about 3 km is present (Kelley, 1977).

Another left offset, somewhat less tangible than those described above, is that of the pinch-out of a Jurassic unit (Todilto; Kelley, 1977) that intersects the rift on the western side near the northern end of the Lucero uplift and possible as much as 30 km south of an estimated pinch-out east of the rift. In the southern part of the rift, northerly to northeasterly Laramide overturning and overthrusting, scattered along the east-side uplifts, occurs from the Caballo Mountains to the Fra Cristobal uplift (McCleary, 1960). On the western side there are no known similar Laramide structures. The reason for this may be that the western bases of the thrusted uplifts are at or near the original Laramide front. Another possibility is that large left slip along the rift moved any west-side thrusts into the extensively covered Basin and Range country of southern New Mexico. Other left offsets may be present but unexposed. Unexposed offsets, in combination with those considered above, could add up to the estimated offset of the Jurassic pinch-out.

There is other evidence of considerable wrenching accompanying the development of the rift. The opposition of downramping of the east and west sides has produced a tectonic discontinuity in the rift process that is of major proportions. Another consequence of the diagonal-stress pattern is the presence of left-oblique faults and folds within the basins, such as those described in the Espanola basin (Kelley, 1978), in the Albuquerque basin between the Jemez River and the Rio Grande, and east of the Lucero uplift (Kelley, 1977). There are others such as the Mud Springs uplift and downramps (fig. 1). The right-echelon pattern of uplifts and basins must have formed early, and the diagonal-stress field prevailed as the rift culminated in its present form.

Many geologists, in constructing structure sections across the rift, have suggested that rift faults at depth are listric (flattening downward) and have used them to infer and calculate extension (e.g., Woodward, 1977). The form of such listric faults requires considerable tilting of the dropped segment (Stewart, 1978). Such tilting is not prevalent, and such geometry does not work well with the echelon pattern and evidence of considerable lateral slip presented here.

The regional tectonic position of the rift is along the boundary between the Colorado Plateau microplate (Kelley, 1979b) and the Laramide orogenic belt in the rift's northern part, and between the Colorado Plateau and Basin and Range structures in the rift's southern part. It has been suggested by Chapin and Seager (1975) and by Kelley (1979a, b) that the rift is located by a major flaw along which increased decoupling (Chapin and Cather, 1981) occurred between the Colorado Plateau and the strongly compressed orogenic belt of the Colorado and New Mexico Rockies. During the Laramide the Colorado Plateau was compressed northeasterly against the buttress of the Uinta and other developing uplifts in northwestern Colorado, accompanied by shortening across northwesterly trending folds (Kelley, 1955).

Within the Colorado Plateau there is considerable right echeloning along monoclines and uplifts. It is well developed along the New Mexico and Arizona boundary in the Defiance uplift area and to a lesser extent in the Zuni and Monument uplifts (Kelley, 1955). All the right echelons along the monoclines are the result of clockwise wrenching. In the High Plateaus subsection bordering the Basin and Range of Utah, very long high-angle faults form a large right echelon (Spieker, 1954) similar to that of the east side of the Rio Grande rift. Nearer to the Rio Grande rift, along the base of the Nacimiento uplift, there are a number of northwesterly plunging folds in the San Juan Basin that form a right echelon (Kelley, 1955; Baltz, 1967). However, this echelon plunges northerly and is opposite to the southerly plunge of the Defiance folds along the western side of the San Juan Basin. The folds along the Nacimiento uplift affect beds as young as Eocene (Baltz, 1967) and therefore might be considered latest Laramide. In summary, the structural evidence indicates clockwise motion of the main part of the Colorado Plateau.

East of the rift in the Sange de Cristo uplift, the Picuris-Pecos fault experienced strong right drag (Montgomery, 1953; Grambling, 1979) locally that may have been Laramide or earlier. In the Sandia Mountains area, the Tijeras fault exhibits left drag and offsets that are mostly post-Cretaceous but may be in part Quaternary (see Connolly, this guidebook). Locally in the rift, there is some suggestion of a component of right shift as indicated by raking slickensides (Woodward, 1977; Steinpress, 1981). Similar low-raking slickensides were observed but not recorded by Kelley and Silver (1952). Thus, the Rio Grande rift has experienced both counterclockwise and clockwise wrenching from Laramide time to well into late Cenozoic. The plateaus and rift have long experienced wrenching which commonly occurs with deformation along monoclines and faults.

It has been commonly assumed that the beginning of the Rio Grande rift was in early Miocene or late Oligocene. It is not likely that all aspects of the rift developed at the same time. If one accepts that the rift was once a part of the Colorado Plateau, then the existence of right echeloning suggests that the rift developed some of its pattern in Laramide time, although the major features seen today are late Cenozoic. In late Cenozoic time wrenching continued to produce the left shifts and offsets that involved the rift and its fill during crustal thinning and foundering. If the left shift described in this paper is accepted, then there is the question as to why right echeloning is not present in the rift northward of Taos or southward of Hatch. Figure 3 shows that there is considerable change in direction of the rift both north of Taos and south of Hatch. The considerable left shift along the part of the rift described above may have opened up the other parts, more or less normal to their borders, with little or no lateral shift.

ACKNOWLEDGMENTS

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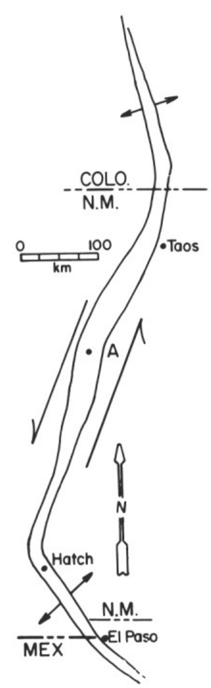

Figure 3. Schematic sketch showing hypothesized left offset and associated rifting.

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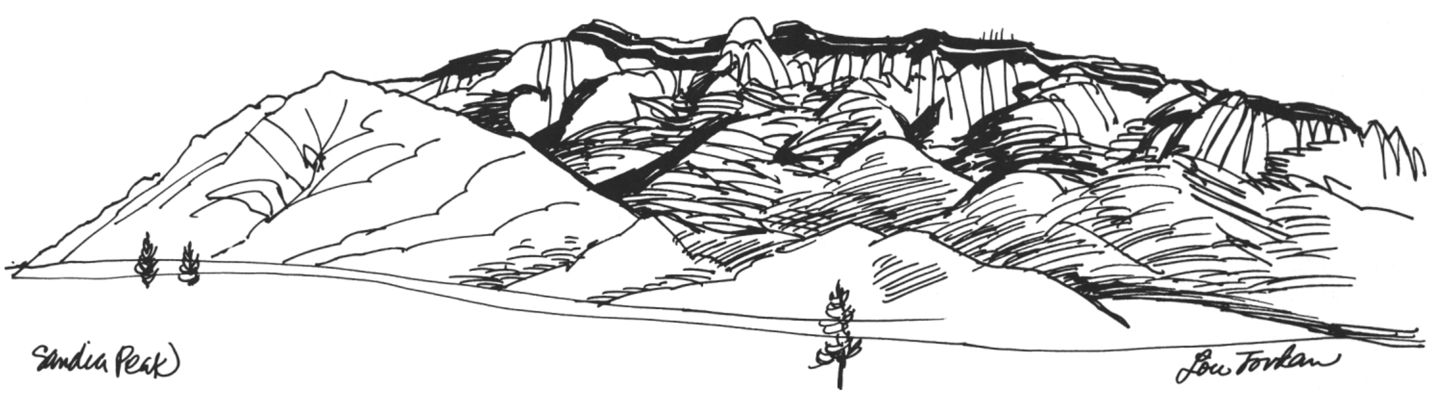
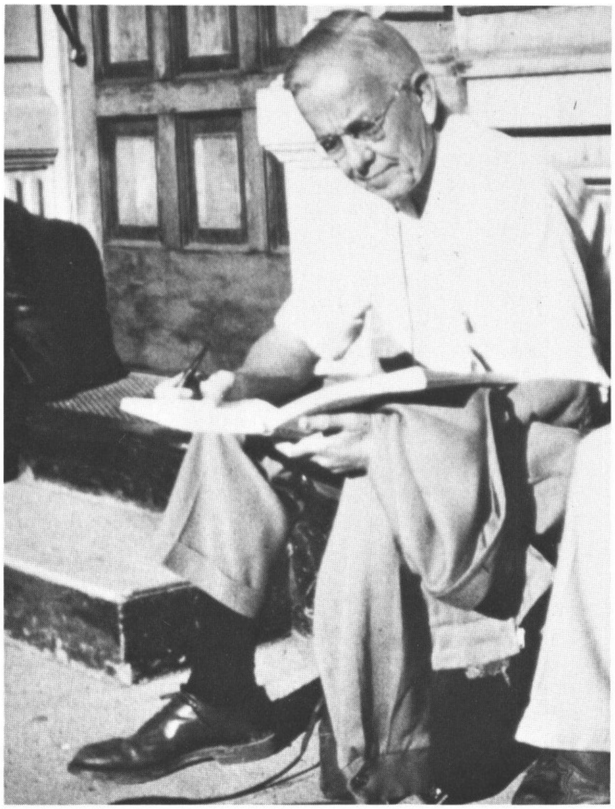
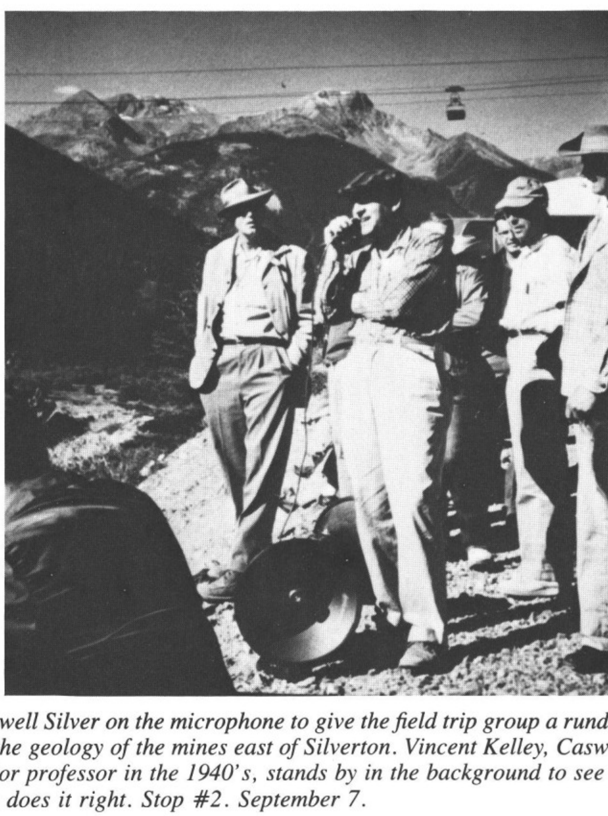
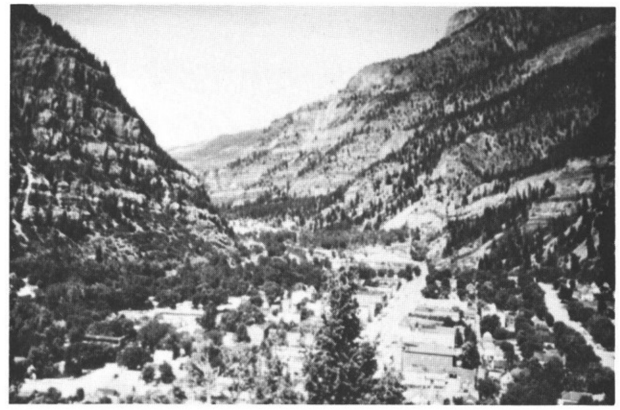




One of the last great "generalist" geologists, Kirtley F. Mather who died in his 90th year on May 7, 1978 in Albuquerque. He added greatly to the success of the 8th field trip. Here he is checking the field trip log for the 2nd day and perhaps also reading his own guidebook article entitled "Geomorphology of the San Juan Mountains," p. 102-108.

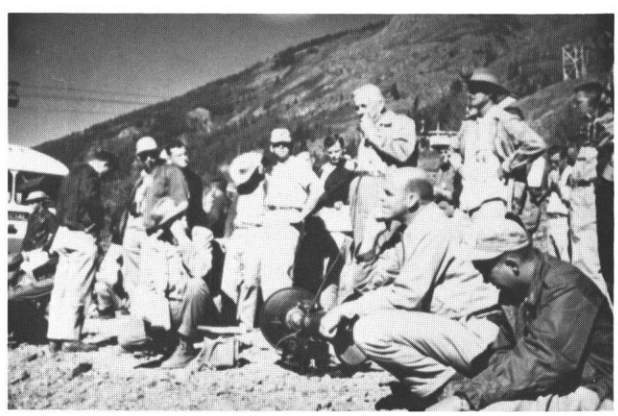


Caswell Silver on the microphone to give the field trip group a rundown on the geology of the mines east of Silverton. Vincent Kelley, Caswell's major professor in the 1940's, stands by in the background to see that Cas does it right. Stop #2. September 7.



The upper Uncompahgre Canyon cut through the Cutler and older formations into the Precambrian at Ouray, Colorado. Ouray is beset by floods out of steep tributaries during summer storms, as well as by deep snow in the winter. Before lunch, stop #7. 2nd day, Friday, September 6.

Shenandoah–Dives Mill in the Silverton caldera east of Silverton. The mines in Arrastre Gulch, and the mill, were an active operation until 1957 and provided the major sustenance of Silverton for the last 10 years prior to 1957. Now Silverton "mines" the tourists! Stop #1. Saturday, September 7.



Time for another talk on glaciation in the San Juan Mountains by Kirtley Mather. Stop #3. Saturday, September 7. How many geologists do you recognize?