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Edward J. Foley

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Edward J. Foley

Consultant, Alpine, Texas

INTRODUCTION

In this paper only those folds on the north side of the Rio Bonito, in the immediate vicinity of Lincoln, New Mexico are discussed. They occur in an area of about 15 square miles and are believed by the writer to have originated as massive landslides or slump. His interpretation is based on several days of field work at Lincoln in 1951, and on six years of general familiarity with the geology of this entire region. During the field work he was accompanied by Mr. D. G. Garrott of the Humble Oil and Refining Company.

The town of Lincoln is situated in southeastern Lincoln County, New Mexico. It lies near the bottom of a deep canyon at an elevation of about 5,700 feet. The top of the surrounding plateau just above Lincoln lies at about 6,400 feet. The Capitan Mountains, six miles to the north, reach 10,230 feet, and Sierra Blanca, 6 miles to the southwest, attains an altitude of 12,003 feet.

Average rainfall around Lincoln is about 15 inches a year. However, the present climate and vegetative cover have no direct relationship to the problem of the origin of the Lincoln folds.

Upstream from their confluence at Hondo, the Rio Bonito and the Rio Ruidoso flow through the Permian Yeso Formation, which is composed of soft sandstone, siltstone, shale, gypsum and thin limestone beds. Overlying the Yeso is the weak Glorieta Sandstone. The rims of the canyons consist of the resistant San Andres Limestone, also Permian in age. Thus, a situation exists in which soft, fissile strata are overlain by thick competent beds. Oversteepened slopes in the soft materials are likely to be developed under such circumstances. The processes of erosion that result in such slopes also encourage landslides as well as mass slump as succeeding events.

DESCRIPTION OF THE DEFORMED AREA

In writing of the folds at Lincoln, Talmage stated (1935, p. 153-154), "In the vicinity of the best exposures, the folds seem patternless; some are inclined toward the east, others toward the west, and some pitch steeply to the south, others to the north. In one case, a strongly asymmetric fold is overturned to the east, and its western limb is broken by three small faults overthrust to the west." One of the folds is shown in figure 1. It is doubtful that adjoining folds are connected as shown by Craddock (1960, fig. 2, and p. 39). The rocks in this deformed area show many slightly open fractures, a condition typical of slides. Such openings are not likely to exist in folds of deep-seated origin. Small notches mark the traces of the apparent upper structural boundaries with undisturbed strata assigned to the uppermost part of the Yeso, Glorieta, and San Andres Formations. The mountain face just north of Lincoln Canyon is probably the slightly eroded main scarp of an old slide. This also applies to some of the other steep slopes in the area. These notches and slipping surface scarps may be seen to advantage on air photos (figs. 2, 3, 4). Scarps in concentric semicircles, depressions on the dip slopes of these, and hummocky topography in general may also be observed. All of these are quite characteristic of landslides. The slipping surface above the old highway slide opposite Salazar Canyon is obvious on the air photos. These slip surfaces, of course, may be considered as faults, though they are superficial, not deep seated.

Figure 1. — One of the small folds in deformed area on bank of Rio Bonito near Lincoln.

PREVIOUS EXPLANATIONS

The folds at Lincoln have been variously explained as crumpling between the massive San Andres Limestone and the igneous rock (Semmes, 1920), as drag folds (Talmage, 1935), as landslides (Panhandle Geological Society, 1939), as disharmonic folding, and as having resulted from forceful intrusion of sills related to the nearby Capitan Mountains pluton. The most recent work published on the area is "The Origin of the Lincoln Fold System, Southeastern New Mexico" (Craddock, 1960). This last paper also describes other roughly similar folds in the same general region which have been well known for many years, including the Y-O, Six Mile Hill, Border Hills, Picacho and Tinnie folds. All of them are complex and difficult to explain but, unlike the Lincoln folds, where only the Yeso Formation is deformed, they all have one thing in common — the San Andres Limestone is also involved in the folding. Craddock's explanation of these other folds and their origin appears to be valid. But, in the writer's opinion, the same explanation cannot be applied to the folds at Lincoln, nor should the words "Lincoln Folds" have been included in the title of Craddock's paper.

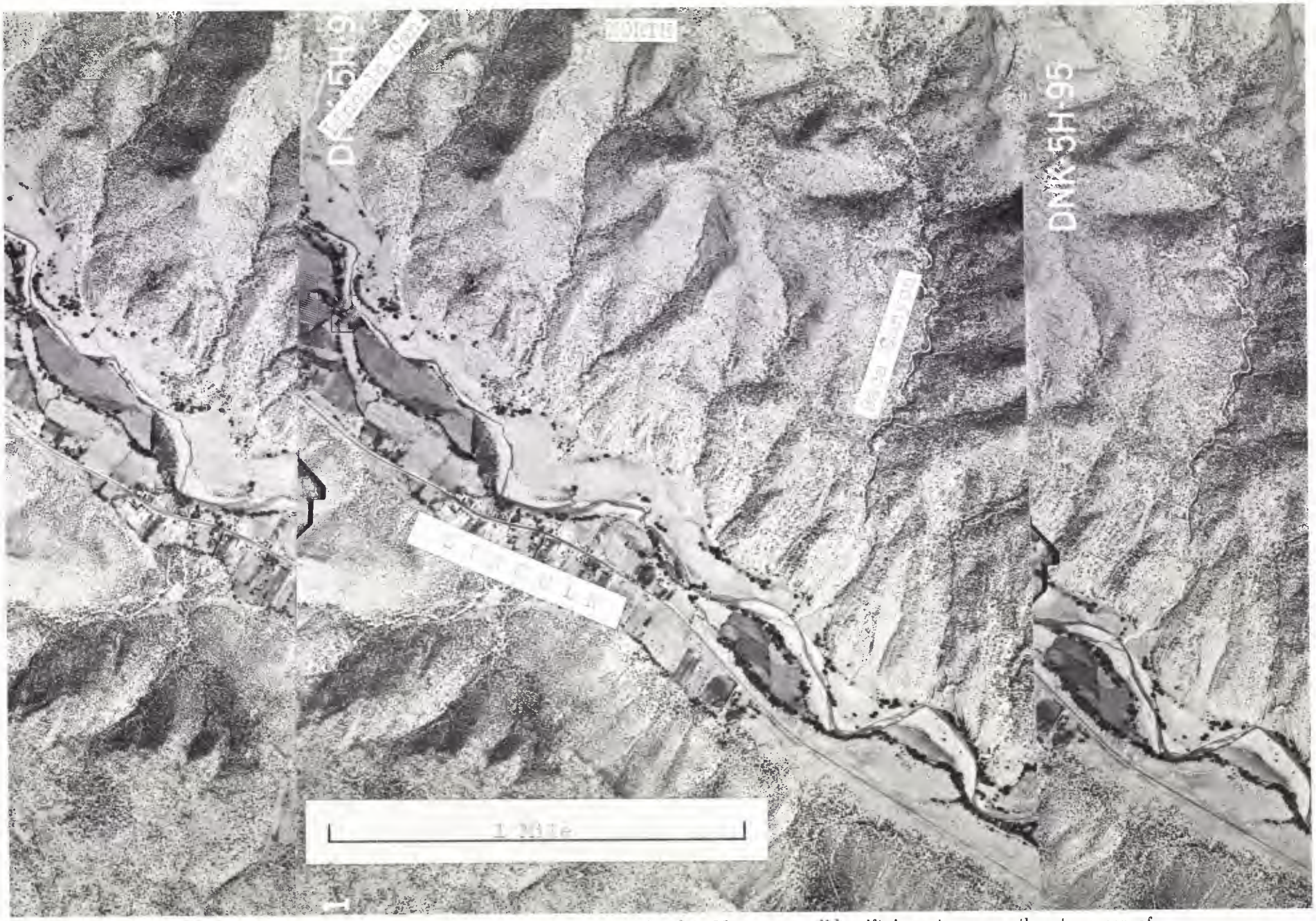

Figure 2. — Stereo triplet showing deformed area at Lincoln. Note open slide rift in extreme northeast corner of photo near head of Baca Canyon. Several small anticlines near floodplain. P.M.A. photo, 1951.

Figure 3. — Stereo pair showing southeast end of deformed area. Note perched slide masses on canyon wall at extreme southeastern end. Divergent strikes just above river.

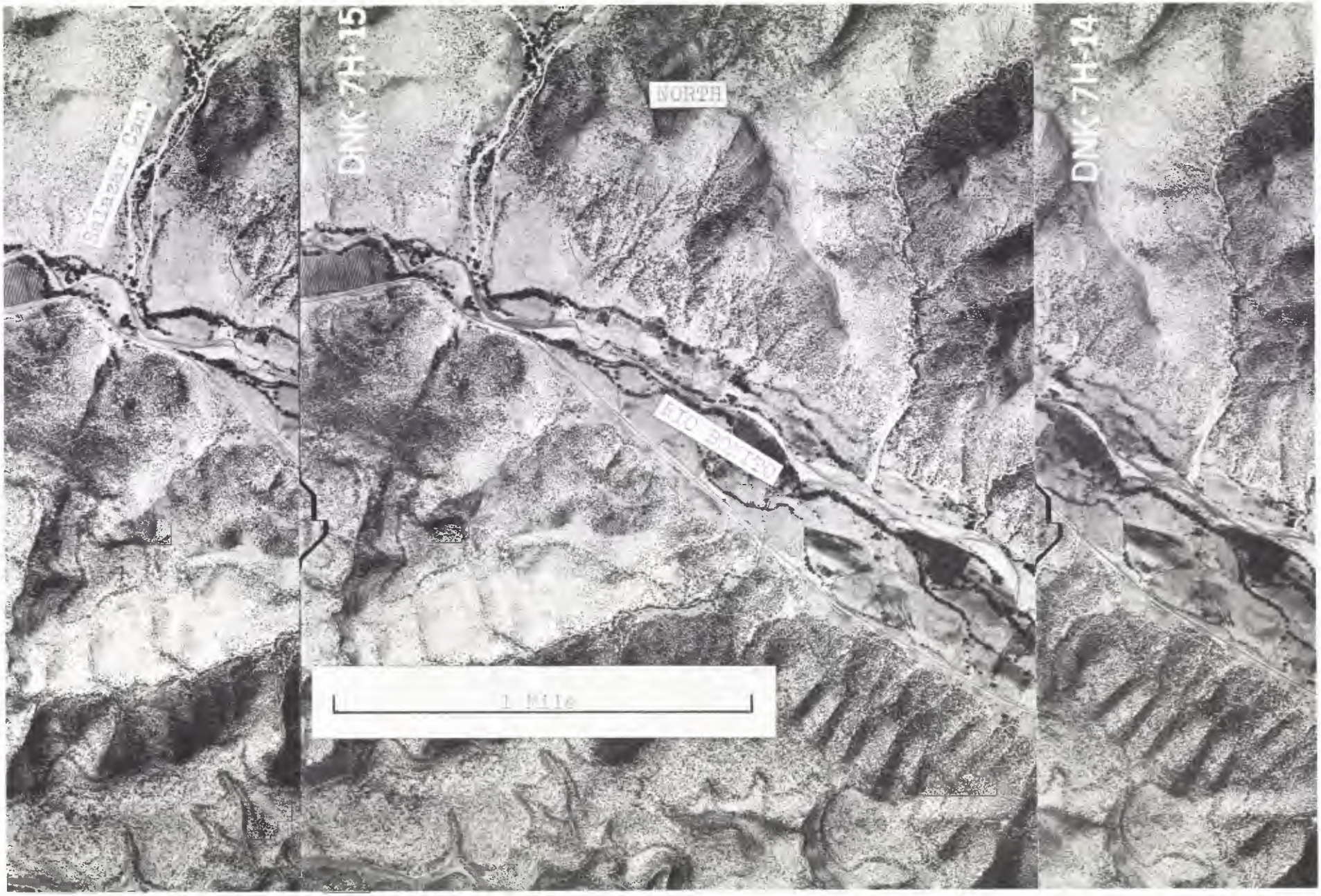

Figure 4. — Stereo triplet showing northwest end of deformed area. There is about a one mile gap between this view and Figure 2. Note huge slide mass opposite mouth of Salazar Canyon. This was caused by Rio Bonito and later reactivated by highway excavation. There are other perched slide masses along canyon walls, such as on east side of Salazar Canyon just below the fork.

One very important reference is a Highway Department sign opposite the mouth of Salazar Canyon, a few miles northwest of Lincoln. It warns against the slide area on the highway there!

ORIGIN OF THE FOLDS

The deformation at Lincoln probably is the result of massive slumping. In late Pleistocene and early Recent time there was a great deal more precipitation in the area around Lincoln than there is at present. At least one glacier existed in the nearby Sierra Blanca, and doubtless the rest of that range and the Capitan Mountains had a more or less permanent snow cap. Melted water from this ice and snow formed torrential streams, whose violence and carrying power is shown by river gravel that contains boulders as large as two feet in diameter. Although the main glacial cirque on Sierra Blanca drained into the north fork of the Rio Ruidoso, most of the northeastern part of the range drained into Rio Bonito. Salazar Canyon, above Lincoln, carried nearly all the runoff from the southern side of the western part of the Capitan Mountains. However, it is possible that Baca and Lincoln Canyons, respectively just east and west of Lincoln, may have carried some of this Capitan Mountain runoff earlier in our present erosion cycle. Canyons were steep sided, and cliffs were more than 800 feet high. The canyons were then considerably deeper than they are at present, as some aggradation has since taken place. Undercutting of these high cliffs is certain to have been a common occurrence, and the obvious result was collapse.

Heavy precipitation in times past also provided lubrication on slip surfaces. Now that the climate has changed and there is a great deal less rainfall, these valley walls are more or less stable except where they are excavated by man, as in highway construction. In recent years the highway itself was moving slightly on the slide mass just opposite the mouth of Salazar Canyon, and the pavement required continual repair because of humps and roughness. Huge limestone blocks, jumbled beds with open fractures, anomalous attitudes, landslide notches and tilted terraces are common elsewhere along the sides of the Rio Bonito and Rio Ruidoso. There is nothing at all anomalous about the presence of slumped and landslide masses in this area, and these have been recorded in a number of publications. (Roswell Geological Society, 1951, p. 2; 1953, p. 3, 4; Allen and Kottlowski 1958, p. 13, 15-17, 38-40.)

Mention has been made of the slip surfaces bounding landslide masses. Such surfaces are typically steep in their upper part and are curved, concave upward, with a cliffward dip at the toe. If, however, they merge with bedding planes the mass could be considered as a block slide. The lowest portion of these slip surfaces at Lincoln nicely fits Craddock's (1960, p. 42) requirement of a plane of "dying out," for it lies at a depth near the former level of the canyon floor; that is, before the later aggradation.

The strikes of the deformed beds near Lincoln are often divergent, although most are more or less perpendicular to the main valley. This is probably due to slumping from the cliffs on the tributary streams just above their mouths. The ancient Rio Bonito, as it undercut its bordering cliffs, doubtless flowed slightly northward of its present course.

A large open rift near the head of Baca Canyon is shown near the northeast corner of figure 2. It represents the initial movement on an old slide which never did progress more than about 30 feet down the canyon wall. This rift is about 500 feet long. It also may be seen in figure 2. Nearby is another incipient slide with an open rift about 100 feet long, 10 feet wide and 5 feet deep.

There are three sink holes on the plateau near the head of Baca Canyon, and these suggest that solution of underlying material may have contributed slightly to the origin of the slides. Incidentally, the steeper dips on the limestone plateau near the very head of Baca Canyon are so close to the Capitan Mountain pluton that they are undoubtedly associated with the uplift caused by its intrusion.

The deformation in the beds bordering Rio Bonito at Lincoln does not extend to the southern side of the canyon. If these steeply dipping beds are resistant enough to crop out on the north side of the canyon, they would do so on the south side if they had been continuous. Also it might be said that the Yeso formation is more or less of the same competency, vertically and laterally. Why then, in a small area, should some of it be folded and some of it not folded? The south boundary of the deformed zone is not a fault, not a fold, and not an intrusion. It is a stream bed. As stated in an early guidebook (Panhandle Geologic Society, 1939), the folding is probably due to solution and slumping rather than compression. Gravitational slumping, relatively unaided by solution, probably is the major cause of the deformation.

Bucher's (1956) laboratory experiments on "disharmonious folding" have been compared to the folding at Lincoln (Craddock 1960, p. 42). His box of wax and grease layers had pressure applied at one end, thereby causing thickening which produced a slope, and subsequent disharmonious folding in the soft grease. The location of the Lincoln folds is only a very few miles east of the crest of the buried ridge that was the Pedernal Positive Element (Roswell Geological Society, 1952, p. 31; Kottlowski, 1963, p. 110). The very gentle slope of the limestone plateau in this area is related to the presence of this buried ridge, not to compressive folding. The nearness of the Pedernal ridge, plus the very gentle slope of the formations at Lincoln, seem to preclude application of Bucher's experiments to this particular problem, although they may explain the folds farther east.

The age of all the folds has been given as late Tertiary. Doubtless this is right for all of the folds except for the ones at Lincoln. Craddock's conclusion (Craddock, 1960, p. 42) is that the most satisfactory explanation of the origin of the folds involves a decollement, or slippage in the lower Yeso and that this produced disharmonic folding. The writer agrees that this could be true of all the other folds in the region, except those in the Lincoln fold belt.

CONCLUSION

The Lincoln folds, that is, those in the immediate vicinity of Lincoln, have an origin that appears compli-

cated, but is in reality very simple. They are the result of landslides that took place in late Pleistocene or early Recent time. The movement involved can be classified as slump, or block guide, with some rockslide and rockfall, and combinations of all four. The remarkable and complex deformation was caused by the pressure resulting from millions of tons of rock sliding against the bottoms or opposite walls of the canyons.

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