Influence of the Onion Creek salt diapir on the late Cenozoic history of Fisher Valley, southeastern Utah

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ABSTRACT

The upper Cenozoic deposits in Fisher Valley, Utah, record a long history of deposition, deformation, and geomorphic changes related to movement of the Onion Creek salt diapir. Apparently, several pulses of salt flowed into the diapir between about 2–3 and 0.25 m.y. ago, and the diapir may still be active. Fisher Creek once headed in the igneous rocks of the La Sal Mountains and flowed along the present course of Onion Creek to the Colorado River. The rising salt diapir impeded the flow of ancestral Fisher Creek, causing deposition of more than 125 m of basin-fill sediments, and eventually diverted the creek down Cottonwood graben to the Dolores River about 0.25 m.y. ago. Onion Creek has eroded headward from the Colorado River, through both the diapir and the basin-fill sediments, and is about to capture Fisher Creek, restoring the original drainage course.

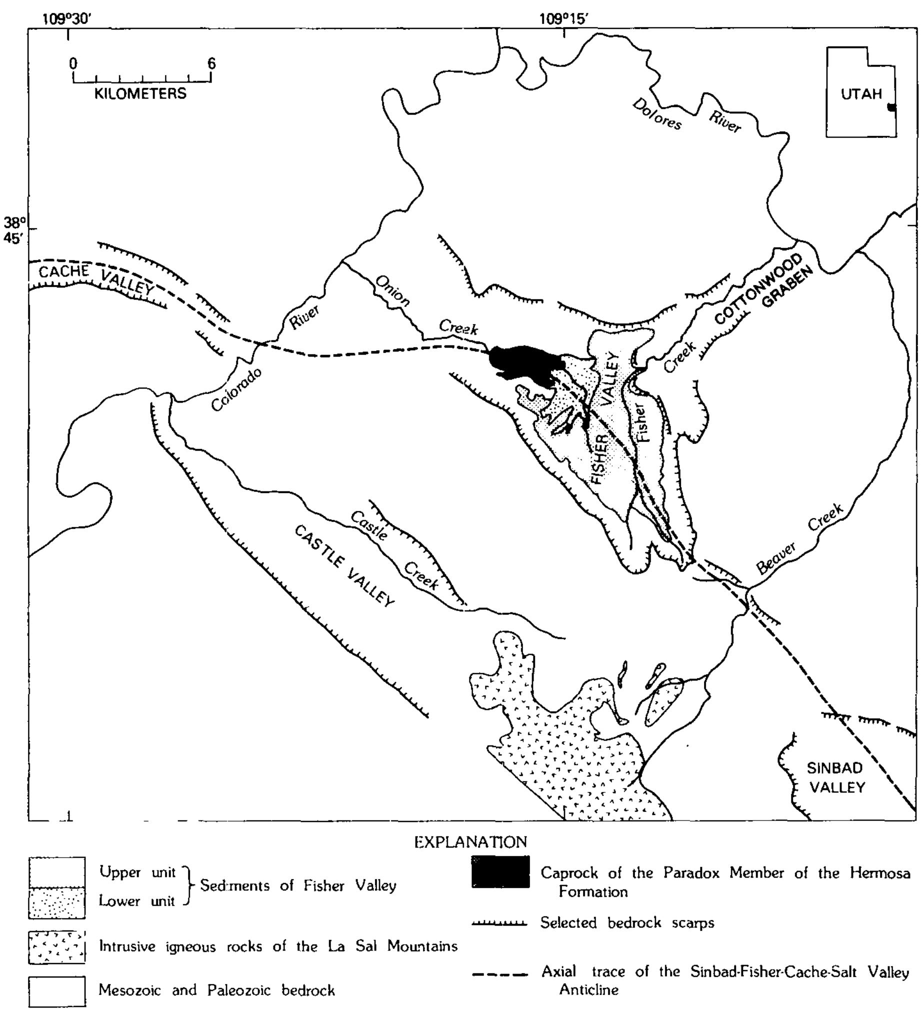

Figure 1. Index map of Fisher Valley area. Geology generalized from Williams (1964). Onion Creek salt diapir roughly corresponds to outcrop of caprock of Paradox Member. See text and Figure 3 for more detailed descriptions of units.

INTRODUCTION

The anticlinal valleys of the Paradox Basin in Colorado and Utah are some of the most prominent geomorphic features of the Colorado Plateau. These valleys are located along the collapsed crests of long, northwest-trending anticlines cored by salt of the Pennsylvanian Paradox Member of the Hermosa Formation. The anticlines have had a long and complex history of salt flowage and dissolution, but their post-Jurassic history is poorly known because of the erosional character of the landforms and because of the scarcity of Cretaceous and Cenozoic sedimentary rocks in the Paradox Basin (Shoemaker, 1954; Hunt, 1956; Kelly, 1958; Cater, 1970).

Salt in the Paradox Member of the Hermosa Formation has been proposed as a repository for nuclear waste at several sites in the Paradox Basin, including two of the salt-cored anticlines. The stability of the salt and rates of geomorphic change in the salt-cored anticlines are among the critical issues for safe disposal of nuclear waste in the salt. Fisher Valley, though not a proposed disposal site, provides a unique setting for examining these issues.

GEOLOGIC SETTING OF FISHER VALLEY

Fisher Valley is on the crest of a long anticlinal structure marked (from northwest to southeast) by Salt, Cache, Fisher, Sinbad, and Roc Creek Valleys. Fisher Valley is a collapsed high point on the crest of this anticline, where the axial trace bends around the north flank of the La Sal Mountains (Fig. 1). The Onion Creek diapir is essentially a cupola of salt on the main diapiric mass that cores the Fisher Valley anticline. Fisher Valley is floored by the flat upper surface of a thick sequence of Quaternary and older deposits. These deposits and the Onion Creek salt diapir are exposed in an erosional amphitheater cut by the headwaters of Onion Creek into the northwest side of Fisher Valley (Fig. 1). The diapiric relations between the Paradox Member and younger rocks are unusually well exposed at the head of Onion Creek. Salt of the Paradox Member is never exposed in the Paradox Basin; at Onion Creek it is expressed at the surface by a caprock consisting of a chaotic jumble of gypsum, anhydrite, limestone, and shale,

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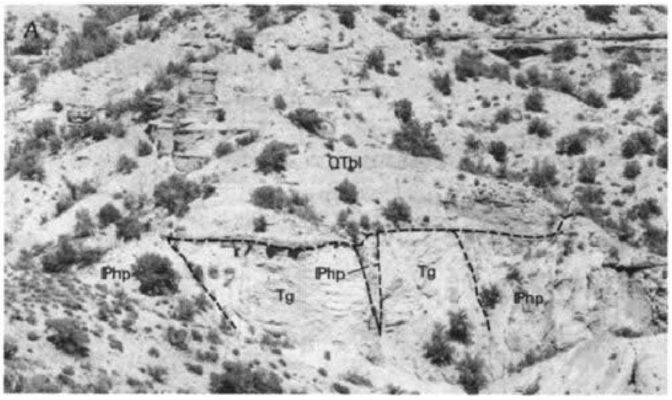


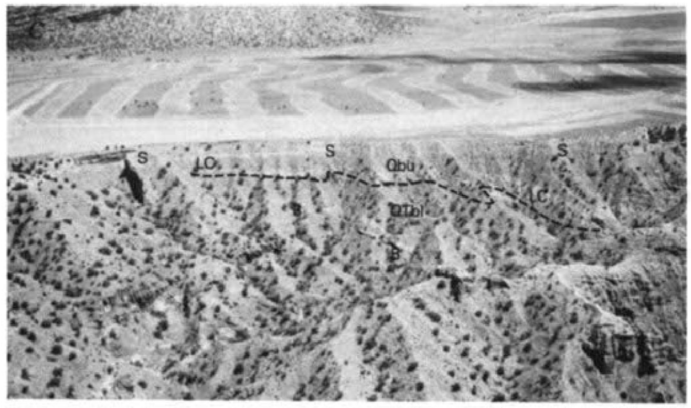


Figure 2. Photographs showing deformed upper Cenozoic deposits in Fisher Valley. A: Pliocene(?) gravels (Tg) containing igneous clasts from La Sal Mountains infolded into caprock (Php) of diapir. Pliocene gravels are unconformably overlain by lower unit of basin-fill deposits (QTbl). B: Lower unit of basin-fill deposits (QTbl) infolded into caprock (Php) of diapir. C: Angular unconformities in basin-fill sediments along northeastern edge of sedimentary basin in Fisher Valley. QTbl and Qbu = lower and upper units, respectively, of basin-fill deposits; LC = Lava Creek ash; B = Bishop ash; S = soil at top of Qbu.

which represents the less soluble interbeds of the original evaporite sequence.

The upper Cenozoic deposits have received relatively little study, despite widespread interest in the diapir. Dane (1935) described the Fisher Valley area in general terms in his reconnaissance work. Shoemaker (1954) mapped the structure in the caprock of the diapir in detail, and described deformation and unconformities in the adjacent upper Cenozoic deposits. Richmond (1962) described a section containing two volcanic ash beds in the Fisher Valley sediments. These two ash beds are now known to be the Lava Creek ash bed (0.61 m.y. old) and the Bishop ash bed (0.73 m.y. old) (Izett, 1981).

The upper Cenozoic sediments in Fisher Valley are exposed in the erosional amphitheater that Onion Creek has cut into the sedimentary basin adjacent to the diapir. The sedimentary basin roughly corresponds to the area of the erosional amphitheater plus part of the area overlain by the floor of Fisher Valley. The upper Cenozoic sediments are in direct contact with the caprock of the Onion Creek diapir. They are more than 125 m thick—the thickest Quaternary sequence in the Paradox Basin and perhaps on the whole Colorado Plateau.

The basal unit of the upper Cenozoic sequence is a gravel that contains abundant igneous clasts from the La Sal Mountains. Similar deposits in nearby Castle Valley have been assigned a Pliocene or early Quaternary age (Hunt, 1956; Richmond, 1962), although no radiometric dates exist for these units. These gravels are complexly infolded into the caprock in Fisher Valley and are unconformably overlain by a sequence of red basin-fill sediments derived from the surrounding Mesozoic bedrock (Fig. 2A). The basin-fill deposits consist predominantly of sand near the center of the basin, and they grade into mostly coarse gravel near the basin margins. They appear to be a mixture of fluvial sand and gravel and subordinate eolian sand.

The basin-fill deposits can be divided into two units. The lower unit, which is tilted as much as 25°, contains the Bishop ash bed (0.73 m.y. old; Izett, 1981) and several buried soils near its top. Paleomagnetic analyses indicate reversed polarity in much of the lower unit below the Bishop ash bed, but the lowermost 20 m of exposed sediments are of normal polarity. The base of the unit probably represents the Gauss normal polarity epoch; if so, it is more than 2.5 m.y. old and late Pliocene in age.

The upper unit of the basin-fill deposits unconformably overlies the lower unit and contains the Lava Creek ash bed (0.61 m.y. old; Izett, 1981) at its base. The upper unit is less deformed than the lower unit but is locally tilted as much as 10°. The upper unit contains several buried soils, including a well-developed calcic soil that caps the unit. Preliminary data on rates of secondary carbonate accumulation in soils in the area suggest that this soil is on the order of 0.25 m.y. old. The upper basin-fill unit is overlain by eolian sand of probable Holocene age.

DEFORMATION OF THE UPPER CENOZOIC DEPOSITS

The upper Cenozoic deposits are complexly deformed, and much of this deformation is clearly related to movement of the salt diapir. The Pliocene(?) gravels are sharply infolded into the caprock, with complex, near-vertical contacts (Fig. 2A). Remnants of the lower unit of the basin-fill sediment are also infolded into the caprock, but less severely than the Pliocene(?) gravels (Fig. 2B). These relations imply that these upper Cenozoic deposits were progressively deformed by several movements of the salt diapir.

The lower unit of the basin-fill deposits dips radially away from the eastern nose of the salt diapir (Fig. 3), with dips commonly in excess of 15°. In places, the dips are toward the valley walls. This pattern of dips indicates upward movement of the diapir, both in an absolute sense and relative to the sedimentary basin to the east.

Farther east, dips of the lower unit are toward the center of the sedimentary basin and apparently do not directly reflect upward movement of the diapir.

The upper unit of the basin-fill deposits has been mostly eroded from the area near the diapir, so that its deformation pattern is less certain. However, near the northeast edge of the diapir, the upper unit is tilted as much as 10° away from the diapir, toward the valley wall (Fig. 3). This tilting indicates that upward movement of the diapir has deformed the upper as well as the lower unit.

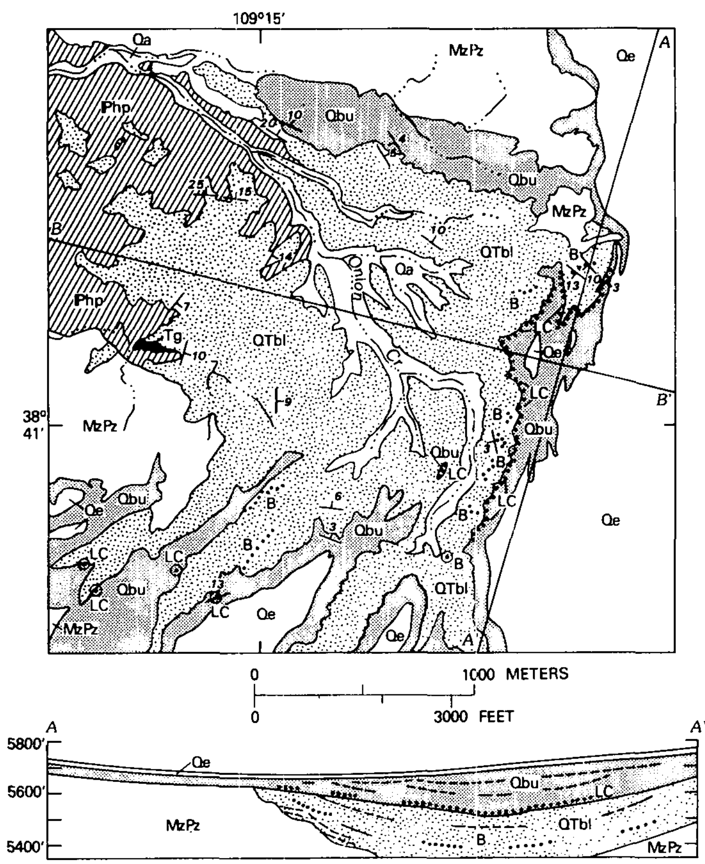
Away from the diapir, several angular unconformities in the basin-fill deposits are exposed along the edges of the sedimentary basin (Figs. 2C, 3). The lower unit rests unconformably on post–Paradox Member bedrock and is in turn truncated by the upper unit. At least one lesser angular unconformity also occurs within each unit of the basin-fill deposits. However, toward the center of the basin, the deposits become essentially conformable (Fig. 3). This pattern of tilting and erosion along the basin margins and conformable deposition in the basin center suggests episodic subsidence of the basin. Accordingly, each angular unconformity, of which there are at least four, represents an episode of subsidence.

The overall pattern of deformation of the basin-fill deposits suggests upward movement of the diapir and subsidence of the sedimentary basin, both in an absolute sense. The upward movement of the diapir is indicated by two lines of evidence: (1) the radial pattern of dips in the upper Cenozoic deposits around the eastern nose of the diapir (Fig. 3), and (2) geologic and geomorphic relations that suggest that ancestral Fisher Creek once followed the present course of Onion Creek toward the Colorado River but was impeded and finally diverted through Cottonwood graben into the Dolores River. These events require upward movement of the salt diapir relative to the upper course of Fisher Creek, not just local subsidence. The upward movement of the diapir must be due to salt flowage.

The differential movement of the diapir relative to the sedimentary basin can be estimated in several ways, but the estimates are minimum values, because the bottom of the sedimentary basin is not exposed and because the caprock atop the diapir has undoubtedly been eroded. The basin-fill deposits are at least 125 m thick, and the relief between the top of the caprock and the lowest exposures of the sediments is 105 m. Projection of dips in the upper Cenozoic deposits on the flanks of the diapir yields an estimate of about 140 m for the total differential movement. Away from the diapir, projection of dips in the upper Cenozoic deposits along the margins of the sedimentary basin suggests a total subsidence of about 70 m.

In summary, the Onion Creek diapir has moved upward at least 70 m, and the adjacent sedimentary basin has subsided a similar amount, for a total relative displacement of about 140 m. These movements occurred, apparently in pulses, between perhaps 2–3 and 0.25 m.y. ago. Younger movement of the diapir is possible but is difficult to demonstrate because younger basin-fill deposits are absent. The steep, unstable valley walls of Onion Creek where it cuts through the caprock suggest that the diapir may still be active.

The upward movement of the diapir is clearly due to salt flowage, but the subsidence of the sedimentary basin could be due either to salt flowage into the diapir, solution of salt that underlies the basin, or a combination of the two. Two lines of reasoning suggest that salt flowage was at least partly responsible for subsidence of the sedimentary basin. (1) The diapir and the sedimentary basin are adjacent to each other, are similar in size, and have been deformed similar amounts (in opposite directions). These relations suggest a genetic link between subsidence of the basin and salt flowage into the diapir. (2) Salt solution is clearly an important geologic process in both the past and present development of the anticlinal valleys



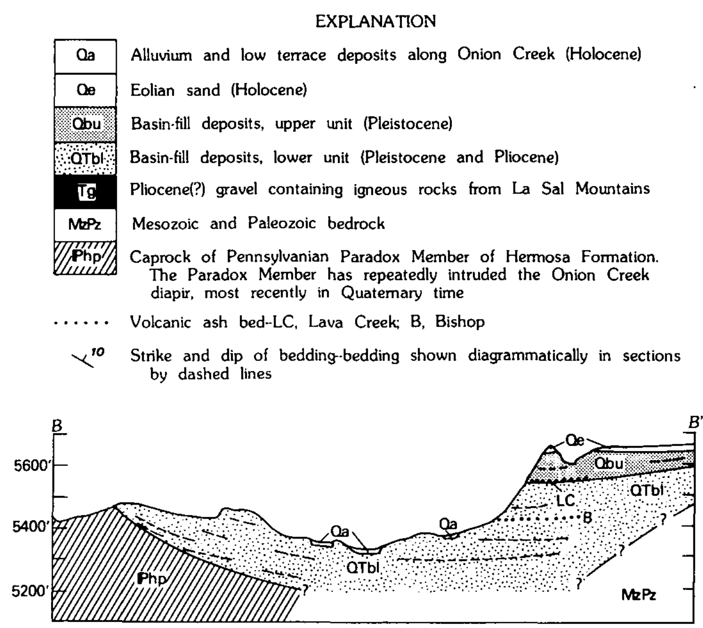


Figure 3. Map and cross sections of erosional amphitheater at head of Onion Creek. Geology and topography of nearby valley wall is projected into cross section A-A'. Generalized from Colman and Hawkins (1983).

(Hite and Lohman, 1973), including Fisher Valley. However, subsurface salt solution in the anticlinal valleys is generally widespread and produces rather chaotic surface expressions; in contrast, subsidence of the sedimentary basin in Fisher Valley is highly localized and comparatively regular.

The cause of salt flowage into the Onion Creek diapir is not known with certainty. Unloading of the Fisher Valley anticline as overlying rocks were eroded and removed during development of the anticlinal valley seems a reasonable explanation. The long-term geologic process of transfer of salt to the anticlines from the flanking synclines may also have contributed to the activity of the Onion Creek diapir. Large blocks of post–Paradox Member bedrock that became detached from the valley walls and then foundered in the salt may also have caused salt flowage (D. W. O'Leary and J. D. Friedman, 1980, written commun.).

Additional evidence of young deformation occurs where the Colorado River crosses Cache Valley, a continuation of the Fisher Valley anticline (Fig. 1). On the *upriver* flank of the structure, leveling and reconnaissance mapping indicate that the two oldest of a set of three terraces are tilted upstream by 1° to 2°. This deformation could not occur as a result of subsidence within the structure. Therefore, salt apparently flowed into the Cache Valley structure in Quaternary time, tilting the terraces. This flow was probably due to erosional unloading along the Colorado River Canyon, although the long-term process of salt flow into the anticlinal structures from the adjacent synclines cannot be excluded as a cause.

DRAINAGE CHANGES

Major geomorphic changes have apparently accompanied the deformation discussed above. The Pliocene(?) gravels that contain igneous clasts from the La Sal Mountains are critical evidence for these changes. The only logical source of these gravels is Fisher Creek, which no longer drains igneous rocks of the La Sals (Fig. 1). The gravels occur at modern stream level in the Onion Creek drainage but are deformed to the extent that their original topographic position is uncertain. Ancestral Fisher Creek apparently once headed in the igneous rocks of the La Sal Mountains and flowed through Fisher Valley, down the present course of Onion Creek, and into the Colorado River. Alluvial deposits of the Harpole Mesa Formation of early Quaternary age (Richmond, 1962) on the north flank of the La Sal Mountains contain igneous clasts and slope toward the present headwaters of Fisher Creek. Similar older deposits since removed by erosion may have been part of the fluvial system that transported igneous rocks of the La Sal Mountains to Fisher Valley. The Harpole Mesa gravels are drained by tributaries of Beaver Creek and are separated from the present headwaters of Fisher Creek by canyons cut by those tributaries (Fig. 1). Beaver Creek probably captured the former headwaters of Fisher Creek and thus eliminated igneous rocks from the present drainage of Fisher Creek.

The thickness of the upper Cenozoic deposits in Fisher Valley (> 125 m) is highly anomalous in the Paradox Basin, where most landforms are strongly erosional. The thickness of these sediments, their deformation, and the fact that Fisher Creek once flowed through the present area of the salt diapir suggest that upward movement of the diapir first impeded and then diverted the flow of Fisher Creek. The diversion of Fisher Creek northeastward into Cottonwood graben and the Dolores River probably coincided with the cessation of basin-fill deposition in Fisher Valley, which is estimated from preliminary data on rates of soil formation to have occurred about 0.25 m.y. ago. Onion Creek, which occupies the former lower course of Fisher Creek, has eroded headward through the caprock of the salt diapir and the basin-fill deposits. Radiocarbon dates suggest that Onion Creek has downcut more than 30 m in the basin-fill deposits in the past 10,000 yr. The headwaters of Onion Creek are now within 1.5 km of capturing Fisher Creek and restoring it to its ancestral course.

Additional geomorphic changes are suggested by scallops in the Wingate Sandstone (Triassic) at the top of the steep escarpments that form the walls of Fisher Valley. The mesas above the escarpments are dip slopes on the flanks of the breached anticline whose crest collapsed to form Fisher Valley. Modern streams head at the scallops in the escarpment and flow away from Fisher Valley in shallow valleys on the mesas. The broad, shallow shape of the scallops suggests that the former headwaters of these streams have been removed by the collapse that formed Fisher Valley. Similar beheaded streams have been described on the flanks of other anticlines in the Paradox Basin (D. W. O'Leary and J. D. Friedman, 1980, written commun.). These relations suggest that the core of the Fisher Valley anticline was once covered by Wingate Sandstone and that collapse of the crest of the anticline is a relatively recent event, recent enough that channels of consequent streams predating Fisher Valley are still preserved.

CONCLUSIONS

The Onion Creek diapir has repeatedly moved upward during the past 2 to 3 m.y. and in doing so has progressively deformed a series of basin-fill sediments in Fisher Valley. The diapir is highly mobile and responds rapidly to changing stress patterns, such as those caused by erosion of overlying rocks. Profound geomorphic changes accompanied the recurrent movement of the diapir, including the blocking and diversion of Fisher Creek. Most of the landforms of the Fisher Valley area are directly or indirectly related to the salt diapir.

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