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1985, pp. 315-318. https://doi.org/10.56577/FFC-36.315

*in:*

*Santa Rosa, Tucumcari Region*, Lucas, S. G.; Zidek, J.; [eds.], New Mexico Geological Society 36 th Annual Fall Field Conference Guidebook, 344 p. https://doi.org/10.56577/FFC-36

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# THE PLIO-PLEISTOCENE CANADIAN BREAKS OF NEW MEXICO: A PROFILE

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## INTRODUCTION

The view northward from the caprock escarpment at Ragland, New Mexico, is across a 100-km-wide breach in the southern High Plains known as the "breaks" of the Canadian River (Fig. 1). In profile, the Canadian breaks exhibit a succession of geomorphic surfaces that are cut into Triassic red beds and which mark episodes in the valley's Plio-Pleistocene history. This history is essentially one of progressive denudation under the influences of regional uplift, cyclic climatic/hydrologic change and subsidence over areas of subsurface salt dissolution.

Figure 2 combines subsurface, topographic and restored/residual profiles across the Canadian breaks. Together, the profiles convey the variety and interdependence of influences on valley development. Well logs are the basis for illustrating subsurface structure, salt occurrence and the pattern and magnitude of salt dissolution. The projected topographic profile was built from 1:24,000-scale topographic maps and published geologic maps using a procedure adapted from King (1967). The virtue of a projected profile is that it highlights geomorphic surfaces within a degradational landscape by minimizing the effects of local downcutting. Relief between the High Plains surface and the modern breaks is a partial measure of Plio-Pleistocene denudation. A restored profile across the breaks of the terminal Ogallala alluvial plain more comprehensively illustrates post-Ogallala downcutting. The role of dissolution subsidence during downcutting is reflected in the residual profile of net salt and salt-bearing-bed thickness missing due to dissolution. Thickness determinations incorporate measured rates of Upper Permian depositional thinning, postulated landscape effects due to dissolution collapse and the deduction that 30–40% of collapse occurred in post-Ogallala time.

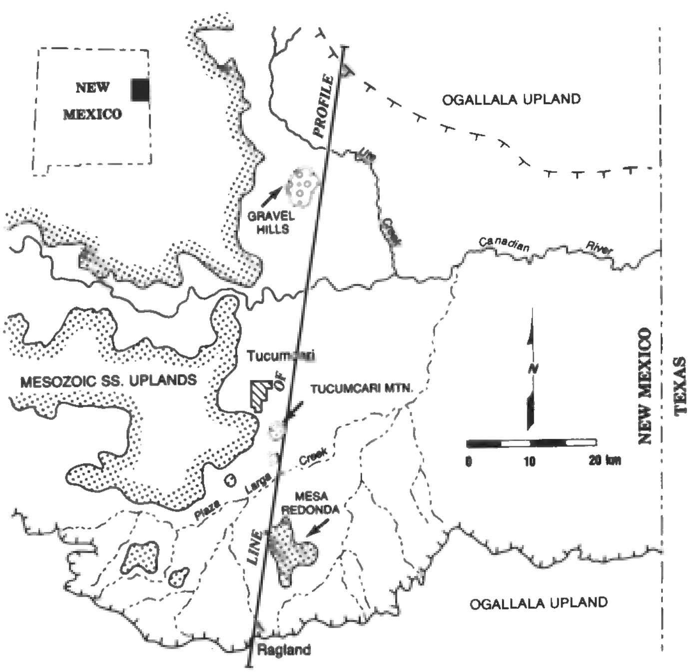


FIGURE 1. Canadian breaks-profile location relative to surrounding physiographic and drainage features of eastern New Mexico.

## THE OGALLALA EROSION CYCLE

The Canadian breaks are superimposed onto a low-relief alluvial plain that began aggrading with middle to late Miocene uplift of the southern Sangre de Cristo Range over 150 km to the west and northwest. Tectonism triggered dispersal of the basal Ogallala Formation within several coalescent, low-gradient, alluvial fan lobes (Seni, 1980). Ragland townsite is situated over the major feeder channel to one such fan lobe (Reeves, 1984). At Ragland, roughly 7 m of lower Ogallala gravel and sand were deposited by a southeastward-flowing fluvial system with montane headwaters up to 250 km away. Coarse channel deposits are overlain by more than 7 m of sandy fluvial and eolian sediments that represent progressive, though intermittent, inundation of a pre-Cenozoic bedrock terrain during the next several million years. Development of the Ogallala alluvial plain ended some 4–5 million years ago (Hawley, 1984) with formation of a caliche caprock under conditions of increasing aridity and tectonic/geomorphic stability. Drainage across this low-relief alluvial surface tended to follow Ogallala interfan swales and other subtle topographic lows formed by epeirogenic uplift, dissolution subsidence- and sub-Ogallala topography (Dolliver, 1984). The Ogallala caprock is buried at Ragland by up to 10 m of calcareous sands and sandy clays deposited during Plio-Pleistocene time by eolian and lacustrine processes (J. W. Hawley, written comm. 1985).

## PLIO-PLEISTOCENE DRAINAGE CONTROLS

### Uplift and climatic change

Geomorphic stability of the Ogallala alluvial plain ended and incision of the Canadian breaks began with abrupt and apparently successive episodes of Plio-Pleistocene tectonism and climatic change. The region of the Ragland profile has risen an estimated 800–1000 m in the last ten million years (Gable and Hatton, 1983). Nearer the Sangre de Cristo Range, relief between remnant piedmont Ogallala surfaces and middle Pliocene basalt flows (O'Neill and Mehnert, 1980) suggests that roughly one-half of this uplift occurred during late Miocene–early Pliocene initiation of Ogallala sedimentation. This deduction assumes that: (1) stream piracy and climate-induced hydrologic changes have not played a major role in pre-Pleistocene fluvial incision, and (2) the relative magnitude of uplift on the piedmont is proportional to that on the plains 150 km to the southeast. Continuing this line of reasoning, relief between middle Pliocene and early Pleistocene basalt flows (O'Neill and Mehnert, 1980) indicates that one-half to two-thirds of the remaining uplift predates the first Pleistocene climatic reversal. Negligible Pleistocene uplift and tilting are attested to by the fact that gradients of linear early Pleistocene basalt flows paralleling several New Mexico High Plains streams differ little from those of modern drainage courses.

The stairstep succession of abandoned alluvial surfaces shown in Figure 2 exhibits the impact which Plio-Pleistocene climatic change has had on the Canadian breaks. Glacial cooling and the accompanying reduction of evapo-transpiration rates affected basinwide runoff, sediment yield and sediment concentration so that stream entrenchment and valley excavation were promoted in the breaks (Dolliver, 1984). Waning glacial conditions favored valley alluviation; relative landscape stability prevailed during interglacial climatic intervals.

### Dissolution subsidence

In addition to (and partly as a consequence of) the combined effects of regional uplift and cyclic climatic change, the Canadian breaks bear the overprint of subsidence due to subsurface dissolution of Permian

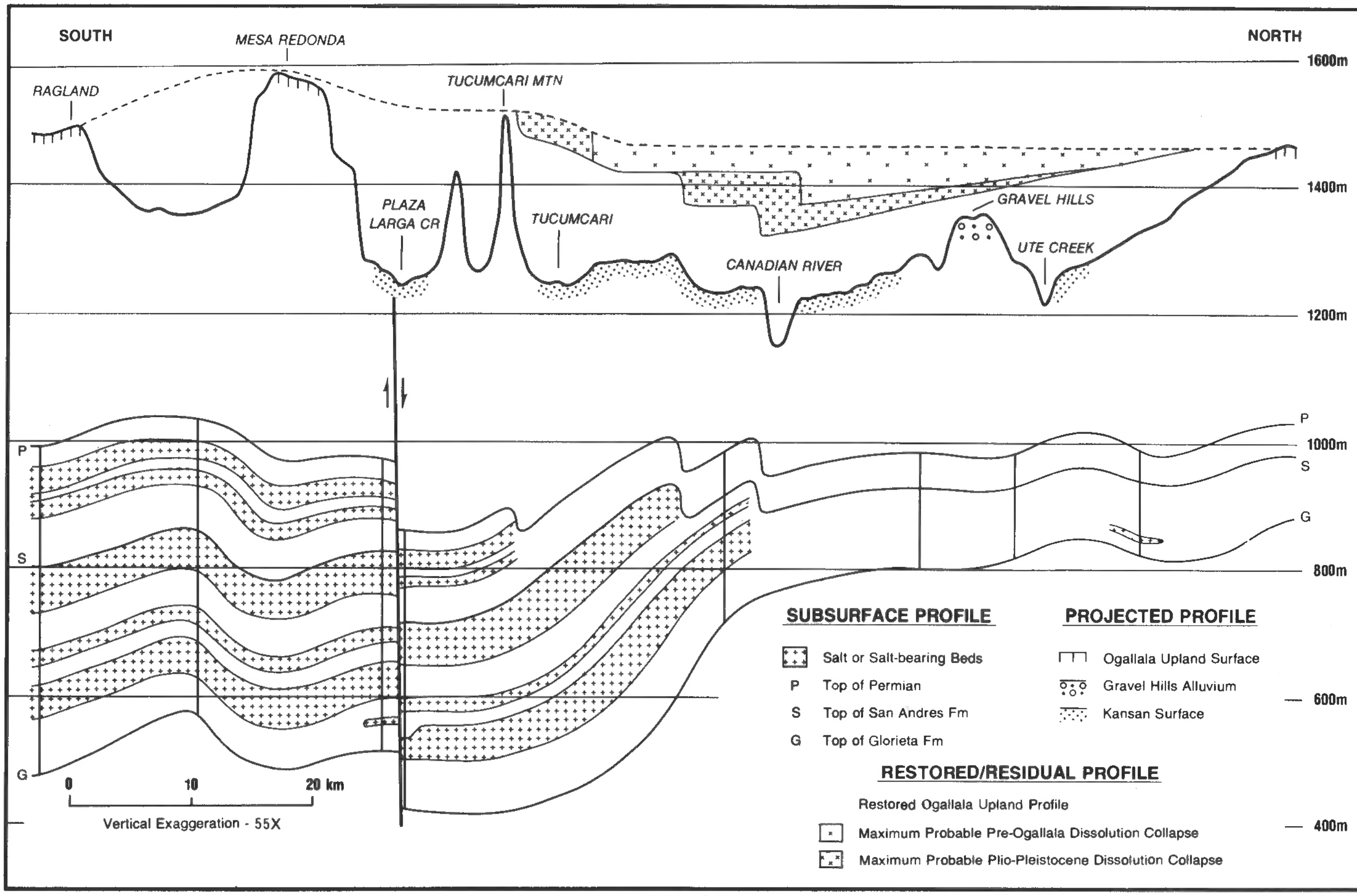


FIGURE 2. North–south subsurface, projected topographic and restored/residual profiles across the Canadian breaks in the vicinity of Tucumcari, New Mexico.

evaporites. Dissolution has proceeded southward, creating a succession of step-like fronts that coincide with the up-dip limits of several salt or salt-bearing beds (Fig. 2). Consolidation of intraformational solution breccias produced in the wake of these laterally receding fronts has resulted in up to 145 m of surface collapse along the Ragland profile. In the western Texas Panhandle, elevations of the High Plains and basal Ogallala surfaces are substantially different on opposite sides of the Canadian breaks (Gustavson et al., 1980). The relative magnitude of the difference suggests that approximately 30–40% of dissolution subsidence has occurred since Ogallala deposition.

The timing and areal extent of collapse along the Ragland profile are most contingent upon the nature and rate of ground-water recharge. Recharge is in turn the product of: (1) proximity to surface drainage, (2) regional climatic change and (3) local fault/fracture geometry and activity. The Canadian breaks are a recharge area for the regional southeastward flow (Orr, 1983) of ground water within Upper Permian salt-bearing strata. Recharge transmitted by Canadian River alluvium is a particularly significant spatial control on dissolution. In fact, former positions of the Canadian and its precursors (such as the Ogallala–Ragland channel) conceivably were both consequences of, and inducements to, dissolution collapse.

Dissolution may have been somewhat episodic, owing to the effects of cyclic Plio-Pleistocene climatic change. Temperature and precipitation changes during the last glacial maximum (Reeves, 1973; Brakenridge, 1978) could have more than doubled mean annual runoff from the Canadian breaks around Tucumcari (Dolliver, 1984). Ground-water recharge rates would have undoubtedly increased in a corresponding (but not necessarily proportionate) fashion. The Plio-Pleistocene has been punctuated by at least three other climatic reversals of comparable severity, although their timing and relative impact on the landscape is the subject of debate. Low transmissivity (less than 0.004 $m^2$/day) of the Upper Permian salt-bearing section (Dutton, 1983) further complicates the relationship between subsurface evaporite dissolution and cyclic climatic change.

The effects of faulting and fracturing on subsurface dissolution are also unclear. Intuition would suggest that joints and faults act as ground-water conduits which enhance dissolution, especially during periods of tectonic activity. A fault which crosses the Ragland profile beneath Plaza Larga Creek belies both intuition and the observed relations of other faults in the region. The Plaza Larga Creek fault apparently does not serve as a major focus of evaporite dissolution. Unlike other area faults (Gustavson, 1980), displacement substantially predates dissolution. In fact, the fault is evidently a Laramide (or older) feature that may have "healed" as a result of carbonate and/or evaporite precipitation along the fault plane. Tectonism is thus a plausible but not essential accompaniment to Plio-Pleistocene episodes of accelerated subsurface dissolution.

## POST-OGALLALA HISTORY

### Late Pliocene–early Pleistocene

Excavation of the Canadian breaks along the Ragland profile began with the superposition of two late Pliocene drainage systems onto the terminal Ogallala alluvial plain (Fig. 3). Each system, one north and one south of the present Canadian River, transported markedly different volumes of coarse-grained sediment from geographically separate source terrains. The two networks also differ in that landscape processes and products associated with the more southerly system were unaffected by dissolution subsidence.

The caprock escarpment at Ragland abruptly rises above a low-relief

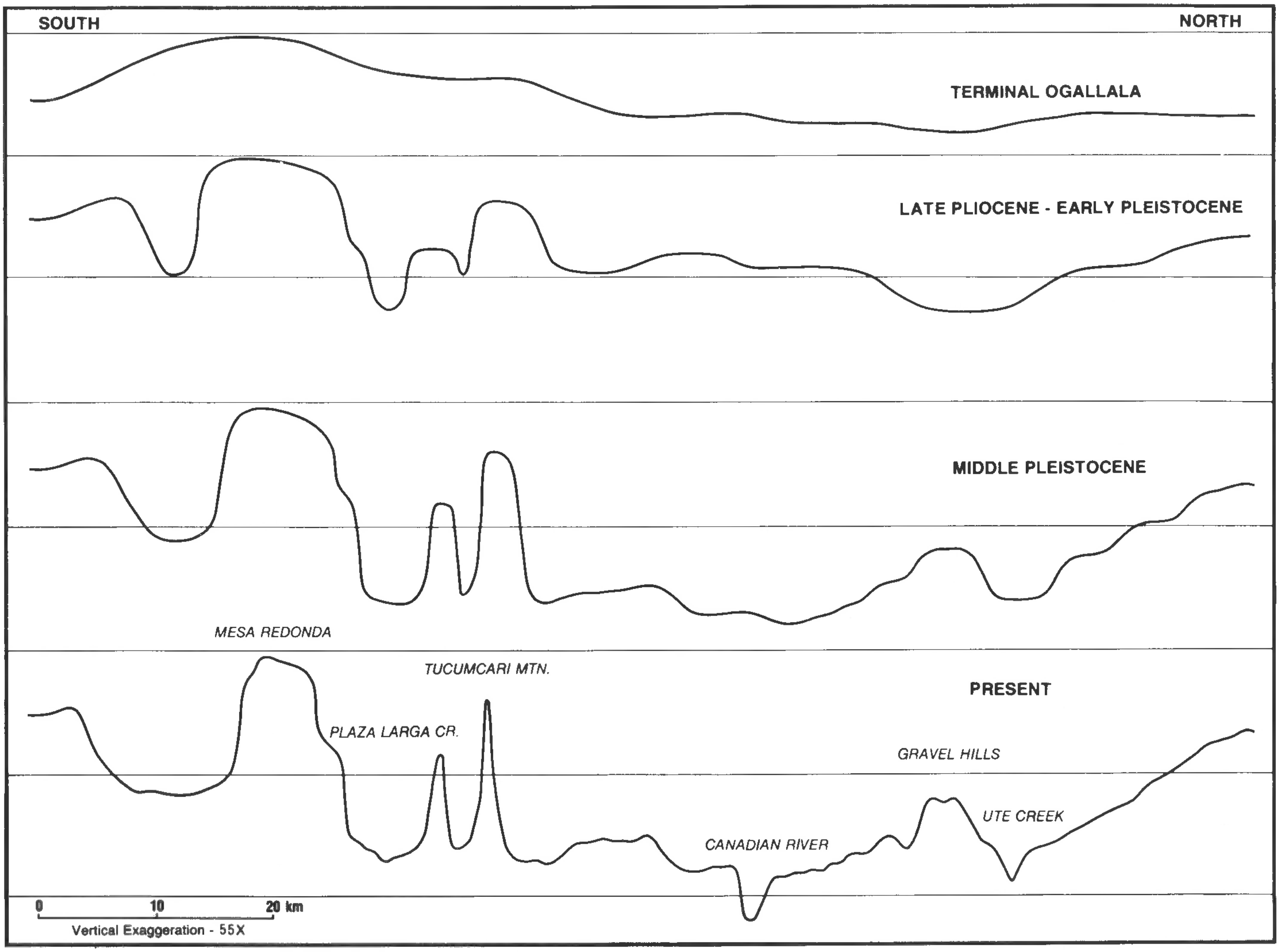


FIGURE 3. Succession of diagrammatic projected profiles showing stages in the Plio-Pleistocene evolution of the New Mexico Canadian breaks. Vertical scale is the same as in Figure 2.

pediment surface developed on Triassic red beds (Fig. 2). Sparse gravel covering the pediment differs substantially from the diverse lithology of Ogallala gravel in the Ragland channel. A significant component of the pediment veneer consists of limestone clasts of unknown origin, but perhaps originally derived from San Andres outcrops on Glorieta Mesa, some 160 km to the west (Dolliver, 1984; C. J. Perusek, oral comm. 1985). Pedimentation has evidently reworked terraces of the fluvial system which transported the gravel, but landscape position relative to other Canadian breaks-geomorphic surfaces indicates that: (1) the inferred paleochannel was probably superimposed onto a sub-Ogallala bedrock high, (2) at least 140 m of post-Ogallala incision and valley excavation took place before cutting of a lower, more areally extensive middle Pleistocene (Kansan) surface and (3) the locus and magnitude of post-Ogallala downcutting was unaffected by dissolution subsidence.

In contrast to the bold, north-facing escarpment at Ragland, the Ogallala outcrop edge north of the Canadian River forms the shoulder of a gradual incline to Ute Creek, a southward-flowing tributary of the Canadian. Windblown sand obscures what further downstream is a subtly terraced profile consisting of (from high to low) the Ogallala upland, truncated Ogallala and remnants of an early Pleistocene drainage channel (Frye et al., 1978). The level of the latter approximately corresponds to that of the Gravel Hills. As their name implies, the Gravel Hills are surmounted by up to 20 m of gravelly "channel deposits" of apparent early Pleistocene age (Trauger et al., 1972; J. W. Hawley, oral comm. 1985). Gravel lithology resembles that of Ogallala channel deposits to the north, though minus basalt clasts of Raton volcanic field—High Plains provenance (Dolliver, 1984; J. W. Hawley, oral comm. 1985). Gravel concentration at this site along lower Ute Creek can be explained by at least three possible means: (1) confluence of an ancestral Ute Creek with a vigorously aggrading proto-Canadian River, (2) alluvial/fan-delta sedimentation into a local basin created by late Pliocene–early Pleistocene dissolution subsidence, or (3) channel deposition by an early Ogallala (pre-Raton basalt) fluvial system.

The asymmetric valley-side profiles of the Canadian breaks graphically display the role of dissolution collapse in late Pliocene–early Pleistocene physiographic evolution (Fig. 3). To the south, beyond the effects of dissolution, eastward drainage across pre-Ogallala bedrock terrain became deeply entrenched under the influences of uplift and climatic change. Incised valleys expanded through scarp retreat and pedimentation to produce prominent sandstone outliers and the caprock escarpment. The less imposing north side of the Canadian breaks bears the imprint of dissolution subsidence. Pre-Ogallala and Ogallala dissolution was probably great enough to form a chaotic collapse terrain resembling that buried beneath thick Ogallala alluvium along the Texas Panhandle Canadian Valley (Gustavson et al., 1980; Gustavson and Budnik, 1985). Early post-Ogallala exhumation of the terrain, presumably by an east-flowing ancestral Canadian River, was locally inhibited by a major south-flowing tributary carrying voluminous amounts of reworked Ogallala sediment. Progressive and episodic incision under the influence of a southward-migrating base level eventually produced the subtly terraced north side of the Canadian Valley.

### Middle–late Pleistocene

The profile of the Canadian breaks within 20 km of the Canadian River depicts a widespread compound erosion surface of middle Pleistocene (Kansan) age. The age of the surface is inferred from landscape position and occurrences of 0.62-m.y.-old Lava Creek B ash (Izett and Wilcox, 1982), though clay mineralogy and the presence of buried soils also aid in its distinction (Frye et al., 1978). Gravels veneering the Kansan surface contain varying percentages of Paleozoic limestone (westerly provenance) and reworked lower Ogallala Formation (northwesterly provenance), implying that Canadian breaks-drainage became integrated by middle Pleistocene time. Drainage integration signals enlargement of the Canadian breaks to essentially their present dimensions.

Middle–late Pleistocene uplift and dissolution subsidence have only locally modified the landscape, mostly along the Canadian River and Ute Creek. Climatically induced hydrologic changes and upstream drainage exchanges (such as possible Pecos–Canadian headwaters piracy) probably exerted greater physiographic impact by inducing cyclic incision and alluviation along the Canadian River. These changes are recorded beneath portions of the Kansan surface and within Canadian Valley alluvium. This record, like others, remains to be deciphered.

## ACKNOWLEDGMENTS

This paper has benefited from careful reviews by John Hawley, Brenda Bryan, O. T. Hayward and Stan Darnell. Special thanks go to Terry Chamberlin, Dave Fox and Edgar Peña for their expertise in illustration. I am grateful to Geomap Company, friends and family for material and moral support.

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