A DIGRESSION ON THE ORIGIN OF SOME ANOMALOUS UNDRAINED DEPRESSIONS MOSTLY ON PLEISTOCENE AND PLIOCENE SURFACES IN THE TEXAS GULF COAST

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Introduction

Undrained depressions in a wide range of area and depth dimensions are found on the Gulf-bordering Pleistocene and Pliocene surfaces of Texas Gulf Coast region from the western edge of the Holocene floodplain of the Sabine River (Barnes, 1982, 1992) to the northern margin of the Holocene alluvial plain-delta of the Rio Grande (Barnes, 1976a). In longest dimension they vary in size form less than 0.25 miles (e.g., in Harris County) to over 2 miles, e.g., La Sal Vieja and nearby Sal del Rey, both in northwestern Willacy County (see Barnes, 1976a; Price, 1933, p. 937). These two lakes are located on the surface of the Pliocene Goliad Formation. Similar in size are the basins of Willow Lake and Sharps Lake in northwestern Refugio County on the Lissie surface (see Barnes (1975), and Price (1968b; 1972, p. 312-314). Small undrained depressions less than 1200 feet in diameter and less than 3 feet deep occur in the rest of Harris County and in all the coastal counties on pre-Holocene surfaces between the Orange and Cameron Counties.

Because many wetlands occupy undrained depressions, or potential sites of lakes, the following distinctions, from Winter and Woo (1990, p. 159) are of interest in view of current problems in the definition and identification of wetlands:

"The existence of lakes and wetlands depends on the specific geologic setting that favors the ponding of water, and on the hydrologic processes that allow a body of water to persist at a given site. Lakes can occur in topographic depressions, but wetlands occur in depressions, on flat surfaces, on slopes and even on drainage divides. Lakes and wetlands have common characteristics, but they differ in many aspects of water storage, water circulation, water loss to the atmosphere, and the thermal and chemical characteristics of their waters."

For discussions of the genesis of Texas wetlands other than those in closed depressions and on surfaces younger than the Pleistocene the reader is referred to the Texas Bureau of Economic Geology's "Submerged Lands of Texas" series, e.g., White et al (1985).

Classification of Undrained Depressions and Lakes

Probably the most comprehensive and exhaustive classification of the origins of undrained depressions and potential lake basins in English is given in Hutchinson (1957, p. 1-163). Precursors to this inventory of basin origins in English include Davis (1882, 1933), Russell (1895, p. 1-32), and Zumberge (1952, p. 1-48). Most texts on limnology, e.g., Cole (1983, p. 107-126) and paleolimnology (e.g., Reeves, 1968, p. 3-22) tend to use abbreviated versions of the Hutchinson categories. Cole (1983, p. 119), however, supplies an additional category, "piping: false karst lakes," with which Hutchinson was apparently unfamiliar as a basin-former. The mechanism, piping (=subsurface erosion or removal of sediment in a solid state), was, however, well-known to engineers especially as a cause of dam failures (e. g., Terzaghi, 1950, p. 102; Terzaghi and Peck, 1948, p. 507-514). Cole's emendation was based largely on an influential, somewhat controversial paper by Wright (1964).

Hutchinson's almost complete classification can serve as a convenient starting point for this discussion. Of the 11 major genetic categories outlined by Hutchinson only four,

[1] Lakes due to fluviatile action,
[2] Lake basins formed by the wind,
[3] Solution lakes, and
[4] Lakes produced by the complex behavior of higher organisms,

survive a first cut* in being applicable to the Texas Gulf coast.

To this list I have appended Cole's new category,

[5] Piping, false karst lakes.

The basins of the Texas Gulf Coast will be discussed in terms of these five categories. Interactions between causal agents and/or geologic settings are common thus breaking down the boundaries separating these categories, merging into multiple origins for many basins.

Fluvial Genesis

The earliest attempt to ascribe a fluvial origin to undrained depressions on the Pleistocene surfaces in the Louisiana and Texas Gulf Coast was proposed by H. N. Fisk (1940, p. 75-78) who suggested that the undrained depressions are the last unfilled parts of the deeper parts (thalwegs) of abandoned and avulsed point

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*Those eliminated are the following: tectonic basins, lakes associated with volcanic activity, lakes formed by landslides, lakes formed by glacial activity, lakes formed by organic accumulation, lakes produced by meteorite impact, and lakes associated with shorelines. With respect to the last category, "shoreline" features are found on the Pleistocene Beaumont Formation surface, principally the Ingleside barrier or strandplain system facies (Price, 1933, 1947; Aronow, 1971; Wilkinson and others, 1975). The undrained depressions on this regionally extensive feature are almost all eolian or blowout in origin and unrelated to littoral processes.

bar swales and channel remnants of the streams that deposited the several Pleistocene formations. The point bar swales and channels were mostly filled with flood basin or overbank deposits during the terminal slackwater stages of flooding contemporaneous adjacent active streams. He referred to these depressions as "pocks" or "pock marks" in a facetious dermatological analog to "pimple" mounds.

Fisk's lead was followed by several of his students and collaborators: Bernard (1950, p. 108-110), Holland and others (1952, p. 62-67), Varvaro (1957,p. 47-51), Bernard and LeBlanc (1965, p. 171).

Holland et al (1952, p. 62-64) calls the undrained depressions "bagols," a contraction of the term "Bay Gall" which was first used in 1873 to refer to a dense thicket in the marshes of Louisiana in part occupied by Bay Galls, a variety of magnolia. Other writers have named them (see Holland et al, 1952, p. 64-65) "lacs ronds" and "natural ponds."

Fisk (1940, p. 77) illustrated his hypothesis by a sequence of sketches showing the gradual isolation and development of these depressions on surfaces ranging in age from Pleistocene to
Holocene.

Eolian or Blowout Origins

Fisk and most of the members of his "school" of fluvial genesis mapped in comparatively high rainfall areas in Louisiana and southeast Texas. Bernard and LeBlanc whose 1965 paper covered the whole of the northwestern Gulf Coast from the Mississippi delta to the delta of the Rio Grande modified their views subsequent to Bernard's dissertation (1950). Pock marks are defined as

"very small circular depressions or intermittent lakes. Their rounded margins are the result of erosion and deposition. Very small low ridges occur on the flank of many depressions. Most pock marks in Texas and Louisiana are incompletely filled parts of abandoned river channels and swales between point bars and beach ridges and swales. Some pock marks are deflated, "blow-out" depressions within the aeolian plain [= South Texas Sand Sheet]. Most pock marks have been wallowing ponds for animals [Bernard and LeBlanc, 1965, p. 171]."

The notion of rims has been added along with those of eolian origin, at least for the South Texas Sand Sheet. The rims or "ridges" remain unexplained, and animal effects are noted.

Another observer, E. S. Deevey (1957, p. 261-262, 312) the eminent limnologist and ecologist, apparently began his observations in semi-arid south Texas and completed them in wellwatered Houston area, most likely on the surface of the late Pleistocene Beaumont Formation--thus spanning roughly the same range as Bernard and LeBlanc, but advancing in the opposite direction:

"The Kleberg County lake district is intermediate, geographically and climatically, between the typical coastal plain in the Houston region and the semi-arid lower Rio Grande country. In the vicinity of Houston the magnificent series of topographic maps of the U. S. Geological Survey (Harris and Galveston Counties, mapped at two inches to the mile with a contour interval of one foot) shows a large number of faint depressions, elliptical or circular in form, seldom deeper than one or two feet, and without any common orientation, but with a tendency to occur on divides. Conspicuous as these features are on the map, they are almost invisible on the ground, though on careful inspection most of them contain water in the spring....Farther south in Willacy and Hidalgo Counties, on the other hand, the depressions occupied by La Sal Vieja and La Sal del Rey are much more prominent features, several miles across and excavated to a depth of ten meters or more. The two groups of basins are three hundred miles apart and do not seem to be related to each other until one sees the Kleberg County ponds, intermediate in character as well as in geographic position [p. 261]...the dimples of Harris County, and the salt lakes of Willacy County form a transitional series and have all been excavated by the wind, perhaps assisted by ungulates [p. 262]."

"A brief and highly speculative consideration of the geomorphology of the basins [of south Texas] in comparison with other circular depressions in the coastal plain suggest that the lakes themselves are eolian in origin, representing the extreme of a series that begins with the almost invisible depressions found on the Beaumont Clay from Houston eastward [p. 312]."

Deevey seems to have missed the significance of the raised rims shown on the contour maps, or may have been puzzled by their absence in field in the Houston area. La Sal de Vieja and La Sal del Rey [="the salt lakes of Willacy County"] are located on the Pliocene Goliad Formation; the other lakes and depressions he refers to, on Pleistocene surfaces. As also observed by Bernard and LeBlanc are animal modifications.

Dake and Brown (1925, p. 28-29) who did not view the Houston area in the field commented in their book on map interpretation
about

"A peculiar type of ridge and depression topography on a very small scale...on the Bellaire (Tex.) sheet. It must be realized that the contour interval on this map is only 1 foot, so that few of the depressions are over 2 feet deep, and probably none of them more than 3 feet. Many of these depressions are entirely or partly surrounded by a low rim, in several cases showing as a crescentic closed contour....While no evidence has thus far been received, it seems more than probable that these represent actual wind-scoured depressions the sand and soil being caught by the grass as a low ridge about the rim."

This is the same conclusion reached by Geib and Bushnell (1928, p. 1942), who provides one of the few references to them. They are described in passing in their discussion of the Edna very fine sandy loam in Harris County:

"Drainage is imperfect and many crawfish holes have been formed. The areas are flat or billowy, similar to the areas of other prairie soils and have numerous mounds and depressions. These depressions are from 6 inches to 2 feet below the general level of the surrounding plain....Many of these depressed areas are surrounded by low ridges of sandy material, probably of wind-blown origin, which range from 6 to 12 inches in height and from 10 to 20 feet in width."

Virtually all of the rims around the depressions in Harris County have since been obliterated by cultivation, land-levelling, and pasture improvements.

Incidentally, G. K. Gilbert (1895), one of the major figures in American geology, touched briefly on the eolian origin of some lake basins of unspecified dimensions in Arkansas where wind-excavated material was deposited as rims.

As noted previously wind-excavated materials accumulating around depressions in south Texas reach many feet in height; the subadjacent depressions may be over a mile in diameter (see Price, 1968a). These "clay" dunes and their associated blowouts first entered the geologic literature in the United States with a paper by Coffey (1909) who described them in south Texas.** They differ from "sand" dunes" in their very high clay and silt content and also in their lack of mobility--they tend to remain close to their blowout sources. Price (e.g. 1933, 1946, 1958, 1963, 1968a) and Price and Kornicker (1961) in a series of papers continued to call attention to their occurrence in south Texas. Fisk (1959, p. 116-117) discuses their occurrence around Laguna Madre. Hills (1940), an Australian geologist, while recognizing their similarity to the south Texas forms described by Coffey and apparently not knowing of Price's papers, re-names the Australian forms "lunettes,"--a term widely used in Australia and Africa. Bowler (1973) reviews their world-wide occurrence and uses the term "clay dunes."

**Price (1963, p. 766) suggests that the very earliest report on clay dunes was made by an Australian explorer, T. L. Mitchell, in 1839. I have not seen Mitchell's report.

Clay dunes, in addition to their location on Pleistocene and Pliocene surfaces, are actively forming at the present time on Holocene floodplain or delta of the Rio Grande south of Port Isabel, particularly in areas where are temporarily flooded during so-called "meteorological" or wind-driven tides. Upon drying, these basins are a source area for sands-sized pellets or chips that are aggregates of mud and silt (see Brown and others, 1980, Environmental Geology map and p. 88-89).

The basin sources of the clay dunes are on a scale, of course, considerably larger than the features in the study area and the rest of Harris County, but the over-all mode of formation is similar, i.e., wind excavation.

Because I consider the fluvial and eolian hypotheses the most plausible for the Texas Gulf Coast an evaluation, and even reconciliation, by weighing relative magnitude of these, is in order. Three variables are of interest in this discussion:
[1] the regional variation of rainfall and vegetative cover from
the Sabine to the northern edge of the South Sand Sheet, [2] changes in climatic regime in time, and [3] progressive changes in time, with and without climatic changes.

An approach to the problem can be made by considering the areal relationships of the smaller undrained depressions on the younger Beaumont surface versus those on the older Lissie surface.

On the younger late Pleistocene Beaumont surface roughly north of the Guadalupe River the soils in most places are neatly partitioned between the higher meander ridges and the lower flood basin areas (see Aronow, 1976), each with characteristic suites of soils. The undrained depressions are pretty much restricted to the slightly elevated (<10 feet) relict meander ridges which are also occupied in part by meandering channel segments and pimple mounds. All these are largely absent from the comparatively smooth, featureless somewhat lower relict flood basin or backswamp surfaces. Segmentation of the relict channels into depressions, curved alignments of depressions as well as randomly occurring depressions can seen on the low ridge areas.

In Nueces County there is in many places a curious reversal of topography in which the sites of the paleo-meander ridges on the Beaumont surface is locally depressed and marked by circular blow-outs. Otherwise a similar soil-partitioning can be discerned (see Aronow, 1971)

By contrast on the Lissie surface both the undrained depressions and the pimple mounds seem to be randomly distributed and the soils are not clearly segregated in terms of a relict depositional topography. Traces of any relict depositional topography in the form of channel segments or alignments of depressions on the Lissie are rare.

The location of present-day minor stream channels on the Beaumont surface in many places is controlled by the lower flood basin swales, as noted by Barton (1930). Most channels, in these swales or crossing meander ridges, are sharply incised into the Beaumont surface. Most of the stream channels on the Lissie surface are flanked by wide, broad sloping areas which merge uphill into the flatter interfluves. Both the slopes to the streams and the flatter portions of the interfluves are equally the sites of undrained depressions and pimple mounds. This areal persistence of the depressions despite the loss of the sharply incised topography which we might reasonably assume might have existed earlier on the Lissie strongly suggests that any relict depressions of fluvial origin on the Lissie have been eliminated or considerably modified by [a] eolian action--as indicated by the small rims or ridges shown on the older quadrangle maps--and [b] mass-wasting and fluvial erosion--as indicated by the long broad slopes adjacent to the stream channels.

Thus in the absence any decisive subsurface data it looks as if the surface depressions and pimple mounds were formed during and after erosion (fluvial and eolian?) and mass-wasting of the surface which obliterated any prior depositional topography on the Lissie surface.

A possibility here is that the formation of the contrasting pock-marked and pimple-mounded surfaces of the Lissie and the Beaumont were contemporaneous. An alternative is that the deterioration and disappearance of the probable relict fluvial topography of the Lissie surface was well-advanced prior to the laying down of the Beaumont Formation. In either case the major differences between the Lissie and Beaumont surfaces are functions of their relative age--and the possibility of several changes in climatic regime with increasing age: the longer the surfaces were exposed the greater the loss of details of the relict fluvial topography.

The Beaumont Formation and its Louisiana correlative, the Prairie Formation, crop out in a great coast-paralleling crescent from the western edge of the Holocene floodplain of the Mississippi River in Louisiana (see Snead and McCullah, 1984) to the vicinity of Corpus Christi Bay in south Texas (see Barnes, 1975). The several segments of the Beaumont were contemporaneously deposited by the late Pleistocene ancestors of the modern streams that now traverse its outcrop area.

When the surface of the Beaumont is examined on a comparative regional basis a gradual loss of relict fluvial detail can be seen from northeast to southwest. The Trinity- and Brazos- deposited parts of the Beaumont display the relict fluvial topography in remarkable detail with many miles of relict channels on meander ridges still in intact. These contrast sharply with progressive

southward regional loss of detail on the Colorado-, Guadalupe-, and Nueces-deposited parts of the Beaumont. On these the continuity of relict channel segments is limited and undrained depressions appear in greater abundance. I suggest that this regional change is due to the decreasing plant cover resulting from the regional decreases in rainfall. And as a result of this the increasing pervasiveness and efficacy of the wind in shaping the landscape. This variation in the surface of the Beaumont may be the spatial or areal analog of the temporal contrast between the Lissie and the Beaumont. A possible conclusion is that the Lissie surface has been modified by eolian effects, among others, whose range of intensities may be similar to the climatic variations from northeast to southwest along the Texas coast.

Depressions as Solution Basins

The presence near the surface, or even at considerable depths, of soluble materials is needed for basins of solutional origin. Commonly occurring soluble natural materials include the calcium carbonate (as caliche or limestone) sodium chloride (halite), calcium sulfate (gypsum and anhydrite). Solutional basins, especially in limestone terrains, are referred to as "karst."
Few of the basins on the younger surfaces of the Texas Gulf Coast qualify as true karst areas because of the absence of thick carbonates.

The many depressions, however, on the caliche-rich Pliocene Goliad Formation of south Texas are probably related to the subsurface solution of the caliche where they may be fracture controlled (see Barton, 1933). Earlier it was noted that the large wind-excavated depressions containing the Sal Del Ray and La Sal Vieja lakes are sited on or at the edge of the Goliad outcrop area. The notion that these depressions are of eolian origin is supported by the large clay dunes on their margins. Brown and others (1980) in the legend of their Environmental Geology refer to this area as "Sands and silts, caliche capped, thin veneer of eolian sand, numerous small circular (karst) depressions (Holocene-Modern)." In their text (p. 84) the area is called the "Lasara loess-veneered caliche (Goliad Formation)" in which "Caliche cements the substrate, and solution processes have created a karst geomorphology." This part of the Goliad outcrop area is located south of the South Texas Sand Sheet which pretty well conceals its northward extension. The Goliad surfaces again north of the Sand Sheet (see Barnes, 1976b, 1975, 1979) and persists as outcrops into Lavaca County where it disappears again as a surface unit. Probably the Guadalupe River marks the northern extent of thick caliche and karst depressions in the Goliad.

Solutional or karst depressions have been reported on for areas deficient in very soluble natural materials. Smith (1931), for example, proposed that for some basins developed in sandy Coastal Plain sediments of South Carolina may form by the solution

of iron and aluminum compounds at shallow depths. Acidic solutions derived from plant decay are suggested as agents. The materials that are dissolved out are not clearly characterized but seem to be hydrated iron oxides and clay minerals.

Isphording and Flowers (1988), outline a similar origin for a local area of subsidence on the Plio-Pleistocene Citronelle Formation (a correlative of the Willis Formation in Texas) in Mobile, Alabama. They believed that what caused the subsidence was the solution of the clay mineral kaolinite $[Al_2Si_20_5(OH)_4]$ and the re-precipitation of the hydroxyl and alumina components as gibbsite $[Al(OH)_3]$ with the silica going into solution. This kaolinite-to-gibbsite transformation produces an ~35% volume loss. Solution of iron oxide grain coatings and intergranular cement probably also contributed to the volume loss.

Twidale (1987) for an area underlain with laterite in north-central Australia attributes sinkholes as large as 160 feet in diameter and over 50 feet in depth to solution of silica by alkaline subsurface water and possibly the solution of iron oxides promoted by acidic waters derived from plant litter.

There is a large literature, of which these papers are a representative sampling, concerning this kind of "non-traditional" karst on volcanic rocks, on granites, peridotites and other igneous rocks, and on quartzites, laterites and clayey sands [see references in Isphording and Flowers (1988), Twidale (1987), and Finlayson and Webb (1988)].

The Plio-Pleistocene Willis Formation of east Texas (correlative with the Citronelle discussed by Isphording and Flowers) contains many plinthitic (iron oxide-rich) shallow materials which are locally "harvested" by scraping the surface. These are among the so-called "iron-ore" gravels much used in East Texas for surfacing roads. The flatter parts of the Willis outcrop area in many places does contain small undrained depressions similar to those in Harris County. Gibbsite, the low-volume product of the desilication of kaolinite, as far as I know, has never been reported as occurring in any Texas Coastal Plain soils. Solution of iron oxides, one of the alternatives suggested by Twidale, remains as a possibility to be investigated.

Origin by Complex Behavior of Higher Organisms

Hutchinson (1957, p. 146-148, 163) for this category gave as examples beaver- and human-constructed dams, and artificial (human) excavations like quarries and mines. To this category Reeves (1968, p. 19-20) has added the wallows [see also Frye (1950, p. 17); Fenneman (1931, p. 14-16); Fairbridge (1968, p. 778)] of cattle and bison ("buffalo"). Reeves notes the small size of

recent wallows: 8-10 feet in diameter and 1-2 feet in depth. Both Deevey and Bernard and LeBlanc, in the quotations given above, also mention this utilization by quadrupeds but seem to limit it's effects to secondary modifications of previously existing depressions.

Holland et al (1952) quote a writer (Clendennin, 1896--a reference I have not seen) who believed the "natural ponds" or "bagols" of Louisiana originated as "buffalo wallows."

Origin by Piping

The term piping was originally used by civil engineers to describe the removal by ground water seepage of material as solid grains under or in the vicinity of dam could potentially lead to the failure of a dam. Possibly the most familiar examples in the Gulf Coast are the alignments of small depressions or collapsed areas a few tens to hundreds of feet upslope from the headwall of a gully.

The meaning of the term "piping" and its several mechanisms are considered in detail in papers by Parker and Higgins (1990) and Jones (1990). Mechanisms (Parker and Higgins, 1990, p. 83-85) that lead to or promote piping include

[a] the formation of "boils" or heaves in natural or in engineering situations where great pressure differentials exist and materials fail with a discharge of sediment-laden water which may not be unrelated to tunnels;

[b] movement of material by elutriation--the passage of finer material (silt or clay) through the interstices of a sand or gravel. Passageways through such sediments may result from the solution of soluble cements such as calcium carbonate. Passageways or tunnels may be later enlarged by scouring;

[c] seepage-face erosion where pressure differentials are great enough to entrain sediments in a permeable unit that is intersected by a steep slope such as the head of a gully or an embankment. As material is removed a pipe is formed which eventually collapses;

[d] joining of pipes or tunnels already initiated with animal burrows or opening left by rotting wood or roots;

[e] cracking by hydrocompaction or volume loss resulting from the wetting of previously dry surface materials;

[f] desiccation cracking in arid regions of expansive or swelling clays, especially those rich in exchangeable sodium.

For a long time it was thought that natural or non-anthropogenic piping was restricted to arid and semi-arid regions. With the development of the notion of interflow or throughflow (shallow surficial subsurface flow) on slopes in temperate and high rainfall regions that supplemented and paralleled surface overland flow to streams the literature on natural piping phenomena in better-watered areas has effloresced (see references in Jones, 1990). Pipes, especially controlled by differences in permeability within soil profiles, are viewed as a means of enhancing this shallow subsurface flow.

One of the suggestions for the origin of undrained depressions on the Great Plains of Kansas (Frye, 1950, p. 14-17), some on the scale of the depressions in Harris County was by "differential silt infiltration," or a variety of elutriation described above.

Though my preferred explanation for the Harris County depressions is eolian, the possibility of contributions by piping mechanisms should not be discounted. Seepage faces and springs where the walls of local stream channels intersect sandy and silty beds are common along many of the drainageways in Harris County. As noted previously, alignments of small collapsed areas up slope from the headwalls of gullies are occasionally seen.

The large playas, mostly less than 15 feet in depth and less than a mile in diameter, of the southern High Plains (Llano Estacado) of north Texas and eastern New Mexico has usually been attributed to wind excavation (Cole, 1963; Reeves, 1966; Carlisle and Marrs, 1982). Recently (Osterkamp and Wood, 1987; Wood and Ostercamp, 1987; Wood, 1990) a more complex origin involving several of the categories of basin origin was proposed: solution of carbonates and silicates by percolating water in the vadose zone, and downward transport of fine-grained clastics and organic matter (a piping-eluviation mechanism), both following an initial eolian deepening.

Earlier Judson (1960) in the pre-piping concept era suggested that for a small area in the Llano Estacado in eastern New Mexico the undrained depressions resulted from the localized solution of calcium carbonate cement in the Ogallala caprock during a moist period. This rendered the remaining clastic material susceptible to wind erosion during a subsequent dry period. Solution might resume when the basins contained lakes during a later moist period following which both clastic Ogallala material and lake deposits might again be removed by the wind.

Two recent papers (Reeves, 1990; Gustavson et al, 1994) again stress complex and multiple origins for the north Texas playas including deflation enhanced by animal activities, rim erosion, and solution of caliche cap rock, soil carbonates, and deeper Permian salt beds. Gustavson et al (1994, p. 11) discount any major

effects of piping. Reeves (1990) suspects, in addition, contributions to playa formation by piping and hydrocompaction. He proposes a typology of playas based on a on the relative efficacy of the several processes over time.

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