Monitoring Ground Movements over Undisturbed Salt Domes with Precise Leveling

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ABSTRACT

Precise leveling was performed over two salt domes in North Louisiana for a four-year period. The objective of the leveling was to collect data for naturally occurring ground surface movements over salt domes undisturbed by man-made activities, e.g., salt and sulfur mining or hydrocarbon production. The collected data furnish examples of levels of "background" surface movements due to rainfall and possible seasonal effects.

Networks of leveling monuments were established over the Vacherie and Rayburn's domes by the National Geodetic Survey (NGS) in 1977. Subsequently, re-leveling surveys were performed in 1978, 1979 and 1982 over the Vacherie dome, whereas re-leveling over the Rayburn's dome was performed only in early and late 1979.

Computer graphics techniques were used to produce contour and surface maps of elevation changes over the domes. Possible reasons for apparent surface movements are discussed relative to site specific characteristics at locations of the leveling monuments. Amounts of rainfall and levels of water tables apparently caused seasonally related small changes in surface elevations. The ground surface elevation changes were relatively small over the four-year monitoring period, and no general patterns of change developed that could be attributed to possible movements of the underlying salt stock of the domes.

Possible monitoring systems which incorporate leveling are summarized for mining activites in evaporite formations.

INTRODUCTION

Background, Objectives and Significance

Surface subsidence over salt formations is of interest because it can indicate dissolution of the underlying salt or mining of minerals associated with salt domes, e.g., sulphur or hydrocarbons. On the other hand, naturally occurring rates of salt stock "growth" associated with the diapiric evolution of Gulf Coast domes have been studied and tentatively quantified on a geological basis as being significantly less than 1 mm/yr (Kumar, in Martinez et al., 1977; and Netherland, Sewell and Associates, 1976). However, such growth rates frequently have been averaged over time periods of millions of years, which tends to give little detail over shorter time periods that may be of more interest for "long-term" storage projects. Stability of the salt stock of domes relative to possible halokinetic movements has been a principal consideration for storage and/or disposal of radioactive wastes in Gulf Coast salt domes. Frequently, this consideration has been mislabeled the "tectonic" stability of salt domes, although tectonism apparently has played little, if any, role in the evolution of Gulf Coast salt domes (Murray, 1968; Kupfer, 1976).

The general objective of this study was to collect and interpret data associated with possible ongoing vertical movements of the Vacherie and Rayburn's salt domes in the Gulf Interior Basin of north Louisiana. Of these two domes, the Vacherie dome apparently has not had subsurface mining activity, whereas Rayburn's dome has been used for limited salt production by bailing and evaporating brine from shallow, hand-dug wells, (Kolb in Martinez et al., 1978). Therefore, the Vacherie dome was considered to be undisturbed by mining activity, whereas Rayburn's dome was subject only to minor disturbance.

In the Gulf Coast region, salt domes and adjoining formations frequently are mined for hydrocarbons, sulfur, and salt; and these activities generally affect ground surface elevations with time. It follows that little elevation-change data are available for domes undisturbed by mining activity. Thus the data collected from this study furnish a base for surface movements associated with salt domes which have been essentially undisturbed, or minimally disturbed, by man-made subsurface activities. The data also make possible a "quick look," in a geological sense, for any effects that can be associated with movement of the underlying salt stock due either to continuing upward

movement or to downward relative movement from dissolution of the dome surface by groundwater.

Leveling Surveys for Monitoring Surface Movements

Land surveying is a profession that has developed over hundreds of years. Technique and instrumentation have been developed to a high degree of sophistication and classification of methods, with specifications, are well established (Phillips, 1975). Surveying data traditionally are the basis for land property control, and thus are readily legally defensible. Elevation monitoring by repeated leveling surveys of network of monuments has been practiced in the U.S. for some time (Chi et al., 1980); and national networks exist to monitor regional behavior (Holdahl and Morrison, 1973).

In some European countries where subsidence is a critical consideration, establishment of a leveling network with an initial survey for elevations reference is required by law prior to initiation of any underground mining or tunneling activity. The resulting data furnish a valuable basis for studying ground movement associated with underground excavation and mining. Similar data in the U.S. generally are considered proprietary.

Leveling data have been published relative to monitoring subsidence from sulfur mining in Gulf Coast salt dome caprock (Deere, 1961), and also reports related to monitoring possible effects of solution mining in salt formations (Piper, 1981; Wong, 1982). These studies illustrate the accepted practice of using repeated leveling surveys, or relevelings, to monitor surface movements over salt formations due to man-made activities. Monitoring surface movements over the Vacherie and Rayburn's domes with releveling thus was an obvious component to be included in any study designed to detect possible ongoing movement of the underlying salt stock due either to uplift or dissolution.

DEVELOPMENT AND IMPLEMENTATION OF LSU-IES LEVELING STUDIES

Development of Leveling Networks over Study Domes

Releveling a network of surveying monuments over the study domes, Vacherie and Rayburn's was considered early in the study performed by the Institute for Environmental Studies at Louisiana State University (LSU-IES). Precise releveling was proposed as one component of an instrumentation system for monitoring possible ongoing movements associated with salt domes. Figure 1 is a schematic of the monitoring system proposed and described by Thoms in previous reports (Martinez et al., 1975–1978).

In 1976 personnel of the National Geodetic Survey (NGS) were contacted to determine the availability of that agency for establishing surveying leveling networks over the study domes. The dome networks were to be tied into the U.S. national leveling network for reference purposes. This was feasible, and planning of the networks over the study domes was carried out in coordinated effort by LSU-IES and NGS personnel.

Implementation of LSU Releveling Study

Field crews of the NGS, accompanied by LSU personnel, established and surveyed networks of leveling monuments over the Vacherie and Rayburn's salt domes in the late spring and early summer of 1977 (Martinez et al., 1977). The leveling networks were incorporated into the NGS national leveling network, and the associated data were compiled into the NGS data base.

Subsequent releveling of the networks was performed by commercial firms qualified to perform modified first order surveys.[1] Dates of these releveling surveys for Vacherie were: September, 1978; August, 1979; and January, 1982. Surveys actually performed were described as modified first order surveys.[2] Releveling surveys of Rayburn's dome were performed in January and August of 1979. Thoms and Gehle tentatively summarized findings from surveys through 1979 in a previous report (Martinez et al., 1979). Data from the January, 1982, survey over the Vacherie dome are incorporated in a report to be published through the Office of Nuclear Waste Isolation (ONWI).

PRESENTATION OF LEVELING DATA AND ITS SIGNIFICANCE

Computer Graphics Displays of Surface Elevation Changes

Figures 2 and 8 indicate locations of leveling monuments established for the Vacherie and Rayburn's domes studies respectively. Approximate locations of dome boundaries, based on information available around 1978, also are indicated. The locations of monuments were selected to essentially cover the area over and around the dome while providing for relatively ready access for future surveys. Thus many monuments were set near existing roads. Tiltmeter sites over the dome flanks were tied into leveling monuments "networks" to furnish complementary information for possible latter analysis of tilt data.

Figures 3 through 7 are computer graphics displays of surface elevation change data for the Vacherie dome from May, 1977, through January, 1982. Figures 3 and 4 represent the same leveling data as Figs. 5 and 6, respectively; however, both are furnished to compare displays generated from the same data by different computer programs. That is, Figures 3, 4 were generated with SYMAP (1975) and SYMVU (1971); and Figures 5 and 6 were generated with SURFACE II (1978) and SAS/GRAPH (1981). The

[1]First Order, Class I, specifications require that vertical control surveying be performed so that the difference in forward and backward leveling will not exceed 3 mm $\sqrt{K}$, where K is the section length in kilometers.

[2]Modified, First Order, Class I, leveling implies that the large loop around the dome was closed with 4 mm $\sqrt{K}$ specification, and each spurline was double run to meet 3 mm K specifications.

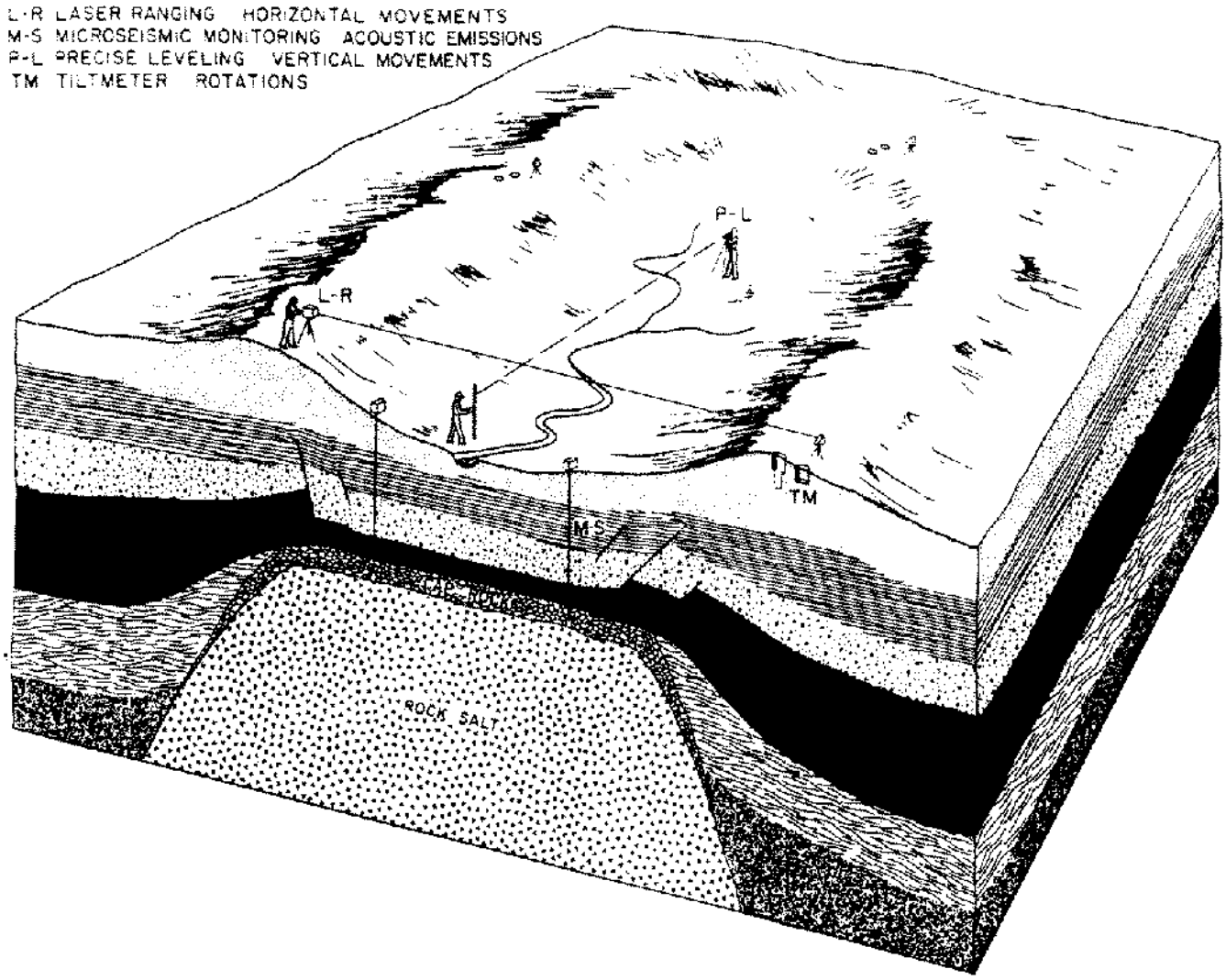

Figure 1. System for monitoring possible surface movements over salt domes.

graphics displays are obviously similar for the same data, which enhances the credibility of the computer graphics programs employed for data presentation. Figure 7 represents data from the most recent leveling survey performed over Vacherie in January, 1982, relative to the initial survey in 1977, and was generated using SURFACE II and SAS/GRAPH.

Figures 9 and 10 are displays of surface elevation changes over the Rayburn's dome based on leveling surveys performed in January and August, 1979, relative to the initial survey performed in June, 1977. The previously referenced programs SYMAP and SMYVU were used to generate the displays.

In Figures 3, 4, 9 and 10, the outline of dome boundaries are defined to furnish an areal scale effect. Comparisons of Figure 3 and 4 with 2; and 9 and 10 with Figure 8, enables the reader to identify locations approximately on the displays of surface elevation changes. A vertical axis for elevation change measured in millimeters is included in each figure.

Significance of Leveling Data

As noted previously, the objective of this study was to use precise leveling to detect possible ongoing vertical movement over the Vacherie and Rayburn's salt domes. From the data obtained to date, a general conclusion was that a much longer time period of observation is required to establish possible trends of naturally occurring movement over these two essentially undisturbed salt domes. That is, relevelings performed over decades, preferably in coordination with regional surveys by Federal agencies such as the National Geodetic Survey (NGS), would yield data whose significance could be more readily interpreted for long-term movement effects. Otherwise, for relatively

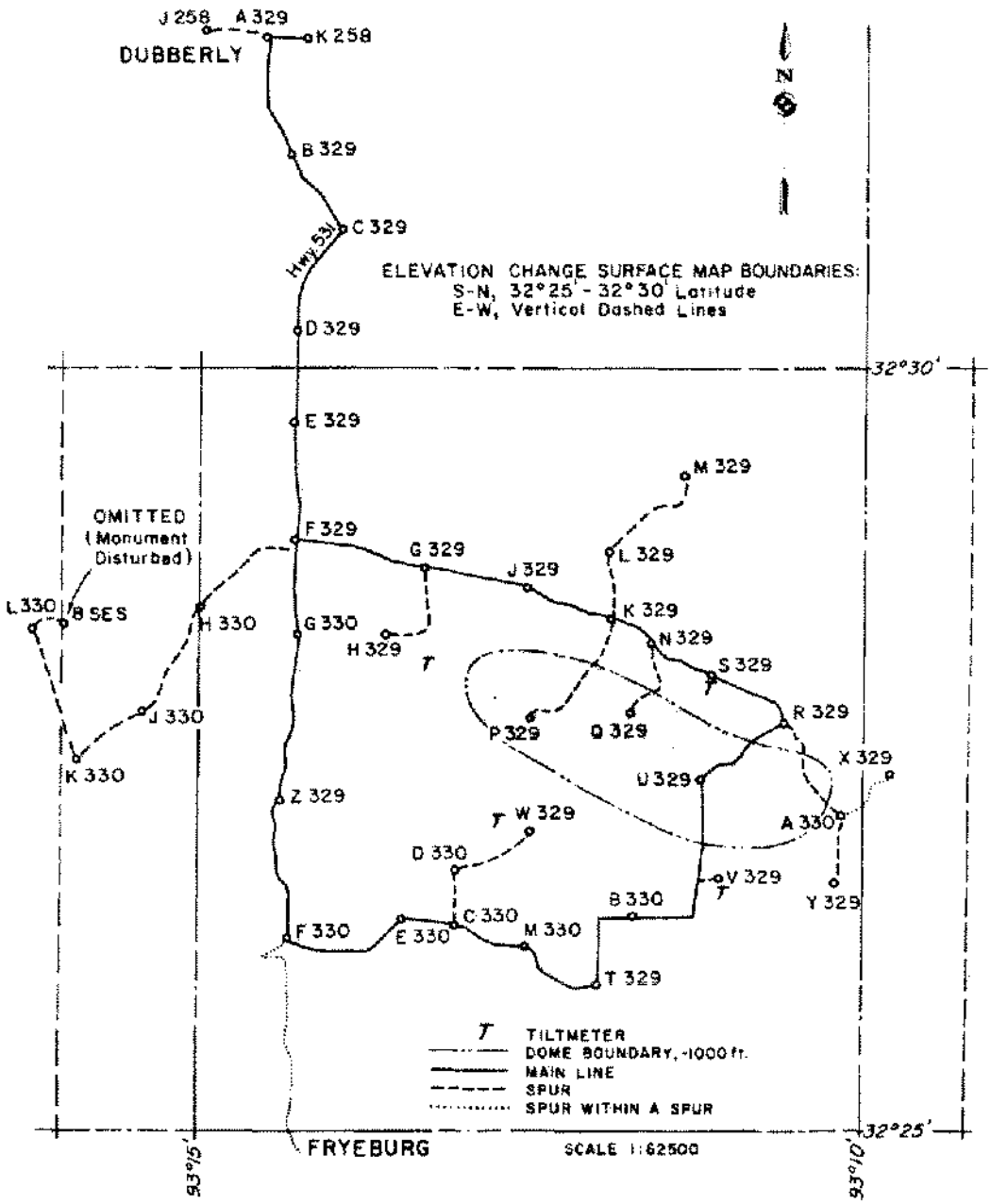

Figure 2. Network of leveling monuments over Vacherie dome.

short periods of a few years of observation, seasonal variations in water table levels and soil moisture content apparently tend to dominate and obscure any "background" long-term trends in vertical movements. Discussion of the practicality of such a monitoring program is beyond the scope of this paper; but obviously, related considerations must take into account the period of interest and planned lifetime of storage and/or mining projects.

Data from the Vacherie dome study can be used to illustrate the above remarks. Figures 3, 4, 5 and 6 depict changes for a time period of around two years (27 months). With reference to these figures, a pronounced localized upward movement was associated with the north-northeastern flank of the dome. Monuments N329 and S329 (Figure 2) displayed pronounced upward movement in September, 1978 and August, 1979, relative to their original surveyed elevations in May, 1977. Monument S329 was located at a tiltmeter site, where soil conditions were investigated with borings and by excavation to depths of around 3–4 m. With heavy rainfall, it was discovered that the tiltmeter site apparently was over a "leaky" perched aquifer, and that the water table would

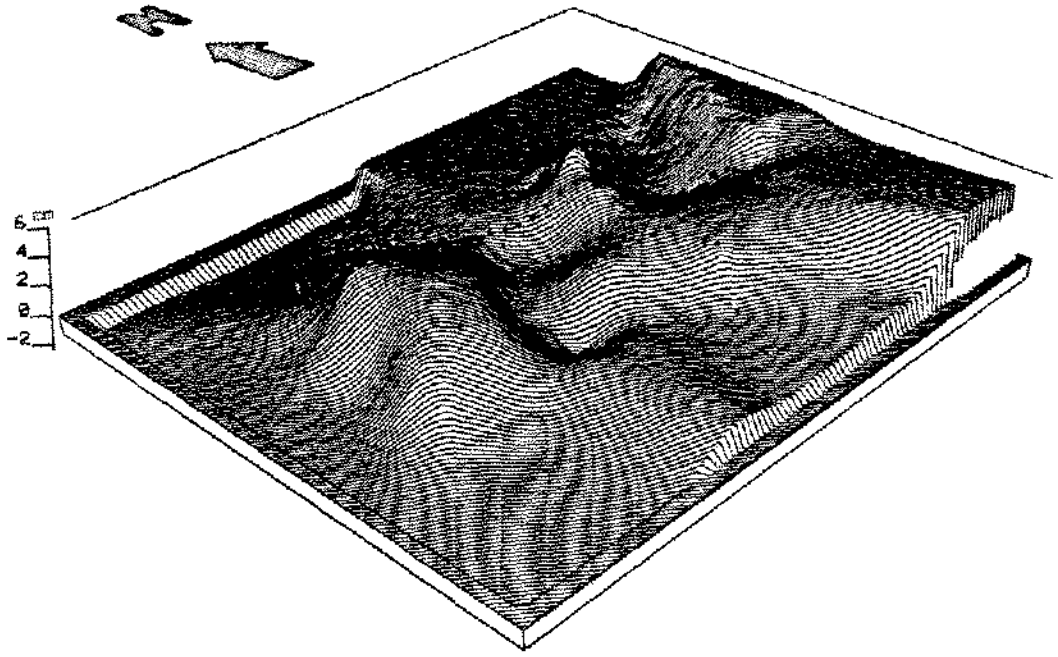

Figure 3. Surface elevation changes over Vacherie. (September, 1978–May, 1977).

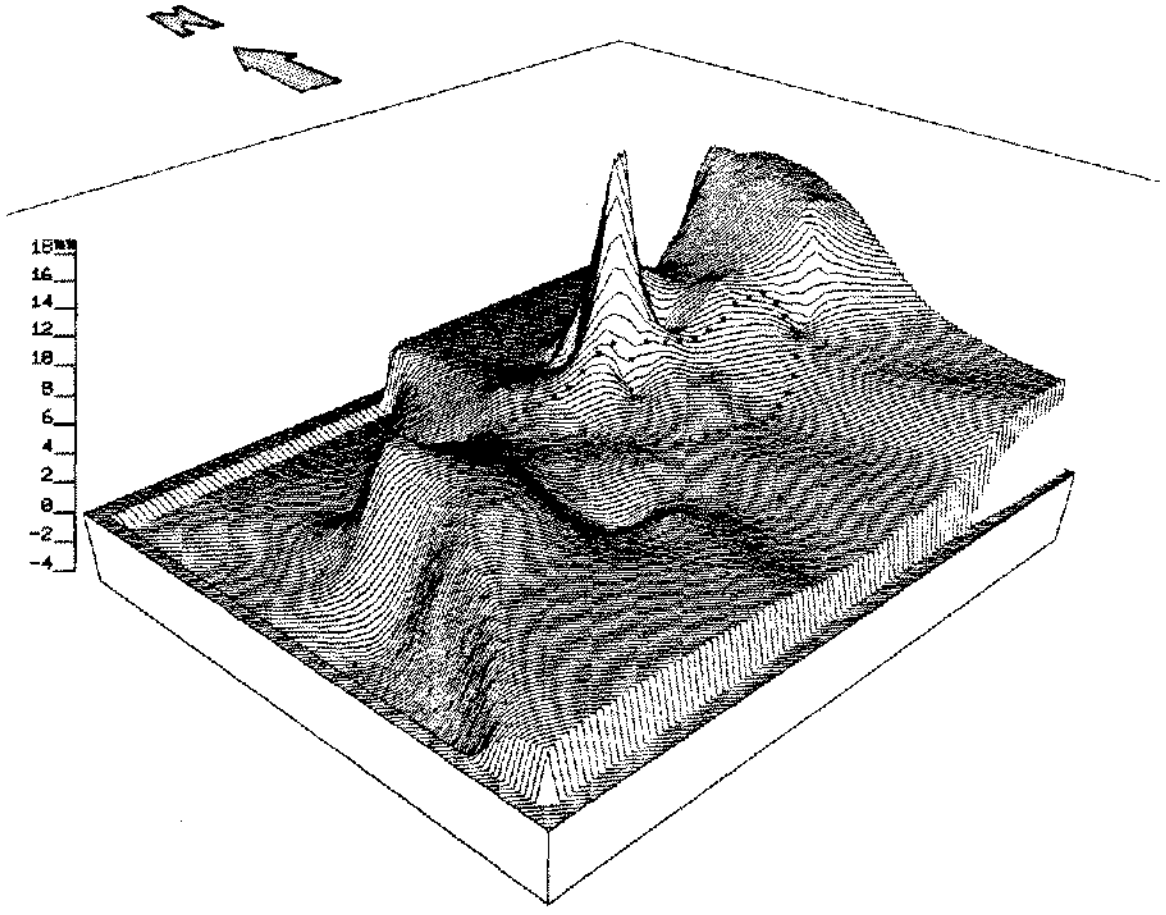

Figure 4. Surface elevation changes over Vacherie. (August, 1979–May, 1977).

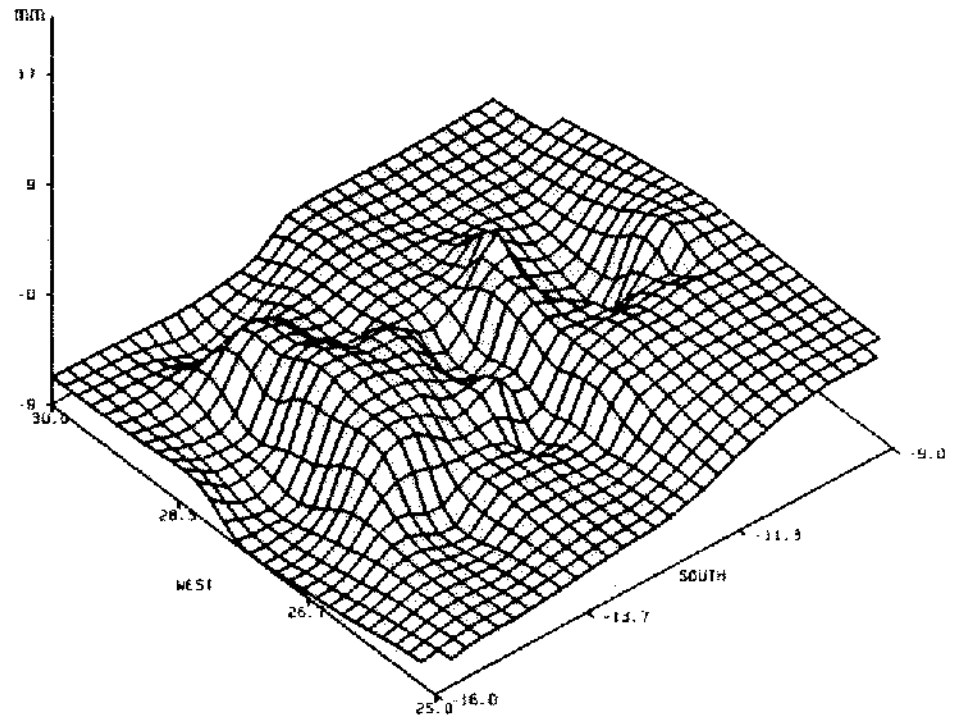

Figure 5. Surface elevation changes over Vacherie. (September, 1978–May, 1977).

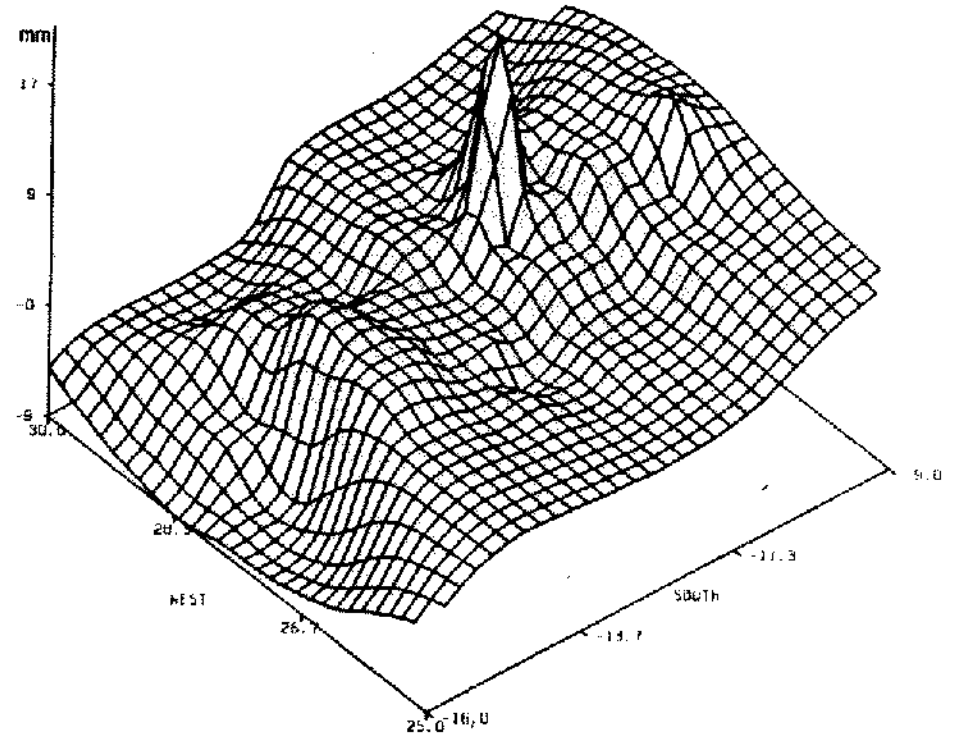

Figure 6. Surface elevation changes over Vacherie. (August, 1979–May, 1977).

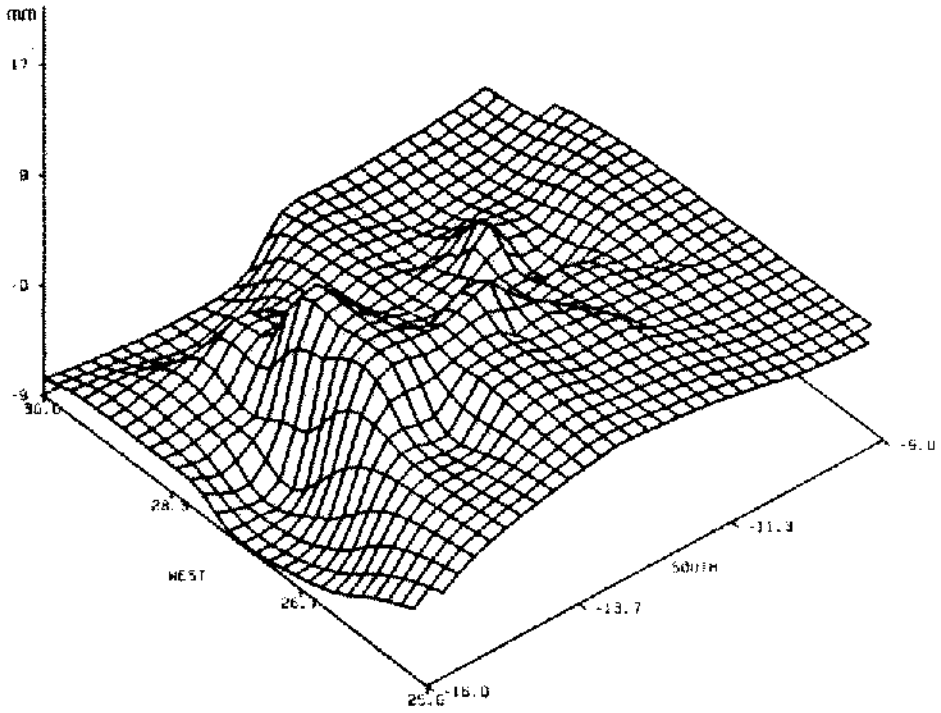

Figure 7. Surface elevation changes over Vacherie. (January, 1982–May, 1977).

rise to within around 1 m from the ground surface. Soil borings corroborated this finding, and the tiltmeter subsequently was moved to another location. During periods of relatively small amounts of rainfall, the water table would slowly fall to significantly greater depths. The summer of 1979 was exceptionably dry in north Louisiana, and August (typically) was the most dry summer month. Thus it was highly probable that the water table in August, 1979 was considerably lower than in May, 1977 at the monuments N329 and S329. Thus, the relative upward movement at these sites was attributed to localized "elastic rebound" of the near surface from the unloading, by slow drainage, from the leaky perched aquifer. With reference to Figure 7, the last leveling survey performed in January, 1982 indicated the surface at these monuments (N329 and S329) had returned to around their elevations of 1977. Because relatively large amounts of rainfall typically occurs in winter in Louisiana, it was highly probable that the near-surface perched aquifer had recharged, and subsequently reloaded the area around monuments N329 and S329. From the experience associated with these monuments, it was concluded that water table monitoring and recording should be incorporated into any detailed surface movements study in regions where significant amounts of rainfall occurs.

Because of the striking similarity of releveling data as depicted in Figures 5 and 7, long-term trends of movement were not identified, nor associated with the presence of the underlying salt stock. The more irregular character of the surfaces evident over the domes in the central portion of the Figures was attributed mainly to the more dense array of leveling monuments (data points) located deliberately over the dome. The computer graphics programs generated the depicted surface to fit data where available; and where monuments were sparsely located off the dome, the surfaces tended to be smooth.

Monument locations and relative elevation changes over the Rayburn's salt dome are depicted in Figures 8, 9 and 10. The most striking aspect of Figures 9 and 10 is the apparent overall uplift associated with the entire network of monuments. This may be a subregional effect; it does not appear to be associated with the underlying salt stock. General upward movements ranging up to around 18 mm (0.71 inches) apparently occurred over the network; however localized movements over the domes were very similar for the two releveling surveys.

The Rayburn's dome was reduced to lower priority, relative to the Vacherie dome, for consideration as a possible nuclear waste repository; and thus an additional releveling survey was not performed in January, 1982. From the data included here, no firm conclusion could be drawn associated with the presence of the Rayburn's salt dome, except to note a possible dissolution effect on its western flank. There an apparent localized relative downward movement

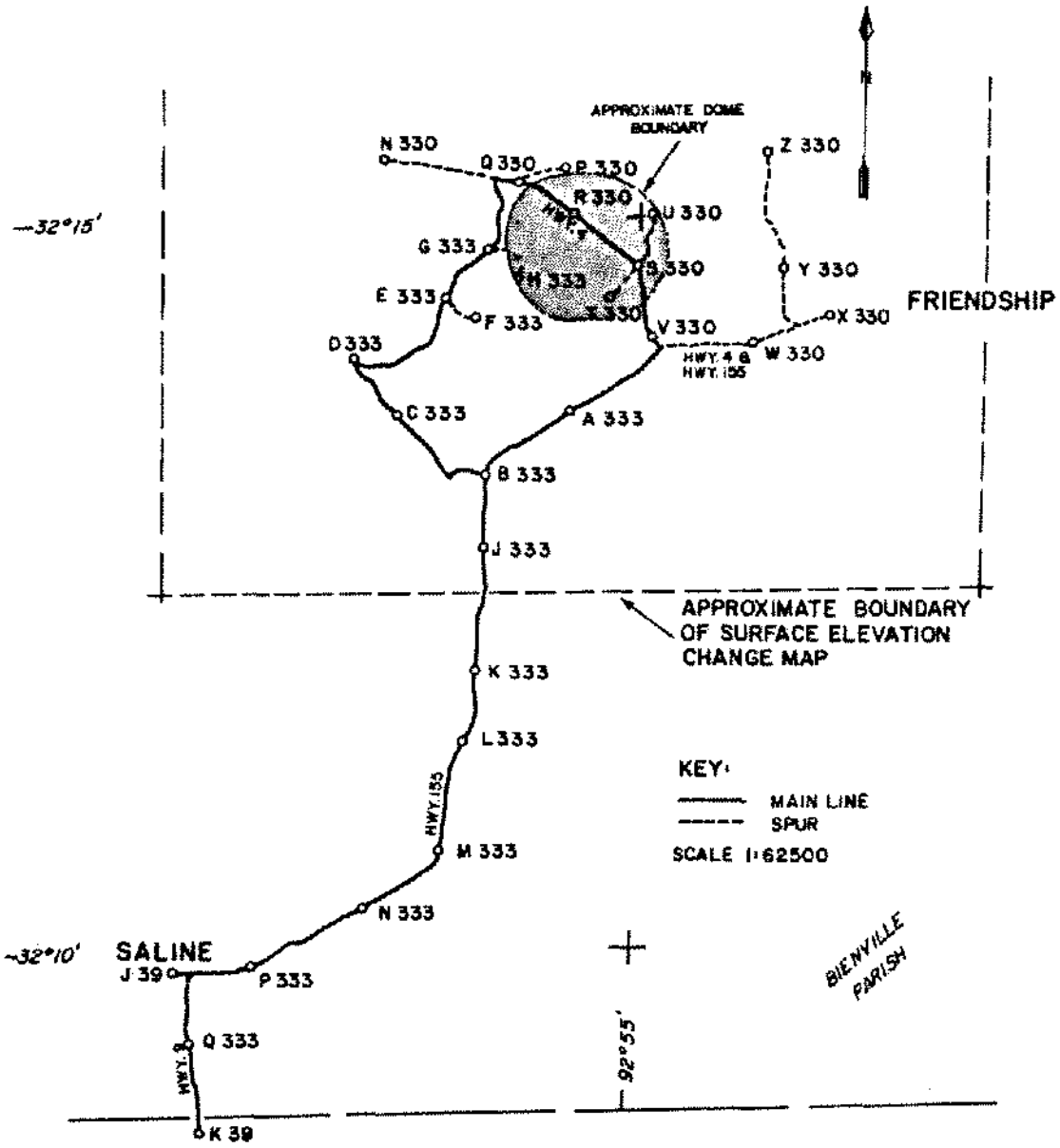

Figure 8. Network of leveling monuments over Rayburn's dome.

occured; however, more data would be required over a longer time period before this downward movement could be attributed clearly to salt dissolution effects.

SUMMARY AND CONCLUSIONS

Near surface vertical ground movements over two essentially undisturbed salt domes in north Louisiana were strongly influenced by seasonal meteorological events and site specific geology. Amounts of rainfall and levels of water tables appeared to dominate among short-term seasonal effects that caused naturally occuring vertical movements monitored with leveling networks. Coupled rainfall and surface geological effects were sufficiently large to obscure any possible long-term trends of movement within the relatively short monitoring period of two to four years.

The upward movements monitored in this study ranged up to around 18-20 mm over two to four years for the domes and surrounding areas. However, the movements over Vacherie dome were localized and cyclic; and what appeared to be an upward subregional ground movement over and around the Rayburn's dome apparently was not related to the presence of the underlying salt stock. Observations and releveling surveys spanning decades probably would be necessary to detect any possible long-term trends

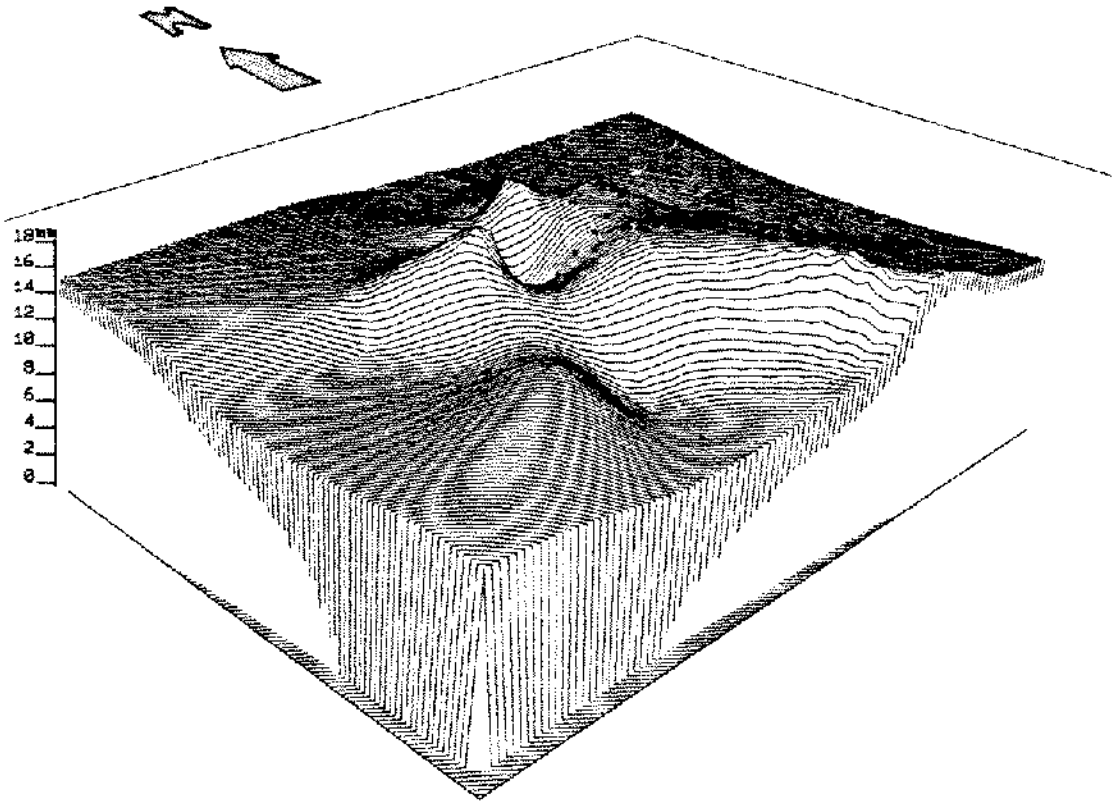

Figure 9. Surface elevation changes over Rayburn's. (January, 1979–June, 1977).

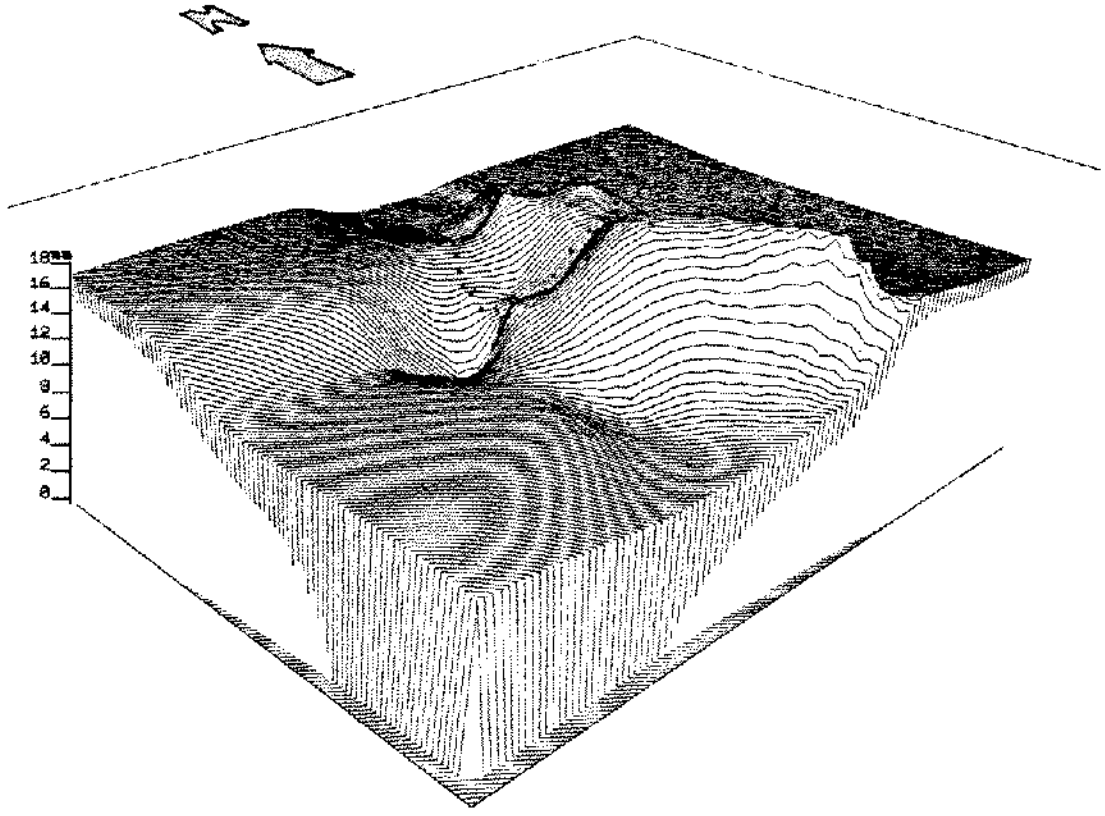

Figure 10. Surface elevation changes over Rayburn's. (August, 1979–June, 1977).

of ground movement over unmined salt domes in north Louisiana.

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