UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

DOCUMENTATION OF POTENTIAL FOR SURFACE FAULTING RELATED TO GROUND-WATER WITHDRAWAL IN LAS VEGAS VALLEY, NEVADA

By

Thomas L. Holzer

Open-File Report 78-79

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature.

January 1978

TABLE OF CONTENTS

CONCLUSION

Leveling data collected in Las Vegas Valley are compatible with the interpretation that ongoing land-surface displacements related to ground-water withdrawal may be precursory to fault offset of the land surface. Zones of potential faulting intersect regions of intense urban development. The degree of risk and the potential economic consequences from possible surface faulting cannot be assessed adequately without additional data and analysis of the relation between surface faulting and ground-water withdrawal.

Introduction

A relation between aseismic (nonearthquake) surface faulting and ground-water withdrawal from alluvial basins has been suggested or implied by many investigators. Examples of such faulting occur in California (Church and others, 1974; Holzer, 1977; Rogers, 1967) and Mexico (G. E. Figueroa Vega, oral commun., 1977). In addition to surface faulting in alluvial basins, some faulting in the Texas Gulf Coast has been attributed to ground-water withdrawal (Kreitler, 1977; Van Siclen, 1967). The principal evidence cited in support of such a relation is the temporal and areal association of such faulting with ground-water withdrawal. This association, of course, does not preclude the possibility that faulting caused by tectonic stresses has occurred contemporaneously with ground-water withdrawal in the areas cited. However, Holzer, Davis, and Lofgren (1977, and unpub. data, 1977) have demonstrated that modern offset on the Picacho fault, a tectonic fault in south-central Arizona, was related to ground-water withdrawal. Their results and the other observations suggest that when water levels in faulted alluvial basins drop significantly, surface faulting may develop.

Leveling data collected near the Picacho fault were sufficient to infer the surficial displacements that preceded formation of the fault scarp (T. L. Holzer, S. N. Davis, and B. E. Lofgren, unpub. data, 1977). The principal basis for recognition of a potential for surface faulting in Las Vegas Valley is a similarity between the inferred displacements that were precursory to surface faulting in south-central Arizona and an interpretation of leveling data collected in Las Vegas Valley. This report documents this comparison and concludes that existing or continued decline of ground-water levels in Las Vegas Valley might induce surface faulting in certain urbanized parts of Las Vegas Valley.

The potential for damage to engineered structures in Las Vegas Valley from fault offset is significant. Damage would depend in part on the amount of fault offset. The height of the fault scarp investigated in Arizona is approximately 1.6 feet (0.5 meter). Heights of other modern scarps suspected to be related to ground-water pumping range from 0.5 foot (0.2 meter) to more than 2.3 feet (0.7 meter) (Holzer, 1977, and unpub. data). All these scarps have increased in height by slow creep rather than by sudden movement. If faulting related to ground-water withdrawal in Las Vegas Valley were to proceed by slow creeping movement, remedial measures for long-term maintenance of some engineered structures, such as highways and utilities might be economical and feasible. However, buildings could be gradually weakened to the point of collapse, gas lines could rupture, and lives could be endangered with little warning. Slow movement during the early stage of formation of the fault scarp can be confused with localized foundation settlement and recognition of the real problem might be delayed or obscured.

History of Land Subsidence and Ground Rupture in Las Vegas Valley

Land subsidence in Las Vegas Valley related to decline of ground-water levels has been documented by many investigators (Domenico and others, 1966; Harrill, 1976; Longwell, 1960; Malmberg, 1964; Mindling and Blume, 1974; Raphael, 1954). Water levels have locally declined more than 180 feet (55 meters) (Harrill, 1976). The maximum subsidence that can be documented by level surveys is 2.96 feet (0.90 meter). The magnitude of land subsidence has been increasing steadily since it was first documented with the 1940-41 releveling. The configuration of subsidence contours has changed with time in response to changes in the distribution of pumping centers and their associated water-level declines. A detailed interpretation of the historical evolution of the subsidence bowl is thwarted by the areal distribution of bench marks. Interpretations of subsidence before 1963 were based on two survey lines that crossed Las Vegas. The network was expanded in the Las Vegas area in 1963 and was resurveyed in 1972. Two interpretations of changes of elevation from 1963 to 1972 based on these surveys are shown in Figures 1 and 2. The maximum decline of water level during this period was approximately 100 feet (30 meters) (Harrill, 1976, fig. 13).

In the late 1950's and 1960's, several earth fissures or large tension cracks developed near two water-well fields in Las Vegas Valley (Domenico and others, 1964). Because of the proximity of the earth fissures to the well fields and the previous association of earth fissures with substantial water withdrawals in Arizona, the fissures in Las Vegas Valley were assumed to be related to ground-water pumping. Since these fissures developed, the number of fissures and size of the area affected by them have increased. The term earth fissure is used here to characterize ground rupture in which movement of adjacent blocks is perpendicular to the failure plane, typically resulting in a large open crack. This relative displacement distinguishes earth fissures from faults, which are ground ruptures in which movement of adjacent blocks is predominantly parallel to the zone of failure. In general, these two types of ground rupture occur separately, with few examples of transitions between them. Only one earth fissure in Las Vegas Valley, which formed in 1961, is reported to have had vertical offset (Johnson Drillers' Journal, 1962). Most fissures, after opening, appear to become inactive. Faults, by contrast, typically remain active over many years. Of possible relevance to Las Vegas Valley is the occurrence of earth fissures areally associated with the Picacho fault. In addition, an earth fissure with no vertical offset and coincident with a portion of the subsequent fault trace formed 12 years before faulting began. If faults and earth fissures associated with ground-water withdrawal are mechanically related, the increase in occurrence of earth fissures in Las Vegas since 1970 (R. Patt, oral commun., 1976) could be very significant with regard to potential for faulting there.

Summary of Pertinent Aspects of Faulting in South-Central Arizona

Holzer, Davis, and Lofgren (unpub. data) document modern fault offset ranging from less than 1 foot (0.3 meter) to more than 2 feet (0.6 meter) in Arizona related to ground-water withdrawal. The fault scarp presently is 9.5 miles (15.3 kilometers) long. The height of the scarp has been increasing since it began to develop in 1961 by slow creep. Results from precise level surveys across the fault indicate that a narrow zone of differential subsidence created a monoclinal flexure of the land surface before surface faulting occurred (Fig. 3). Over approximately a nine-year period, from 1952 to 1961, the flexure affected an area approximately 1000 feet (300 meters) wide and produced relief of more than 1.0 foot (0.32 meter). Reconstructions of topography based on bench marks established in 1964 demonstrate the presence of the flexure. They also show that growth of the fault scarp has been primarily by transformation of the flexure into surface rupture.

A preliminary interpretation based on recent (September 1977) exploratory drilling adjacent to the Picacho fault in Arizona indicates that the modern surface faulting coincides with a preexisting normal fault of tectonic origin. Modern offset is in the same sense as the prehistoric geologic offset. Depth to bedrock at the fault is approximately 1000 feet (300 meters). Prehistoric fault offset has caused the alluvium to be approximately 100 feet (30 meters) thicker on the downthrown side of the fault. In addition, neutron logs from the test holes indicate that the top of the zone of saturation is 110 feet (34 meters) deeper on the downthrown side of the fault than on the upthrown side. The test hole results, when combined with the analysis of geodetic data, indicate that local differential compaction across a preexisting fault has caused the modern surface faulting near Picacho.

Comparison of Las Vegas Valley with South-Central Arizona

Recognition of the potential for surface faulting in Las Vegas is principally based on the interpretation that localized zones of differential subsidence have formed across preexisting faults in a manner similar to the development of the zone that preceded the faulting in south-central Arizona. The evidence for localized differential subsidence in Las Vegas Valley is reviewed below, and the inferred analogy between the displacements preceding faulting in Arizona and the ongoing displacements in Las Vegas is described.

Interpretations of subsidence from 1963 to 1972, the period with the densest coverage of bench marks, by Harrill (1976) and Mindling and Blume (1974) are shown in Figures 1 and 2, respectively. Two narrow linear zones of differential subsidence were mapped -- a north-trending zone in the east part of T. 20 S., R. 61 E. (Fig. 1), and a north-northwest-trending zone in the east part of Tps. 20 and 21 S., R.60E., the western margin of the subsidence bowl (Fig. 1). In addition, three maxima of subsidence were mapped by Harrill (Fig. 1). The north-trending zone of differential subsidence in the east part of T. 20 S., R. 61 E. coincides with a geologic fault (Fig. 1), downthrown to the east, originally mapped by Maxey and Jameson (1948). Domenico, Stephenson, and Maxey (1964) identified more than 100 feet (30 meters) of fault offset of stratigraphic units across this fault. The interpretation of a relatively narrow zone of differential subsidence is credible because it is based on adequate leveling data. Projection of leveling data from bench marks on Bonanza Road and Lake Mead Boulevard (See Fig. 2 for location) into a single east-west profile (Fig. 4A) shows the zone of differential subsidence in T. 20 S., R. 61 E. mapped by Harrill (1976) and Mindling and Blume (1974), although the width of the zone of differential subsidence as shown in Figure 4A is seriously distorted by the offset in the profile. The decrease of subsidence from 1963 to 1972 between bench marks K169 and V170 (See Fig. 1 for location), which are on opposite sides of the geologic fault mapped by Maxey and Jameson (1948), is 0.819 foot (0.250 meter). It is important to note that the leveling data indicate a lowering of the ground surface west of the fault. Thus, differential surface movement is in an opposite sense relative to prehistoric fault movement. The zone of differential subsidence along the western boundary of the subsidence bowl is more conjectural because the leveling data are sparse. The principal evidence for a zone of localized differential subsidence is based on releveling of bench marks on Charleston Boulevard, the north boundary of T. 21 S., R. 60 E. (Fig. 1). A zone of localized differential subsidence in the profile based on these bench marks is coincident with a geologic fault, downthrown to the east, mapped by Maxey and Jameson (1948) (Fig. 4B). In this case subsidence of the surface and prehistoric fault movement both resulted in downward surface movement east of the fault. The three maxima of subsidence interpreted by Harrill (Fig. 1) are associated with pumping centers and presumably are related principally to localized maxima in water-level declines.

The interpretation that a zone of differential subsidence resulting in a narrow monoclinal flexure preceded surface faulting in Arizona is based on surveys of bench marks spaced much more closely than bench marks in Las Vegas Valley. Results based on leveling of comparably spaced bench marks from both Las Vegas Valley and Arizona, however, can be compared. In Figure 4 the two profiles of subsidence from Las Vegas Valley (Figs. 4A and 4B) are compared to a profile from Arizona (Fig. 4C). The profile from Arizona is based on leveling data collected during the period when the pre-fault flexure developed. Subsidence before 1963 along the two profiles from Las Vegas Valley cannot be directly evaluated because most of the bench marks on which the profiles are based were established in 1963. The history of development of the zone of differential subsidence shown in Figure 4A, however, can be inferred by use of other bench marks and compared with the history of the differential subsidence associated with the fault in Arizona. Figure 5 shows the history of the subsidence of bench marks L169 and K169 relative to bench marks Q315 and Z314, respectively, near the downtown area of Las Vegas (See Fig. 1 for location). Bench mark L169 is 10,300 feet (3140 meters) from Q315, and bench mark K169 is 8,000 feet (2,440 meters) from Z314. The pairs of bench marks presumably were established after the differential subsidence had already begun. Both pairs of bench marks span the geologic fault mapped by Maxey and Jameson (1948) (Fig. 5, map insert). Differential subsidence of bench mark K169 relative to Z314 in excess of 2 feet (0.6 meter) has been observed over 23 years. Figure 6 is a record of the differential subsidence from 1948 to 1977 of bench mark F279 relative to G279, two bench marks that are 7,090 feet (2,160 meters) apart and on opposite sides of the modern fault in Arizona. Subsidence in the vicinity of the fault before 1948 was negligible (T. L. Holzer, S. N. Davis, and B. E. Lofgren, unpub. data, 1977). The fault scarp began to develop in 1961 after bench mark F279 had subsided approximately 1.0 foot (0.3 meter) relative to bench mark G279 over 9 to 13 years. Modern displacement is down on the northwest side of the fault, consistent with preexisting displacement.

Discussion

Results from Arizona indicate that differential subsidence over a narrow zone can be precursory to surface faulting caused by ground-water withdrawal. In most field situations, including Las Vegas Valley, the distribution of bench marks is inadequate to delineate such zones clearly and to distinguish them from broad zones of differential subsidence. Several aspects of the field situation in Las Vegas Valley, however, indicate that monitoring of surface displacements in at least one area is needed. First, the distribution of bench marks in this area, the north-trending zone of differential subsidence in T. 20 S., R. 61 E., is adequate to support an interpretation that differential subsidence may be occurring over a relatively narrow zone. The magnitude of the differential subsidence is comparable to and may exceed that which occurred in Arizona, although the width of the zone cannot be precisely determined with existing bench marks. Second, the zone of differential subsidence in T. 20 S., R. 61 E. in Las Vegas coincides with a geologic fault, as did the zone of differential subsidence that preceded surface faulting in Arizona. And third, the zone of potential surface faulting cuts through a heavily urbanized area so that a significant impact on existing engineered structures is likely if faulting were to occur.

In addition to this specific concern, the general experience with faulted alluvial basins undergoing substantial water-level declines is pertinent. As noted in the introduction, observations in these basins indicate that there is a potential for surface faulting related to ground-water development. Because Las Vegas Valley is cut by several faults, monitoring of surface displacements near these faults is needed if the potential for surface faulting in Las Vegas is to be evaluated.

REFERENCES CITED

Church, J. P., Castle, R. O., Clark, M. M., and Morton, D. M., 1974, Continuing crustal deformation in the western Mojave Desert: Geol. Soc. America Abs. with Programs, v. 6, no. 7, p. 687-688.

Domenico, P. A., Mifflin, M. D., and Mindling, A. D., 1966, Geologic controls on land subsidence in Las Vegas Valley: Eng. Geol. and Soils Eng. Symp., 4th, Moscow, Idaho, Proc. p. 113-212.

Domenico, P. A., Stephenson, D. A., and Maxey, G. B., 1964, Ground water in Las Vegas Valley: Nevada Univ., Desert Research Inst., Tech. Rept. No. 7, p. 1-53.

Harrill, J. R., 1976, Pumping and ground-water storage depletion in Las Vegas Valley, Nevada, 1955-74: Nevada Water Resources Bull. 44, 70 p.

Holzer, T. L., 1977, Ground failure in areas of subsidence due to ground-water decline in the United States: Internat. Assoc. Hydrological Sciences land subsidence symposium, 2nd Anaheim, Calif., 1976, Proc. (Pub. no. 121), p. 423-433.

Holzer, T. L., Davis, S. N., and Lofgren, B. E., 1977, Active surface faulting caused by ground-water extraction near Picacho, Arizona: Geol. Soc. America Abs. with Programs, v. 9, no. 4, p. 437.

Johnson Drillers' Journal, 1962, Land subsidence in Las Vegas: November-December, 1962, p. 5-6.

Kreitler, C. W., 1977, Fault control of subsidence, Houston, Texas: Ground Water, v. 15, no. 3, p. 203-214.

Longwell, C. R., 1960, Interpretation of the leveling data, in Smith, W. O., Vetter, C. P., Cummings, G. B., and others, 1960, Comprehensive survey of sedimentation in Lake Mead, 1948-49: U.S. Geol. Survey Prof. Paper 295, p. 33-38.

Malmberg, G. T., 1964, Land subsidence in Las Vegas, Nevada, 1935-63: Nevada Dept. Conserv. and Natl. Resources, Ground Water Resources - Inf. Ser. Rept. 5, 10 p.

Maxey, G. B., and Jameson, C. H., 1948, Geology and water resources of Las Vegas, Pahrump, and Indian Spring Valleys, Clark and Nye Counties, Nevada: Nevada Water Resources Bull. 5, 121 p.

Mindling, A. L., and John A. Blume and Associates, 1974, Effects of ground-water withdrawal on I-15 Freeway and vicinity in North Las Vegas: Center for Water Resources Research, Desert Research Inst., Project Rept. no. 33, 37 p.

Raphael, J. M., 1954, Crustal disturbances in the Lake Mead area: U.S. Bur. Reclamation, Eng. Mon. no. 21, 14 p.

Rogers, T. H., 1967, Active extensional faulting north of Hollister near the Calaveras fault zone: Seismol. Soc. America Bull., v. 57, no. 4, p. 813-816.

Van Siclen, D. C., 1967, The Houston fault problem: Am. Inst. Prof. Geologists, Ann. Mtg., Texas Sec., Dallas, 1967, 3rd, Proc., p. 9-31.

ILLUSTRATIONS

Figure 6. Differential subsidence of bench mark F279 relative to G279 in Arizona. Fault scarp began to develop in 1961. Map insert shows locations of bench marks and trace of modern fault scarp. Fault is approximately parallel to lines of equal subsidence.

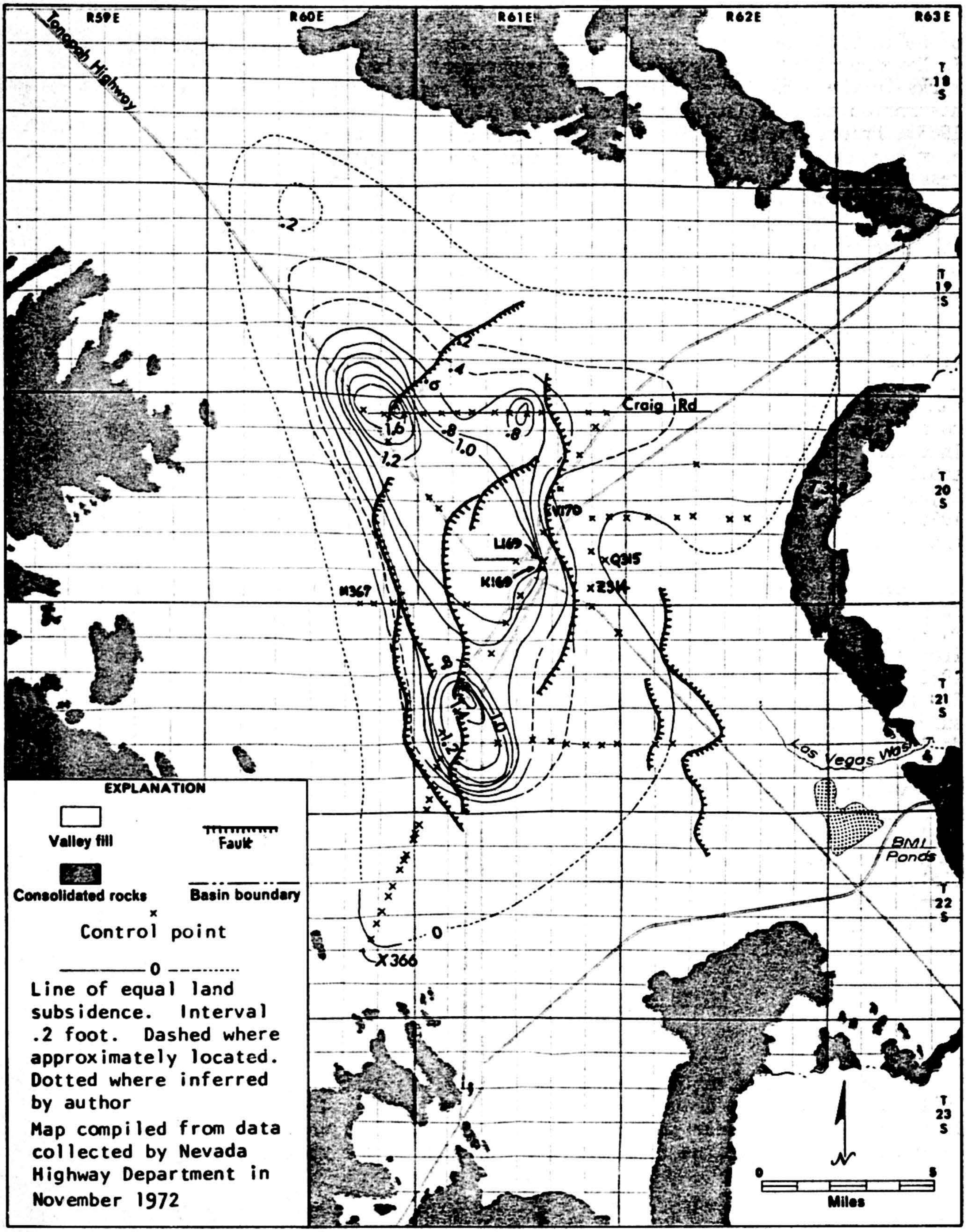


Figure 1.--Approximate land subsidence, 1963-72. (From Harrill, 1976)

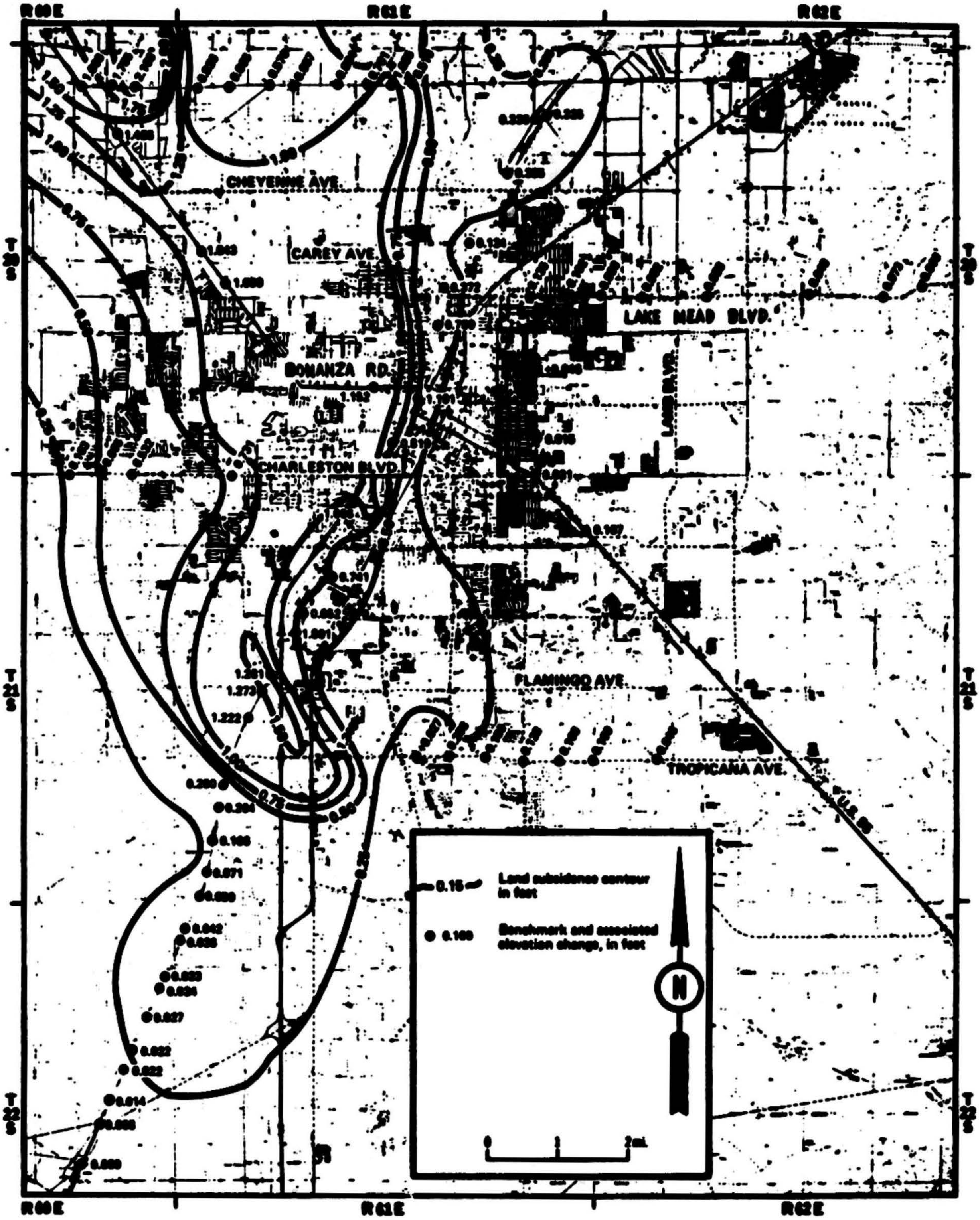
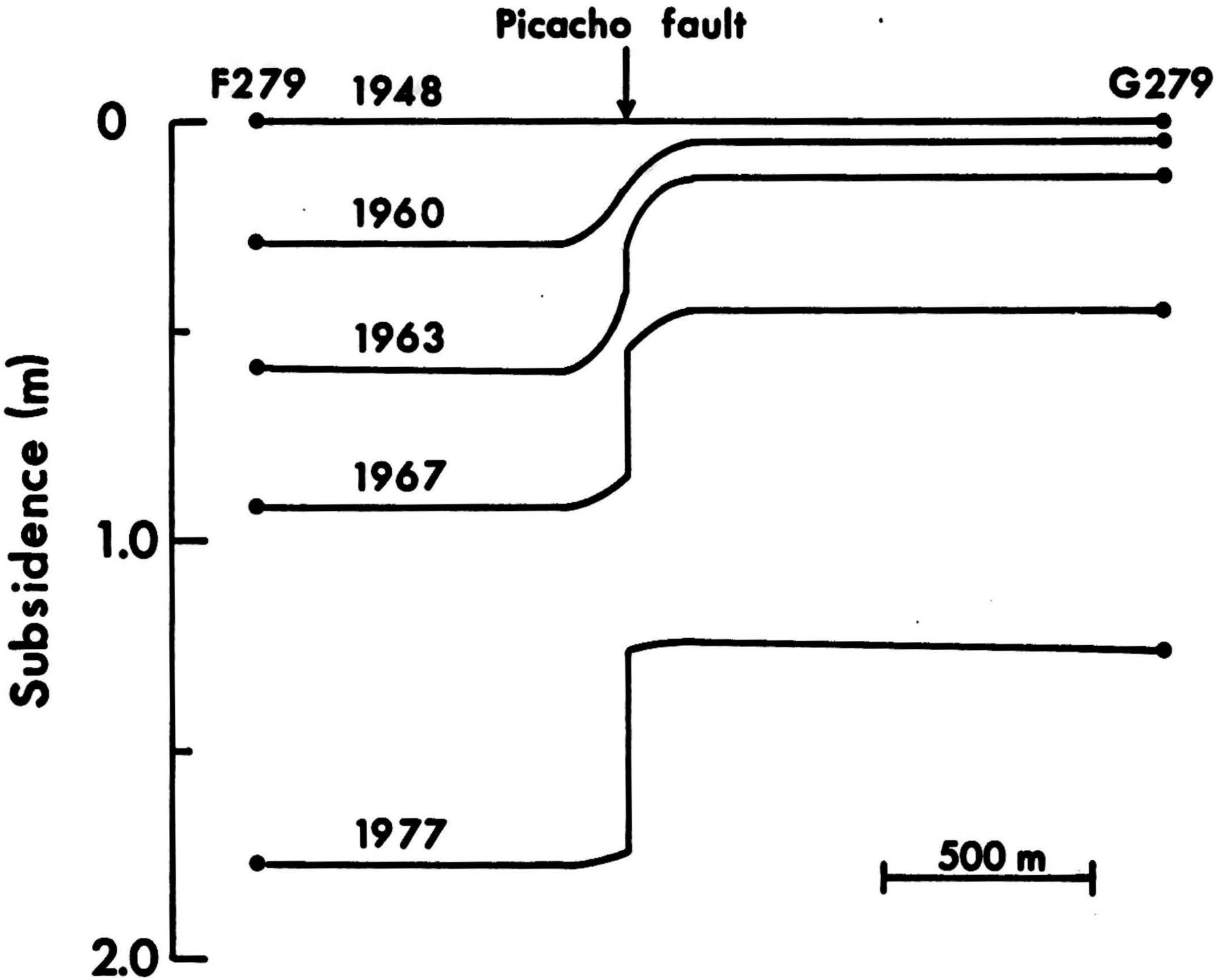


FIGURE 2. Land subsidence in feet in Las Vegas Valley between 1963 and 1972. (From Mindling and Blume, 1974)



Picacho fault
F279
1948
G279
0
1960
1963
1967
1.0
1977
500 m
2.0
Subsidence (m)

Figure 3

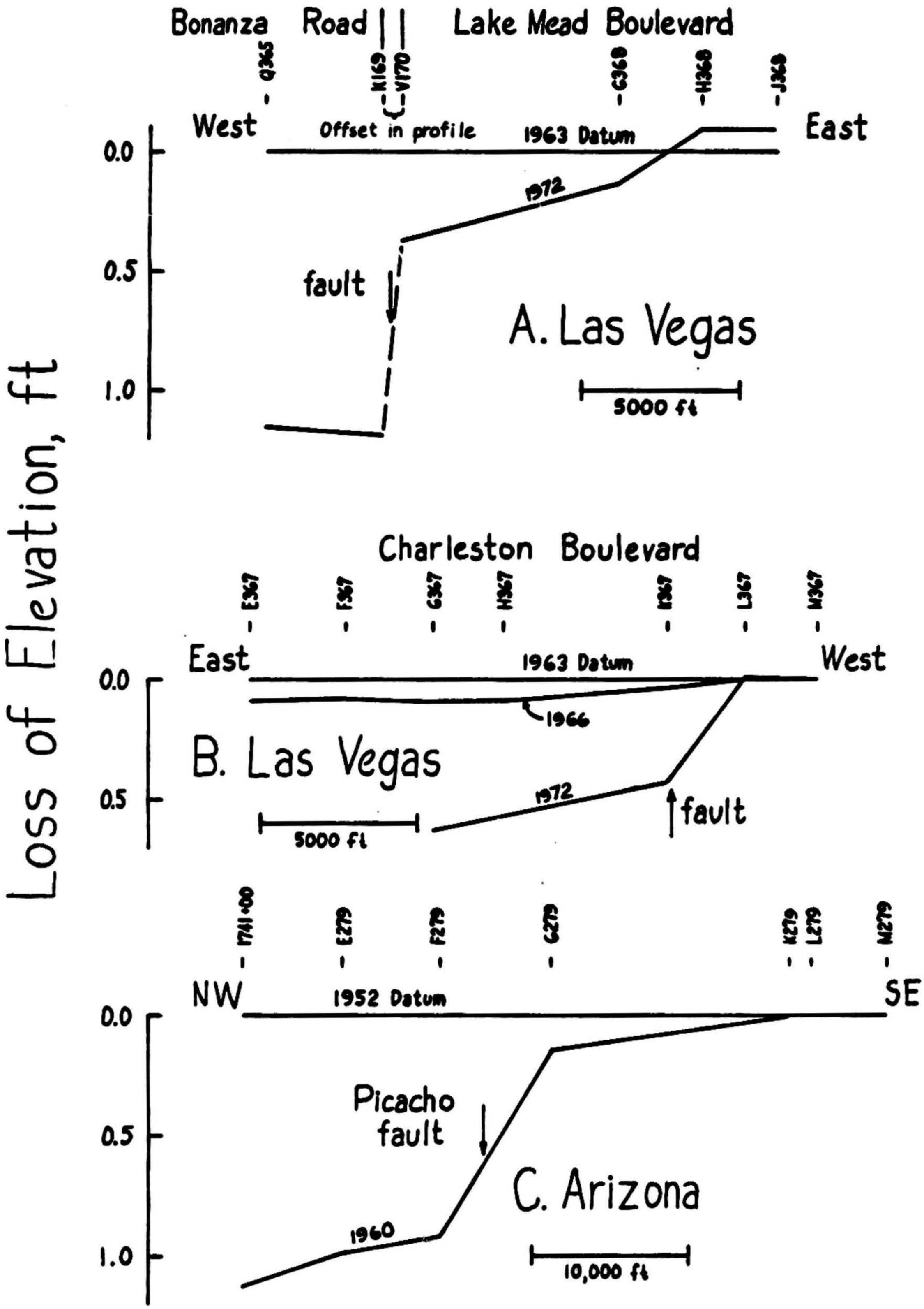

Loss of Elevation, ft
Bonanza Road
Lake Mead Boulevard
Q365
K169
V170
G368
H368
J368
West
Offset in profile
1963 Datum
East
0.0
0.5
1.0
1972
fault
A. Las Vegas
5000 ft
Charleston Boulevard
E367
F367
G367
H367
K367
L367
M367
East
1963 Datum
West
1966
B. Las Vegas
1972
fault
5000 ft
1741+00
E279
F279
G279
K279
L279
M279
NW
1952 Datum
SE
Picacho fault
C. Arizona
1960
10,000 ft

Figure 4

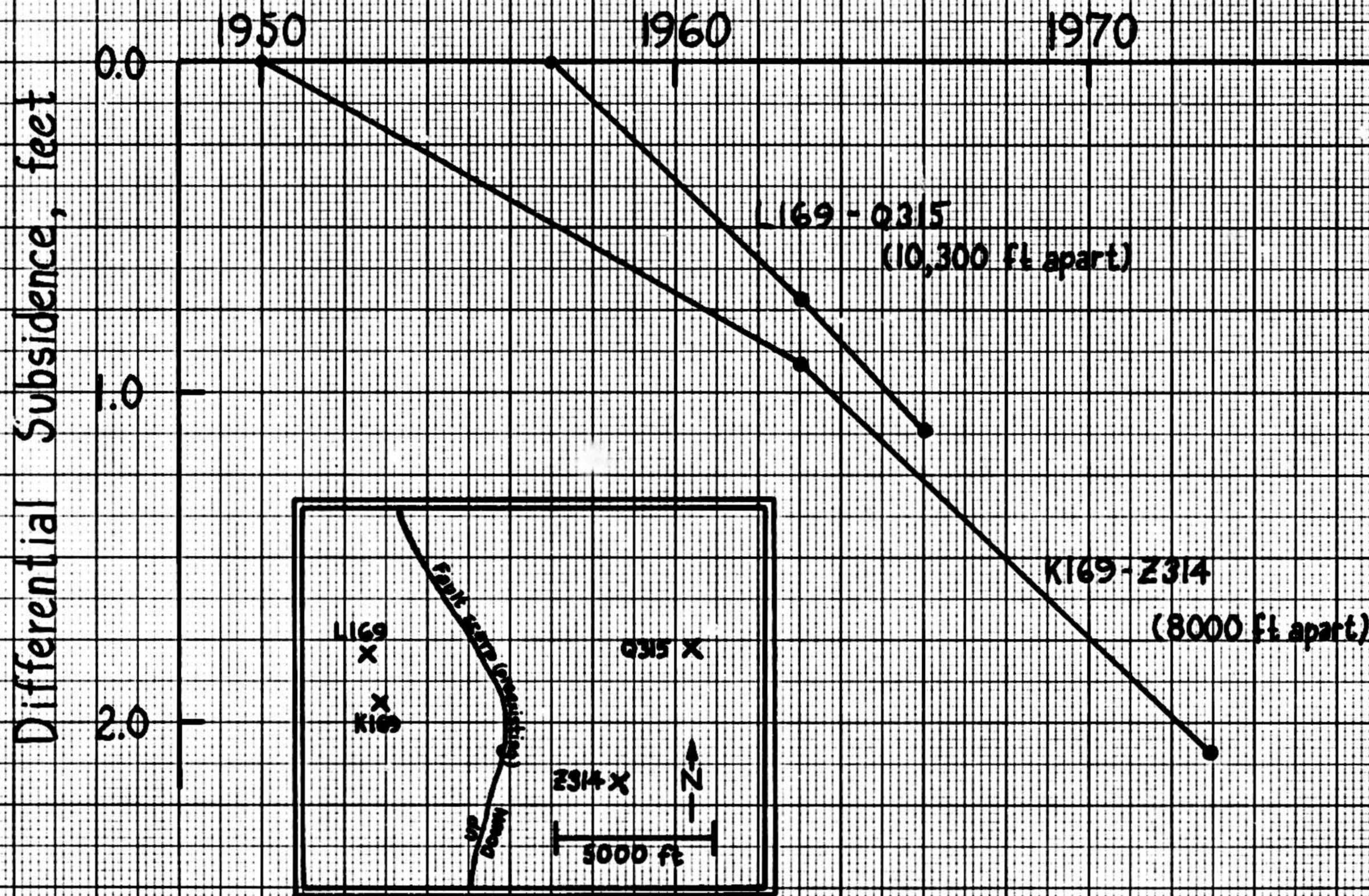

1950
1960
1970
0.0
1.0
2.0
Differential Subsidence, feet
L169 - Q315
(10,300 ft apart)
K169 - Z314
(8000 ft apart)
L169
K169
Q315
Z314
N
Up
Down
5000 ft

Figure 5

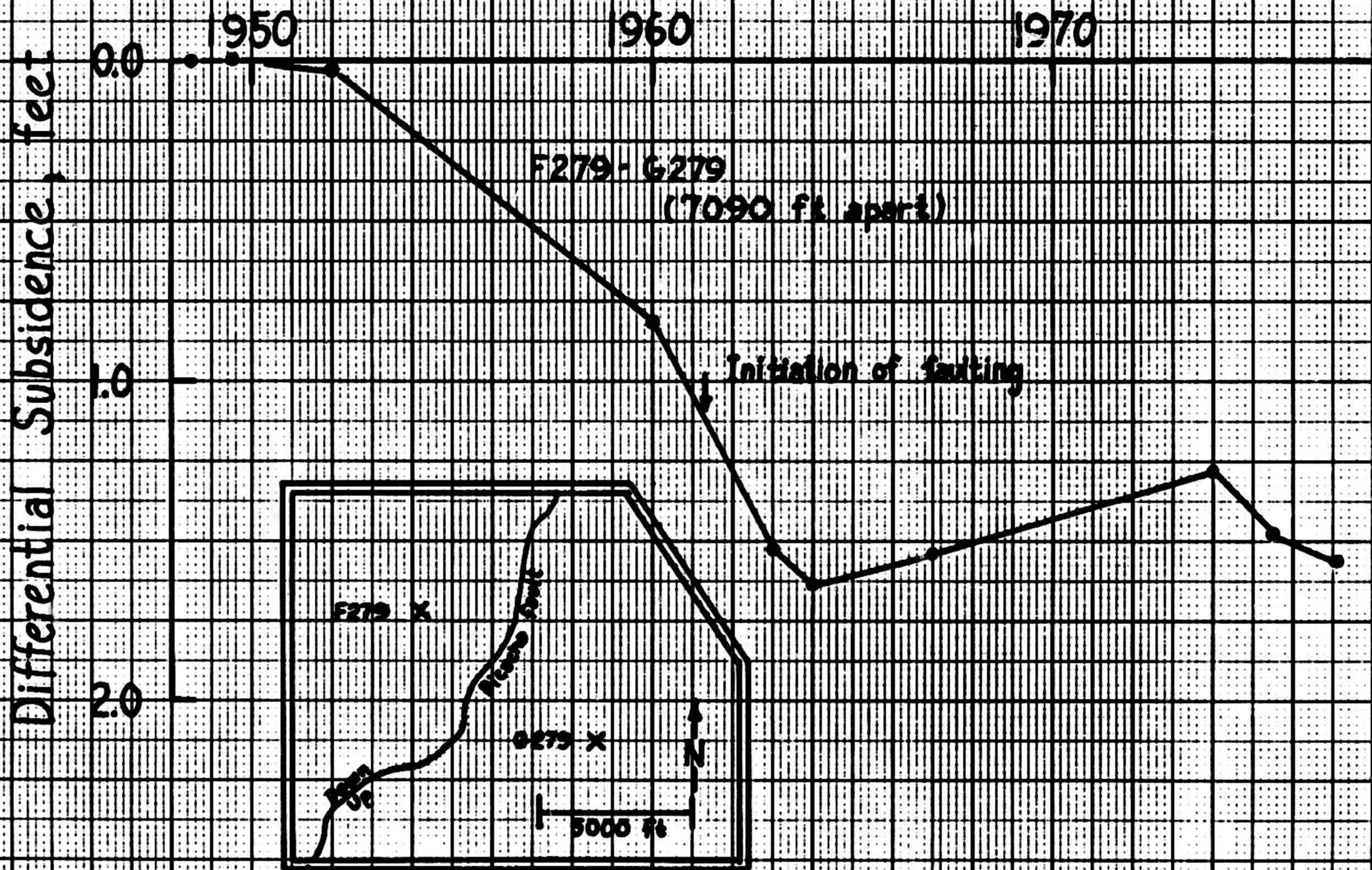

1950
1960
1970
0.0
1.0
2.0
Differential Subsidence, feet
F279 - G279
(7090 ft apart)
Initiation of faulting
F279
G279
N
5000 ft

Figure 6