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PRELIMINARY REPORT ON RECENT SURFACE MOVEMENTS THROUGH JULY 1962 IN THE BALDWIN HILLS, LOS ANGELES COUNTY, CALIFORNIA

Staff, Geological Survey

January 1964

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

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PRELIMINARY REPORT ON RECENT SURFACE MOVEMENTS

THROUGH JULY 1962 IN THE BALDWIN HILLS,

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INTRODUCTION

The Baldwin Hills are located in the western part of the Los Angeles basin (figure 1) near the northern end of the Newport-Inglewood uplift or fault zone, a major structural feature which is the locus for several highly productive oil fields. The hills are a slightly dissected physiographic high, rising about 400 feet above the surrounding alluvial plain and are roughly severed in two by the Inglewood fault, the dominant structural feature of the area (see plate 4).

Parts of the Baldwin Hills, in common with other areas in the Los Angeles basin, have undergone measurable elevation changes in the past two or three decades. Up to 1939, elevation changes of +0.03 foot per year (relative to a bench mark at the Los Angeles County Courthouse) were recorded for a point immediately south of the Baldwin Hills (Grant and Sheppard, p. 302, 319-322). In recent years surface movements, locally manifesting themselves as actual ruptures, have been observed within parts of the Baldwin Hills, and several local governmental agencies have made closely spaced geodetic surveys in order to more closely measure both the vertical and horizontal movements.

This preliminary report summarizes some of the information available to the middle of 1962 on the character and extent of surface movements in parts of the Baldwin Hills, particularly the north-central area. These data were obtained as supplemental information during the Survey's investigation of the surface geology of the Baldwin Hills area (Castle, 1960).

Acknowledgements

The generous assistance of the several agencies and many individuals that have contributed to the preparation of this report is gratefully acknowledged. Particular thanks are extended to the Department of Water and Power, City of Los Angeles, and to Mr. H. B. Hemborg, Principal Engineer of the Water Engineering Design Division, for permission to incorporate the results of precise leveling surveys carried out under the supervision of Stephen A. Hayes and Francis J. Walley. Appreciation also is extended to Robert R. Wilson of the Department of Water and Power for the contribution of background geologic data. Compilation of precise leveling data and measurements of horizontal movement undertaken by the Department of County Engineer, County of Los Angeles, have been under the direction of Ira H. Alexander. Douglas R. Brown, formerly Supervising Civil Engineer, Department of County Engineer, has helped in the preparation of the report through contribution of information on local surface cracking. Professor Clearence R. Allen of the California Institute of Technology has contributed data on local seismicity.

GEOLOGIC AND SEISMOLOGIC FEATURES OF

BALDWIN HILLS AREA

The surface geology of the Baldwin Hills area was mapped in detail in 1958 and 1959 at a scale of 1:12,000 (Castle, 1960). The oldest sedimentary rock exposed in the area is Pliocene-Pleistocene(?) in age and consists mainly of poorly consolidated marine silt and very fine sand with local lenses of coarser sand and pebbly material. Locally clay-rich, particularly along the northwest flank of the Baldwin Hills, the entire sequence is commonly thinly laminated and well bedded with dips as steep as 35° but averaging considerably less. Unconformably overlying this unit is a dominantly marine sequence of unconsolidated coarse- to medium-grained sand that is commonly pebbly or cobbly. This material of Pleistocene age is relatively flat-lying, but dips as high as 12° have been recorded. Unconformably overlying the older units are Recent alluvium and flood-plain deposits consisting mainly of unconsolidated silts, sands, and gravels of nonmarine origin.

The stratigraphic section underlying the Baldwin Hills comprises Quaternary and Tertiary sedimentary rocks and Tertiary volcanic rocks that in turn rest upon a metamorphic basement complex at a depth probably in excess of 12,000 feet (McCulloh, 1957). Deformation resulting in folding and faulting of the Cenozoic rocks may have begun as far back in Tertiary time as middle Miocene (Reed and Hollister, 1936, p. 131) and geologic evidence indicates it has continued through much of Quaternary time. The very youthful dissection of the hills and locally close correspondence of stratigraphic and physiographic surfaces is geomorphic evidence of the recency of this deformation.

The pattern of faulting and jointing at the surface in the north-central Baldwin Hills, the area with which this report is most concerned, is shown in figure 2. The faults and joints dip steeply and have a prevalent strike of north-northwest or north-northeast, except toward the northern edge of figure 2 where the effects of a possibly major fault system may begin to influence the structure.

The subsurface pattern of faulting in the north-central Baldwin Hills is shown in the structure contour maps on figure 3 (Driver, 1943, p. 307) and 4 (California Division of Oil and Gas, 1961). The only major differences between these two summary interpretations occur in the southeast portion of the map area where the subsurface data from recent developments in this part of the Inglewood oil field aided in the interpretation. There are some differences, however, between the subsurface fault interpretations and the pattern of faulting mapped at the surface. Some of the discrepancies may be only apparent, attributable simply to inclination of the fault surfaces and to generalizing the structure at depth. In figures 3 and 4, the Inglewood fault is shown as a relatively straight feature, whereas surface mapping suggests far more structural complexity in the vicinity of the La Brea Avenue-Stocker Street-Overhill Drive intersection than has been shown on either of the subsurface maps.

All the faults shown in figure 2 have been active during Quaternary time. Displacements along several of the major faults, such as the Inglewood fault, may have been substantial, whereas displacements along the northeast-trending faults that offset the Inglewood fault may have been no more than a few feet. It has been suggested (Driver, 1943, p. 308; Hill, 1954, p. 10) that considerable lateral displacement occurs along the Inglewood fault and along the Newport-Inglewood fault zone. Driver has noted that the direction of striae in many drill cores indicates a larger component of horizontal than vertical movement, and Hill has deduced major right-lateral movement along the Newport-Inglewood zone from electric log correlations. Quaternary right-lateral movement of about 2,000 feet is suggested vaguely by the relative topographic offset of the hills on either side of the Inglewood fault as shown in the left foreground of plate 4. This same physiographic feature might have resulted from a complicated series of dip slip movements. Positive evidence of recent lateral displacement has not yet been found. Along the Inglewood fault, for example, where it is reflected locally by a scarp about 200 feet high, there is no suggestion of offset in the stream channels or fan deposits that go across the surface trace of the faults.

Local seismicity

The distribution of earthquake epicenters in the western and central parts of the Los Angeles Basin from January 1, 1934 to June 30, 1962 is shown on plate 1. However, what may have been the largest earthquake to have taken place in the vicinity of the Baldwin Hills in historical time occurred on June 21, 1920 (Taber, 1920). According to Taber (1920, p. 135) this earthquake had an intensity of "about eight and one-half in the Rossi-Forel scale," and an investigation of its intensity distribution showed "that the origin was located a short distance west of Inglewood, possibly not more than a mile" (Taber, p. 137). Kew (1923, p. 158) concluded on the basis of subsequent geologic studies that the earthquake of 1920 was caused by movement along a major fault lying about a mile to the east of the center of the city of Inglewood and en echelon with the Inglewood fault (see figure 2). Kew's conclusion, however, does not require that the earthquake epicenter necessarily lay along the surface trace of this fault, for according to Willis and Ballantyne (1943, p. 313) this particular fault (now known as the Potrero fault) probably dips steeply to the west.

The major concentration of epicenters in the vicinity of the Baldwin Hills is to the southwest, east and southeast (plate 1). Within the north-central section of the Baldwin Hills, however, there is recorded for this period only one epicenter; this earthquake is reported to have had magnitude of between 1 and 1.90.

RECENT EARTH MOVEMENTS

Regional elevation changes

There have been several attempts to describe the pattern of regional vertical movement over large sections of the Los Angeles Basin. Grant and Sheppard (1939), working with very limited data, were able to define several broad areas of relative subsidence and at least one zone of positive movement. According to these writers (p. 302) there are broad subsiding areas directly north and directly east of the Baldwin Hills. The only area of relative positive movement noted by Grant and Sheppard was detected along a more or less east-west level circuit immediately south of the Baldwin Hills. The trend of this zone of relative positive movement was not ascertained by Grant and Sheppard. Subsequent precise leveling investigations, described in an unpublished 1943 report by Hayes (Los Angeles Department of Water and Power, 1962, oral communication), however, showed that the points of maximum positive movement along two level circuits in the southern Baldwin Hills area lay along an approximately north-south line (but about one-half mile east of the point referred to by Grant and Sheppard). Although the above information is inconclusive, it suggests that there may exist a regional axis of positive movement roughly parallel or subparallel with the Newport-Inglewood fault zone.

Stone (1961, p. 58) recently has evaluated elevation changes from repeated surveys "for more than 9,000 stations leveled over the past 25 years by the Los Angeles City Engineer." The results of Stone's studies indicate that in general the areas "within late Quaternary sedimentary basins are subsiding, while some foothill stations are rising." He has concluded, moreover, that "even minor features of local geology affect the rates of movement."

Surface movements in the north-central Baldwin Hills

Movements revealed through direct observation

A series of major earth cracks began to develop in the north-central Baldwin Hills at least as early as 1957. These cracks are expressed as simple ruptures or displacements of the ground surface along more or less straight lines, and insofar as is now known they have never occurred as open fissures. The only actual open fissures associated with the cracks occur in asphaltic pavements (see figures 5 and 6) or other artificial structures where they appear to have resulted from stretching as a secondary effect of vertical displacement.

Some cracking may have begun as early as 1955, but this possibility has not been documented. In May of 1957, Professor F. C. Converse (1961, oral communication), a consulting foundation engineer, examined Crack I (figure 2) in a large compacted fill on the east side of Stocker Street. Within about a week he found that the crack extended southward through a school yard (see figure 5) and eventually the crack, with local discontinuity, was traced a total distance of about a half mile. In 1958 Cracks II, III, and IV, shown on figure 2, were observed and located during precise leveling surveys carried out by the Los Angeles Department of Water and Power (1960, oral communication). Between 1958 and the middle of 1962, movement continued along all the cracks with the possible exception of Crack IV, but there has been little apparent linear extension of the cracks beyond their limits of 1958. Crack V, which has been traced for only a few tens of feet, is the only new rupture known to have been formed in this part of the Baldwin Hills between 1958 and the middle of 1962. Cracks III and IV may be continuous with each other, but there is a gap of 200 to 300 feet between them.

Field measurements have shown that the cracks are nearly vertical and that the movement along them is essentially dip slip. Where cracks have cut white lines painted on paved surfaces, there has been no discernible lateral displacement of these lines. The relative movement along the individual cracks is shown on figure 2. The land surface between Cracks I and IV (figure 2) has been depressed forming a small graben-like structure bounded by these cracks. Insofar as is now known, there has been no obvious reversal in the sense of movement along any of the cracks through their history of growth.

There apparently has been some variation in the rate of movement along the cracks from the time they were first observed through the middle of 1962. For example, measurements in the school yard along Crack I between October and December, 1957 indicated that movement was proceeding at a rate of about 0.10 foot per month, whereas movement during the following 33 month period from December 1957 to October 1960 totalled about 3 inches (D. R. Brown, 1962, oral communication). According to an unpublished report by Walley (Los Angeles Department of Water and Power, 1963, oral communication), the cracked section on Overhill Drive was resurfaced in early 1959 and since then the displacement along Crack I has been less than one inch. Another example of variation in rate of movement is shown by Crack IV where it crosses a section of La Brea Avenue which was resurfaced in 1959. There was no apparent disruption of the pavement along this stretch of Crack IV from 1959 through the middle of 1962.(Discernible cracking had resumed by 1963, however.) Characteristics of the movement on Crack II are shown in figure 6, a photograph taken in a parking lot in January 1961. Within a few months after resurfacing the lot, movement was again observed on Crack II.

Maximum vertical displacement on the five known cracks has occurred along Cracks I and II. According to one report, up to 4 inches of "cracking" had been observed in the school yard athwart Crack I by November 1957 (D. R. Brown, 1962, oral communication). Since November 1957, vertical movement on Crack I has exceeded 2 inches; therefore, the maximum displacement through July, 1962, may have been as much as 6 inches. The total movement on Crack II through January 1961 was about 4 inches, and by the middle of 1962 the total displacement amounted to a minimum of 5 inches. The displacement has resulted in disruption of pavement and foundations (see figures 5 through 7).

There is no direct evidence of the depths to which crack displacement extends below the ground surface, but several features of the cracks strongly imply displacements to depths of more than a few feet or even tens of feet. First might be mentioned the long linear extent of Cracks I and IV. Second is the considerable local relief of the terrain crossed by Crack I, which can be traced along the ground surface through a difference of elevation of about 75 feet between Overhill Drive and Stocker Street. Third is the apparent constancy in the sense, even if not the amount, of displacement along the trace of a given crack.

The geologic setting of the cracks is shown in part in figure 2, which brings out the striking degree of parallelism between the cracks and faults and joints in their vicinity. There is no apparent correlation, however, between lithology and location or character of the cracks. Crack I, for example, can be traced through sediments representing the majority of the stratigraphic units exposed at the surface in the Baldwin Hills, including sands, silts, gravels, and artificial fill.

Movements revealed by precise leveling and triangulation surveys

Few precise elevations were established in the Baldwin Hills area prior to 1930, and little is known of changes in elevation of the land surface that may have occurred before this time. In particular, there is no way of knowing with certainty what sort of measurable elevation changes, if any, this area was undergoing prior to discovery of the Inglewood oil field. Through analysis of the results of a 1917 topographic survey and recent precise leveling data described in an unpublished 1943 report, S. A. Hayes (Los Angeles Department of Water and Power, 1962, oral communication) computed changes in elevation (relative to a Los Angeles City datum used prior to 1925) for eight points in the central Baldwin Hills for the period 1917 to October 1943. Hayes found that of the eight points, the maximum elevation change, about -4.2 feet, was found at a point about 800 feet east of Department of Water and Power precise bench mark (PBM) 122. PBM 122 is about 2,000 feet north-northwest of the La Cienega Boulevard-Stocker Street intersection, and approximately coincident with the area of maximum subsidence as shown by Department of Water and Power surveys conducted since 1950. Continuing measurements by the Department of Water and Power (1961 and 1963, oral communications) indicate that PBM 122 underwent elevation changes (relative to bench mark Hollywood E-11) of about -1.73 feet between 1950 and 1958, and about -0.57 feet between 1958 and 1962. The relative average rate of movement of PBM 122 from 1950-58 was about -0.20 foot per year and by using this rate for the period October 1943 to 1950, the computed subsidence for PBM 122 between 1943 and 1962 is seen to be about 3.6 feet. It is interpreted from this information that total relative subsidence of PBM 122 between 1917 and 1962 was around 8 feet.

Information on the surface movement in the Baldwin Hills area recently has been summarized by the Los Angeles Department of County Engineer. A synoptic representation of these data as of June 1961 is given in figure 8, to which has been added the location of Cracks numbers I through IV. According to the Department of County Engineer, the point of maximum annual subsidence established in this compilation is about 300 feet west of the area shown on figure 8. On figure 8, the annual rate of vertical movement, shown by the isobase lines, is based on averaged values for individual survey stations in which the periods of observation vary from station to station. Thus, whether or not the particular point used in constructing the isobase lines shown on figure 8 is represented as experiencing rapid movement may be a function in part of the period of observation of the precise leveling. Furthermore, data compiled for individual stations reveal cases of apparent (though generally minor) reversals of movement during the total observation period so that even sense of movement locally might prove a function of the selected observation period. Nevertheless, the combination of points of long observation with those of short observation is such that figure 8 probably represents the general character of vertical movement as of the date of compilation.

The relative horizontal movement of BM Baldwin Aux. is shown on figure 8 and is based on a 1961 retriangulation of this point, relative to its position determined by a 1934 Cooperative Control survey of the metropolitan Los Angeles area (Alexander, 1962, p. 2469). Other horizontal movement vectors shown on figure 8 were determined from secondary triangulation related to the 1961 position of Baldwin Aux. A fourth vector has been determined for a point (not shown on figure 8) about 7,000 feet N. 52° W. from Baldwin Aux. Horizontal movement at this point is 0.95 foot S. 7° W. (Alexander, p. 2473).

In 1939 the Department of Water and Power of the City of Los Angeles began the establishment of an extensive series of precise level circuits in the Baldwin Hills. The results of these precise leveling surveys have been described in a series of unpublished Department of Water and Power reports by S. A. Hayes, dated 1943, 1947, 1951, 1955, and 1959, and by F. J. Walley, dated 1963. Since 1939, the precise leveling surveys of the Department of Water and Power have been rerun more or less quadrennially, and the density of stations has been increased steadily so that even localized changes in elevation now may be detected. The area shown on figures 8 through 13 is determined by the extent of the detailed precise leveling survey carried out in 1950 by the Department of Water and Power.

Elevation changes detected in the course of the Department of Water and Power level surveys have been determined from a bench mark near the northern edge of the hills known as "Hollywood E-11," which in 1946 was given the permanently assigned elevation of 470.304 feet. In 1953, Hollywood E-11 was destroyed (Hayes, 1955) but prior to its destruction, bench mark FBM 40-C, 33.5 feet from Hollywood E-11, was established as a fixed elevation reference bench mark. Because the elevation of Hollywood E-11 relative to FBM 40-C is assumed to have remained unchanged since 1953, Hollywood E-11 has been retained as the reference bench mark in this report even though it has been abandoned as the reference point in the Department of Water and Power reports beginning in 1963. During each series of level circuits, Hollywood E-11 has been tied to bench marks outside the immediate area through reobservation of points along a control circuit designated as "level circuit C" by the Department of Water and Power (see plates 2 and 3). Level circuit C was abandoned as a control circuit during the 1962 surveys owing to the destruction of many bench marks along its route; however, points common to both level circuit C and level circuit E, as shown in the 1963 report by Walley, have been plotted on plate 3 in order to illustrate the general trend of movement along level circuit C since 1958. The southern reference bench mark (PBM-1) along level circuit C (plate 2) is at the intersection of Centinela Avenue and Market Street, Inglewood, and the northern reference bench mark is approximately four and one-half miles north of PBM-1 at the intersection of Washington Boulevard and Vineyard Avenue (PBM-58) in Los Angeles.

The relative elevation changes along level circuit C are based on the assumption that PBM-1 has not changed elevation (see plate 3). That the two end points are relatively stable with respect to each other is suggested by traverses completed in 1946 and 1950. The subsidence troughs shown on plate 3 contain some minor irregularities that resulted in part at least from local backward legs in the line of circuit (e.g., precise bench marks 29, 30, 31).

The approximate pattern of average annual elevation change in the north-central Baldwin Hills for the period 1950-54, as compiled by the Department of Water and Power, is shown on figure 9. According to Hayes' report of 1955 (1962, oral communication) the elevations of 174 precise bench marks had been established in the northern Baldwin Hills by 1950, chiefly within the area of figure 9. The 1950-54 period consequently became the first in which the density of stations was considered high enough to contour the relative movement over the area shown. It is apparent that for the 1950-54 interval the general pattern of movement, relative to Hollywood E-11, was negative and more or less concentrically disposed around a point near the western edge of the map. The isobase pattern, moreover, is elongated somewhat along a northwest-southeast line roughly paralleling the axis of the Inglewood oil field structural dome.

The approximate pattern of average annual elevation change in the north-central Baldwin Hills for the period 1954-58, compiled by the Department of Water and Power, is shown on figure 10. By 1954, according to Hayes' report of 1955 (1962, oral communication), elevations had been recorded for 361 precise bench marks in the northern Baldwin Hills. As a result of increase in number of control points, the accuracy of the isobase lines shown on figure 10 is greater than those on figure 9. The gross pattern of movement is much the same.

The major difference in the movement patterns shown on figures 9 and 10 for the periods 1950-54 and 1954-58, respectively, is near the Stocker Street-La Brea Avenue-Overhill Drive intersection. comparison of the survey data shows that in this area the isobase gradient increased sharply after 1954. Although the graben-like structures defined by Cracks I and IV is crudely reflected by the isobase pattern on figure 10, this relation cannot be clearly established without additional information. A minor difference in the isobase patterns between figures 9 and 10 is shown in the wedge-shaped area east of Stocker Street and Overhill Drive where during the period 1954-58 parts of this wedge-shaped area began to experience relative positive movement at an average rate of up to +0.02 foot per year.

Toward the end of 1960 when it had become apparent that movement along some of the major earth cracks was continuing, the Department of Water and Power ran an interim series of precise level circuits in the area of cracking. Figures 11 and 12 present two interpretations of the pattern of average annual elevation change for the period 1958-60 based on the results of these interim surveys. Figures 11 and 12 differ between themselves only in the area extending north-northeast from the La Brea Avenue-Stocker Street-Overhill Drive intersection; figure 12 shows a trough defined by more or less parallel isobases of negative movement whereas figure 11 shows a much more irregular configuration. However, figures 11 and 12 differ significantly from figure 10 in the same area. Figure 10 shows decreasing subsidence toward the north-northeast, whereas in figures 12 and 11, subsidence is represented as being more uniform or perhaps increasing respectively to the north along a zone crudely defined by a northward extension of Cracks I and IV. It must be stressed, however, that this indicated difference between figure 10 and figures 11 and 12 does not necessarily imply a change in the movement pattern between the two survey periods. Interpolation of isobase lines between widely separated control points is a subjective process, and prior to 1958 very few precise elevations had been recorded northeast of the La Brea Avenue-Stocker Street intersection. A relationship of possible significance that shows up on figure 12 and, to a lesser extent, on figure 11, is that a sharp break in the rate of vertical movement parallels Crack IV, but this break is displaced 150 to 200 feet east rather than being coincident with the crack. This anomaly may be a reflection of abatement of movement along Crack IV and the eastward shift of more pronounced subsidence. The evidence is inconclusive, but broken pavement and sagging curbs noted in the fall of 1961 suggest incipient cracking along a zone approximately 150 feet east of the northern reaches of Crack IV.

The approximate pattern of average annual elevation change in the north-central Baldwin Hills as compiled by the Department of Water and Power for the period 1958-62 is shownnon figure 13. According to Hayes' report of 1959 (1962, oral communication), the elevations of 643 precise bench marks had been recorded in the northern Baldwin Hills by the end of 1958, and an additional group of stations was set northeast of the Stocker Street-La Brea Avenue intersection at the beginning of 1961 (Department of Water and Power, 1961, oral communication). In compiling the map on figure 13, points representing a relatively short observation period (1961-62) have been mixed with those of the standard four-year observation period for the area east of La Brea Avenue; there is no reason to believe that this departure from the procedure used in compiling figures 9 through 12 has altered in any significant way the results presented on figure 13. The most conspicuous difference between the isobase patterns represented on figure 13 and those shown on figures 9 and 10 is the sharp reduction in the rate of subsidence. A second difference is expressed as an apparent reduction in the rate of relative positive movement, as contrasted with that for the 1954-58 period, in the block east of Stocker Street and Overhill Drive from +0.02 feet per year during 1954 to 1958, to +0.01 feet per year during 1958 to 1962.

CAUSE OF GROUND SURFACE MOVEMENTS

Subsidence is the dominant type of ground movement within the area considered in this report. The cause or causes of the subsidence, together with the other types of surface movements, remain unknown but they may be very complex. In their study of subsidence in the Long Beach Harbor area, Gilluly and Grant (1949, p. 488) considered four general mechanisms that might have induced subsidence in that area. The four suggested mechanisms consist of the following:

(1) changes in reservoir pressure due to oil operations

(2) changes in ground water conditions

(3) compaction of sedimentary materials

(4) tectonic movements

Because surface movements in the Baldwin Hills area are in part analogous to those in the Long Beach Harbor area, each of these possible causes is briefly considered below.

(1) Oil field operations are considered by Gilluly and Grant (1949, p. 463, 501), Grant (1954, p. 19), and Plumlee (1961) to have caused subsidence in the Long Beach Harbor area. This conclusion, however, was reached after a long, detailed

study of the subsurface geology, history of subsidence, and history of production. There appears to be some correspondence between the center of subsidence in the Baldwin Hills area and the approximate center of the Inglewood oil field and the "mean" center of the producing structure (see plate 4 and figures 3, 4, 8, 9, 10, and 13); any possible relationship between oil field operations and subsidence, however, probably cannot be firmly established without a prolonged, careful study of the production history and its relation in time and space to earth movements throughout the Baldwin Hills and adjacent areas. A lack of quantitative data presently precludes any conclusion regarding the relationship between oil field operations and subsidence. Inasmuch as the possible relationship between subsidence and oil field operations cannot be firmly established, it is almost impossible to attempt to relate any of the other surface movements to oil field operations, for if they are in any measure attributable to oil field operations it is probably in connection with the subsidence.

(2) Changes in ground water regimen may have contributed to local subsidence in the Los Angeles Basin (Gilluly and Grant, 1949, p. 494-497). In the Inglewood area, the maximum lowering of the static water level between 1930 and 1946 was about 60 feet (Poland et al, 1959, pl. 13 and 14).

The amount of subsidence in this area is thought to have been slight and perhaps within the limits of error of the precise leveling surveys. Moreover, the near surface geologic formations in the Baldwin Hills area are largely non water-bearing (Poland et al, 1959, pl. 9, 11, 12). However, the incompleteness of available data indicates further study of the ground water conditions in the Baldwin Hills is needed before conclusions can be made regarding earth movement and changes in ground water conditions in the Baldwin Hills.

(3) Compaction of sedimentary rocks is a continuous process attributable to loss of water and increased loading at the surface by the addition of new materials. No evidence has been found within the north-central Baldwin Hills that suggests such processes caused the surface movements described on the preceding pages.

(4) Southern California is a tectonically active area. Although tectonic activity may be involved in different ways in the surface movements of the northern Baldwin Hills area, the evidence is obscure and difficult to establish. Cracks I through V display a pattern that seems to conform with that of many of the joints and faults in the immediate area; it is not improbable, therefore, that the fractures along which these major earth cracks occur were established by tectonic activity. However, this in itself in no way

demonstrates that the most recent movement along these fractures (as indicated in figures 5 and 6) is necessarily attributable to tectonism. Considerable additional study will be necessary to determine any possible relation between earth movement in this area and local and regional tectonic activity.

RECOMMENDATIONS FOR FUTURE INVESTIGATIONS

Any effort to learn more about the character and cause of the ground surface movements in the Baldwin Hills necessarily will involve continuation and some expansion of the precise leveling and triangulation surveys now under way. Needed in particular are many more measurements of horizontal movement and more frequent measurements of vertical movement in the area within and around the zone of cracking. In addition, information on subsurface movements might be obtained and related to surface movements through a study of any oil or gas wells that may have been displaced.

Because the area of subsidence in part coincides with the Inglewood oil field, a rigorous investigation of production data, and pressure decline, should be made and these data correlated with the surface subsidence. Particularly important is the rate of subsidence as related to the rate of total withdrawal of fluids in the oil field.

An effort should be made to learn more about the character and rates of strain along the major earth cracks. Ideally, continually recording strain gauges might be installed across the cracks. Alternatively, frequent measurements (employing conventional surveying methods) of both horizontal and vertical movement might be made between paired points arranged on opposite sides along the cracks. An even simpler but less informative procedure might employ some simple strain gauge device for regular, direct measurements between paired points across the cracks; the only parameter measurable by this technique, of course, is simple extension. Without more precise information than is currently available on the strain rate along these cracks, the establishment of any possible connection between movement and seismicity (whether tectonically induced or not) will remain almost impossible. Better knowledge of the strain rate, moreover, would help to show whether the movement has been of the creep type, or whether instead it has occurred as a series of very small but discrete jumps.

Some effort should be made to measure the regional tectonic strain pattern in order to determine that portion of the surface movements possibly attributable to tectonism. This might be done through utilization of the already established Cooperative Control triangulation network. Alternatively, it might be implemented through special surveys specifically designed to measure any dilatation or contraction that might occur along the more probable axes of shortening and elongation in this part of the Los Angeles basin.

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Plate 4. Oblique air photograph of the Baldwin Hills looking south-southeast. (A) Trace of the Inglewood fault; (B) Stocker Street-LaBrea Avenue-Overhill Drive intersection; (C) Physiographic high in the Baldwin Hills; (D) Approximate position of point on ground directly above structural high east of the Inglewood fault on surface 50 feet above Vickers-Machado zone (the Inglewood fault dips westward here); (E) Approximate position of point on ground directly above structural high west of the Inglewood fault on surface 50 feet above Vickers-Machado zone; (F) Approximate location of reference bench mark Hollywood E-11; (G) Approximate center of subsidence in the Baldwin Hills area as shown by Department of Water and Power precise leveling surveys conducted since 1950. Photograph taken November 1952 by Spence Air Photos.


F
C
A
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D
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Fig. 1

Figure 1.--Index map of the Los Angeles basin showing location of the Baldwin Hills area and several major structural features.

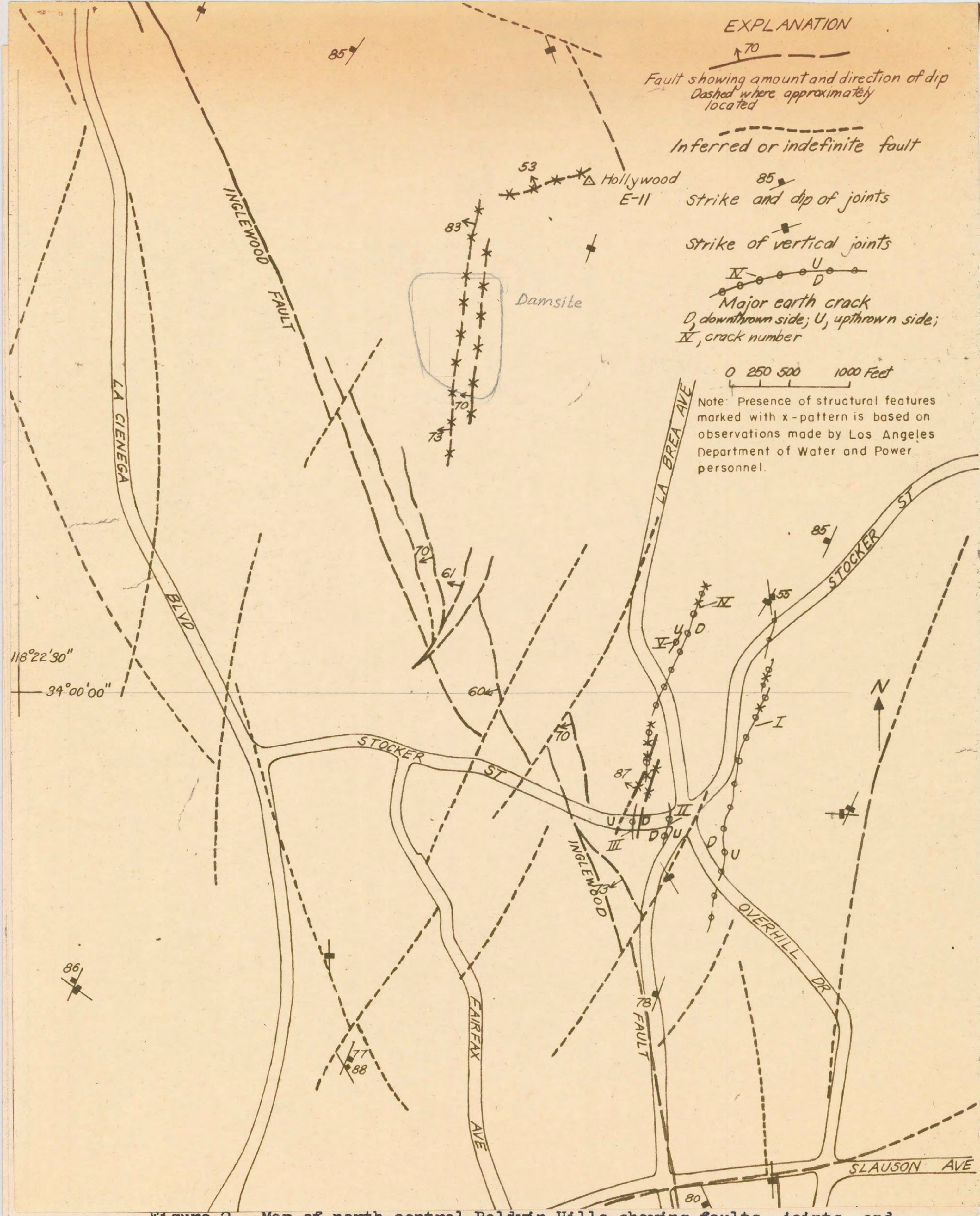

Figure 2.--Map of north-central Baldwin Hills showing faults, joints, and major surface cracks as of July 1962.

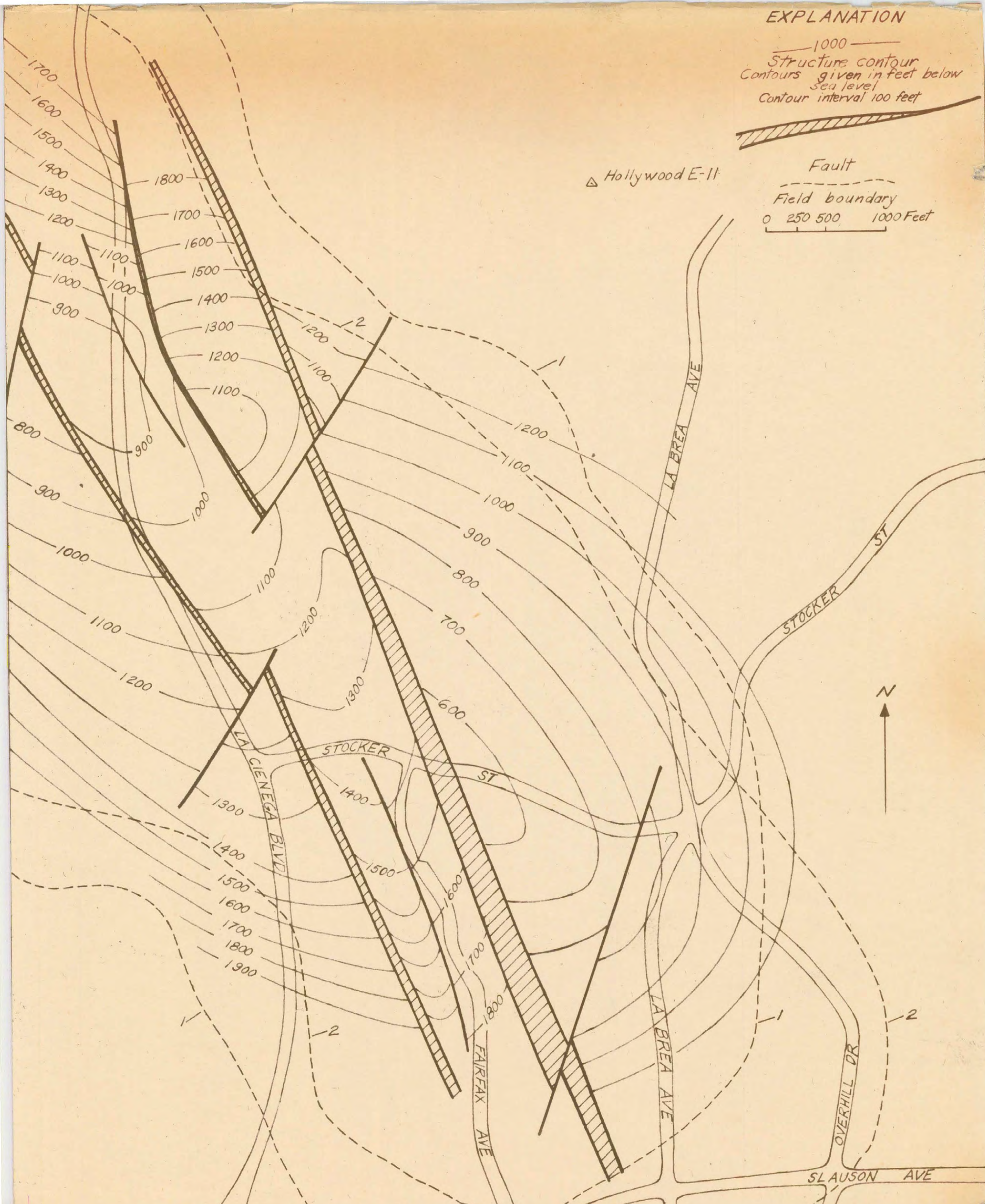

Figure 3.--Structure contour map on top(?) of Gyroidina zone, north-central Baldwin Hills.

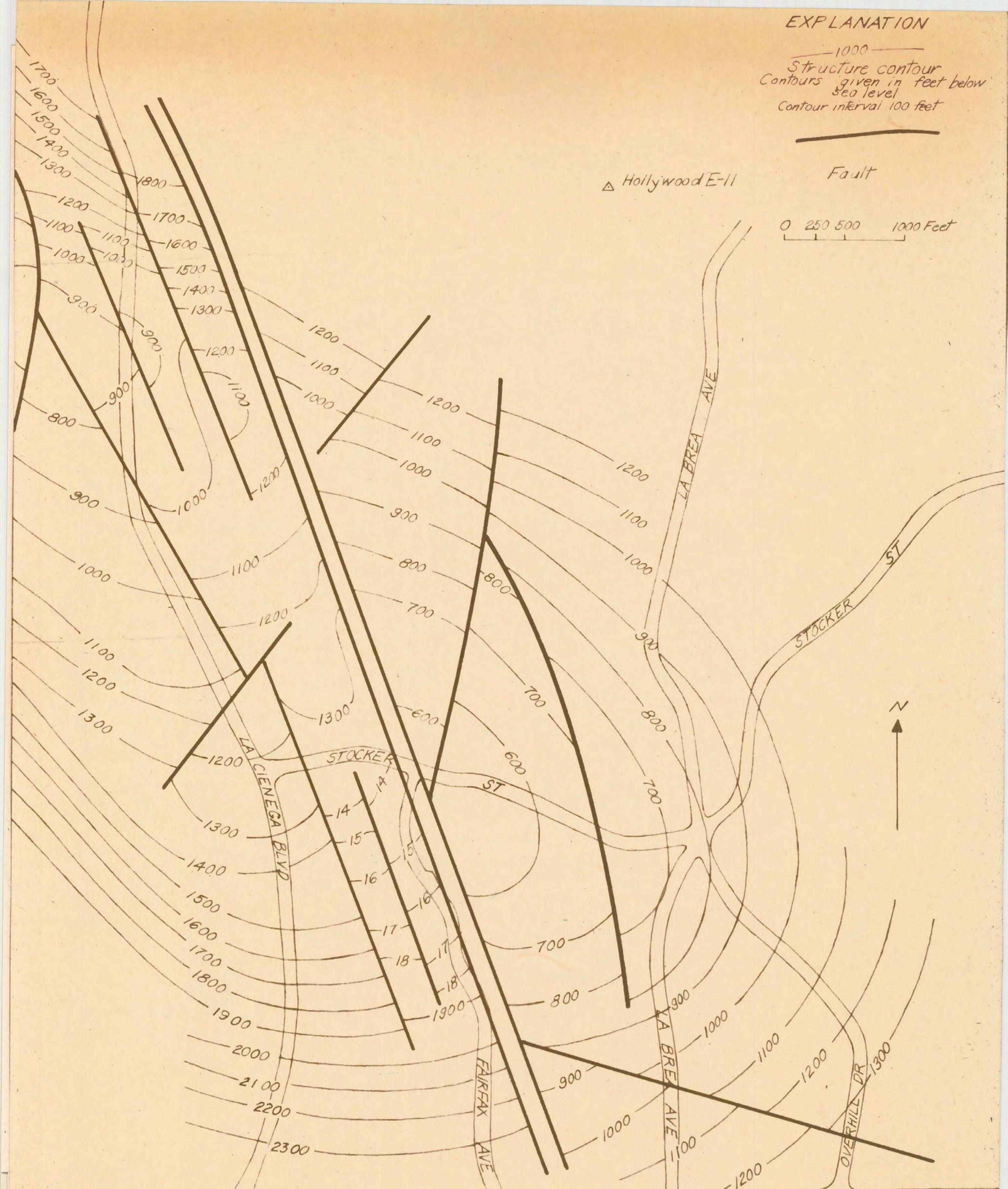

Figure 4.--Structure contour map on surface 50 feet above Vickers-Machado zone, north-central Baldwin Hills.

Figure 5.--Photograph showing extensive, locally broken, patching along major earth Crack I where it passes through school yard north of Overhill Drive.

Figure 6.--Close-up photograph of major earth Crack II.

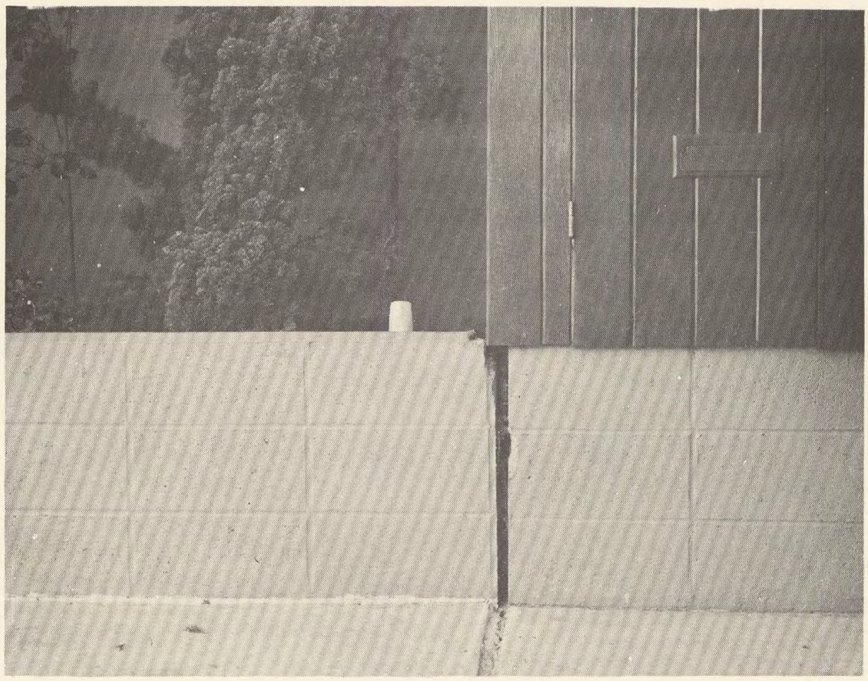

Figure 7.--Photograph of damaged residential foundation lying athwart major earth Crack I.

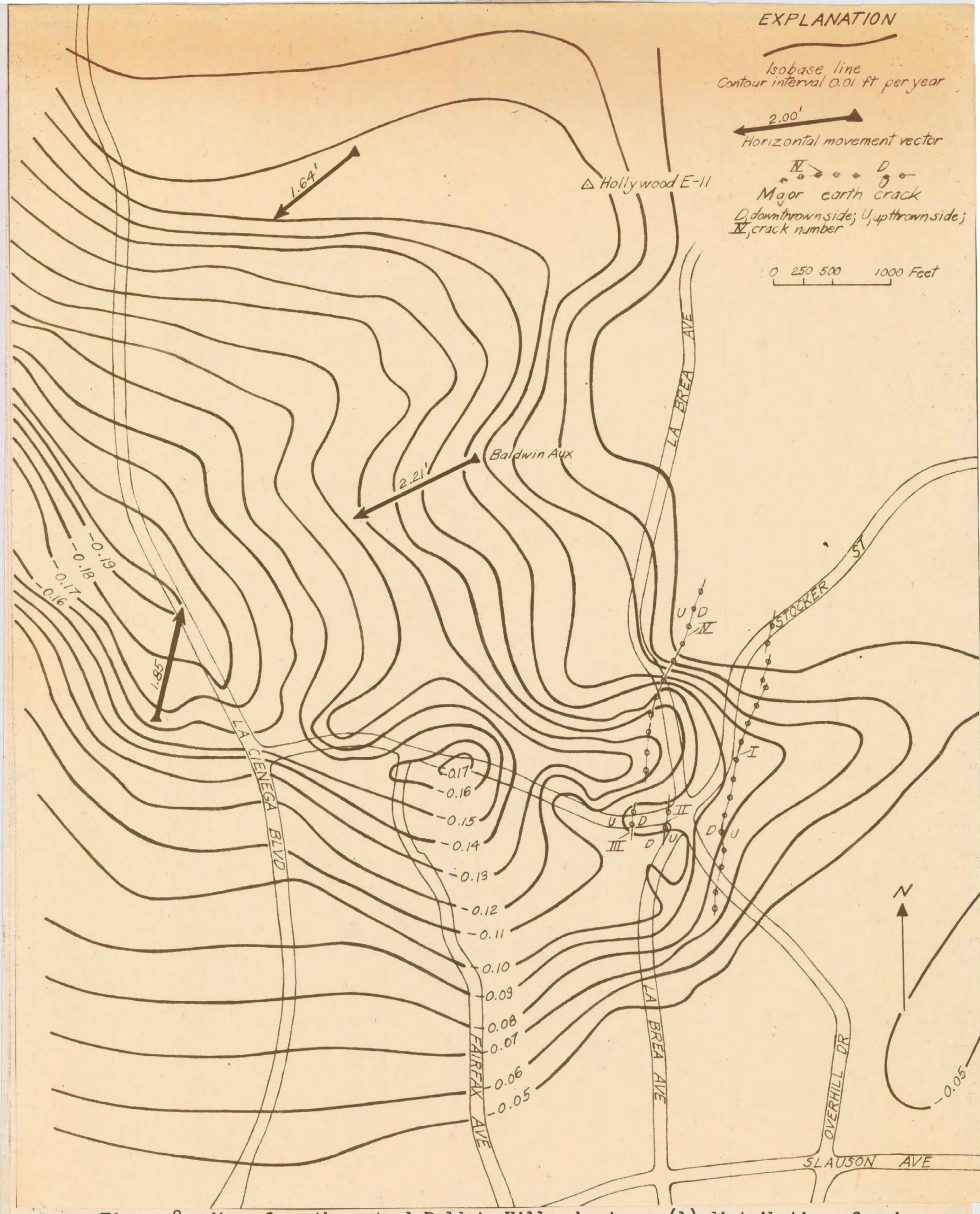

Figure 8.--Map of north-central Baldwin Hills showing: (1) distribution of major surface cracks as of June 1961, (2) approximate pattern of average annual elevation change relative to U.S.C. & G.S. bench mark Tidal 8-1929 San Pedro as of June 1961, (3) horizontal movements relative to base line east of the Baldwin Hills for period 1934 to 1961.

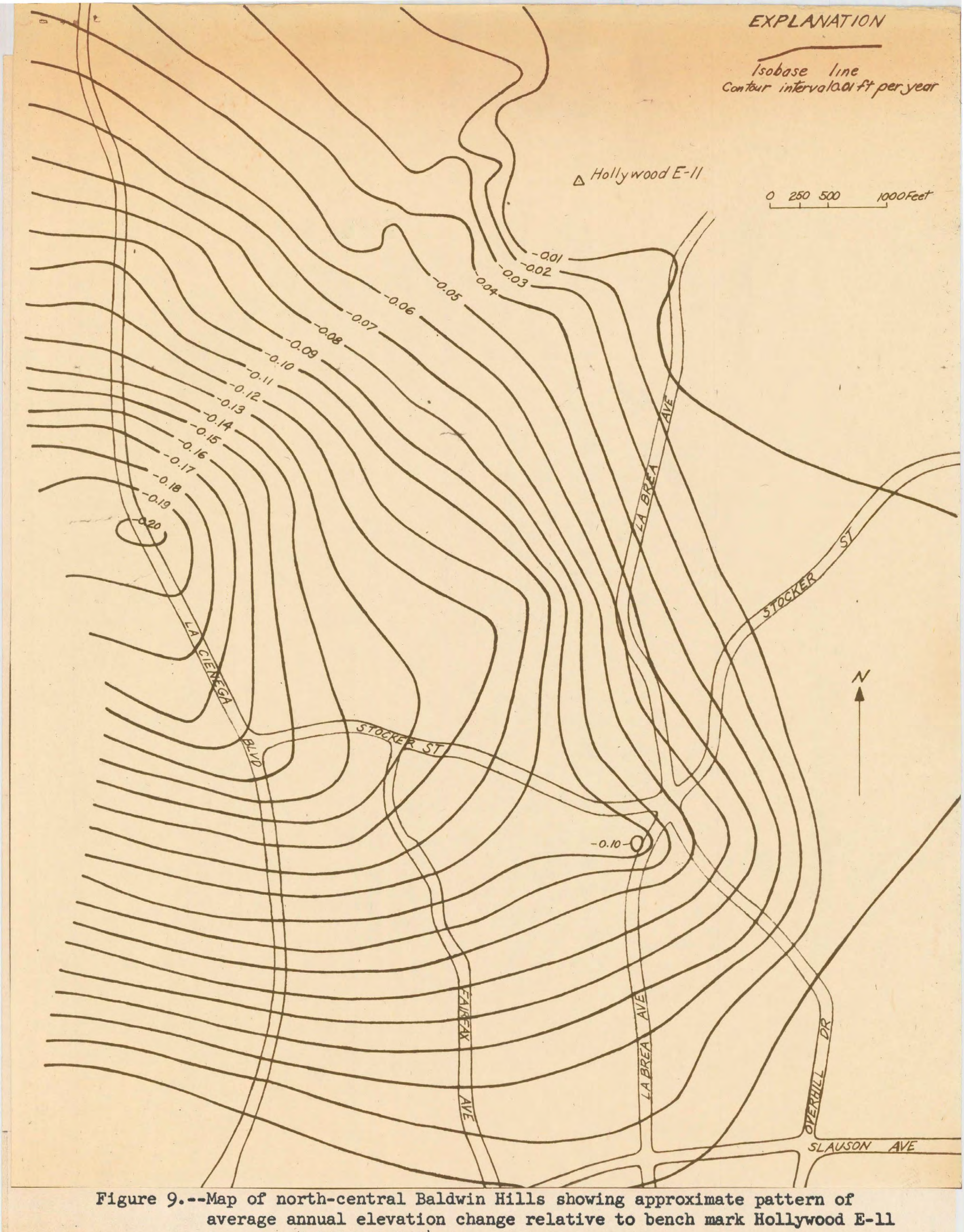

Figure 9.--Map of north-central Baldwin Hills showing approximate pattern of average annual elevation change relative to bench mark Hollywood E-11 for period 1950 to 1954.

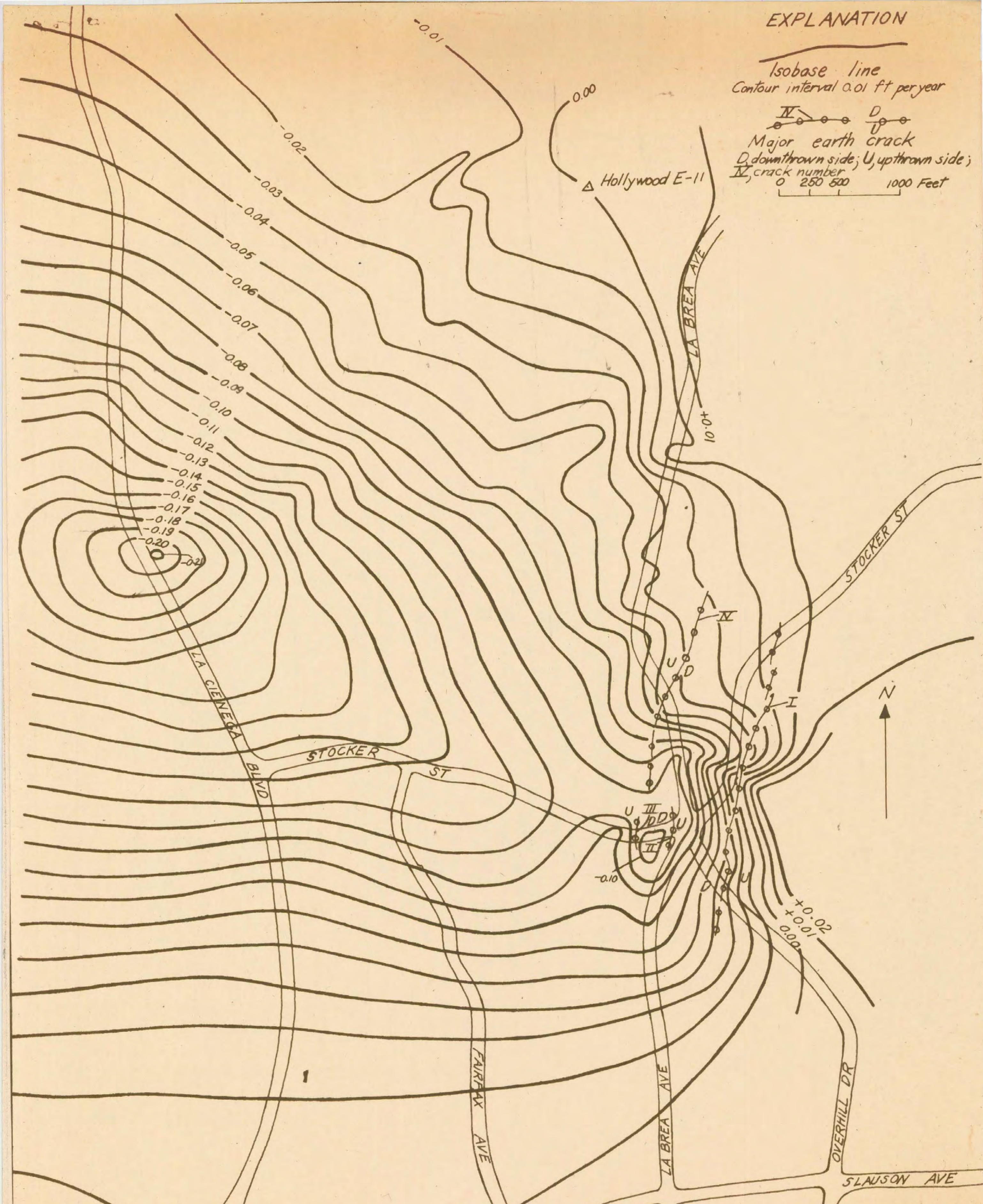

Figure 10.--Map of north-central Baldwin Hills showing distribution of major surface cracks and approximate patterns of average annual elevation change relative to bench mark Hollywood E-11 for period 1954 to 1958.

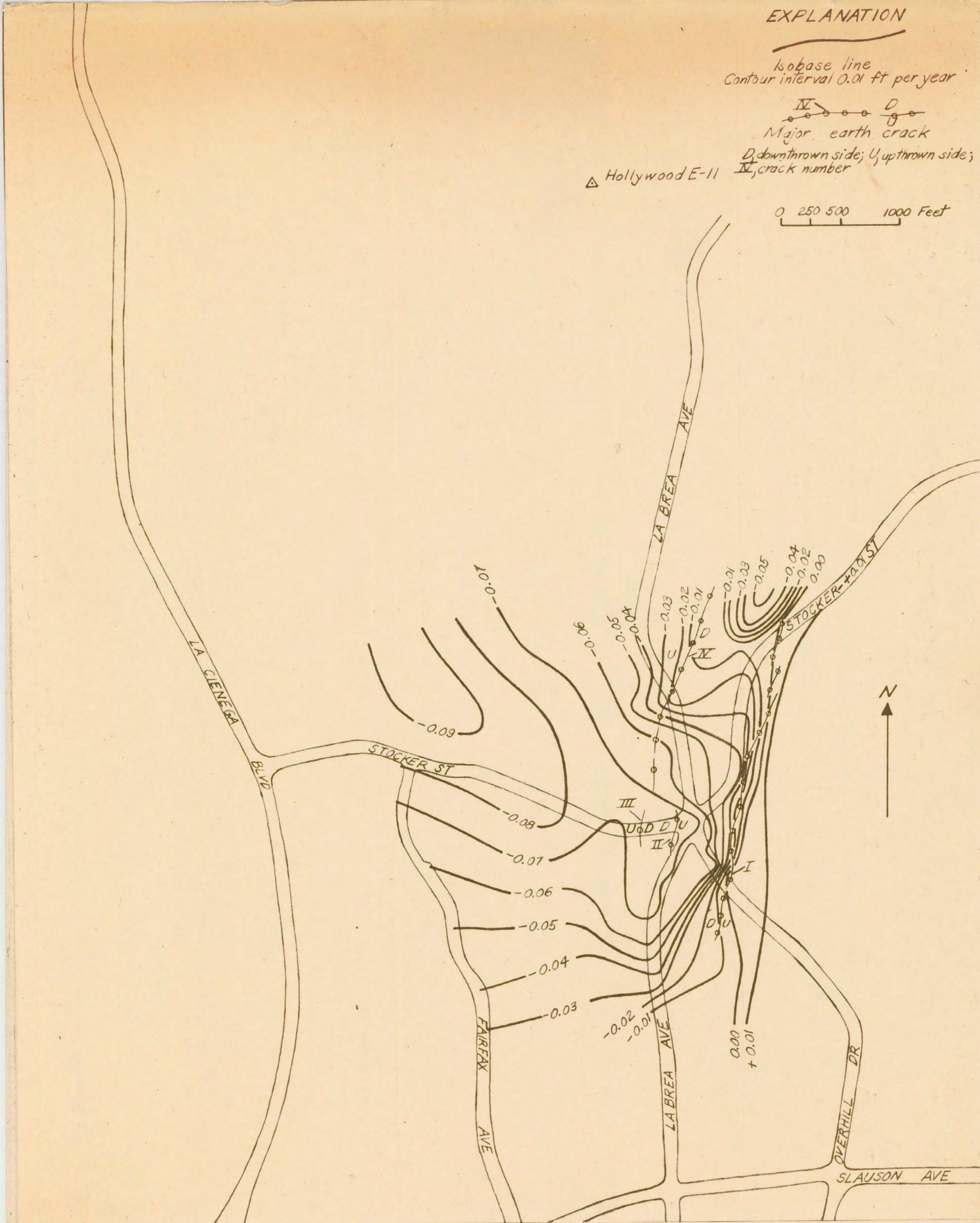

Figure 11.--Map of north-central section of Baldwin Hills showing distribution of major surface cracks and approximate pattern of average annual elevation change relative to bench mark Hollywood E-11 for period 1958 to late 1960. (Compiled by Department of Water and Power.)

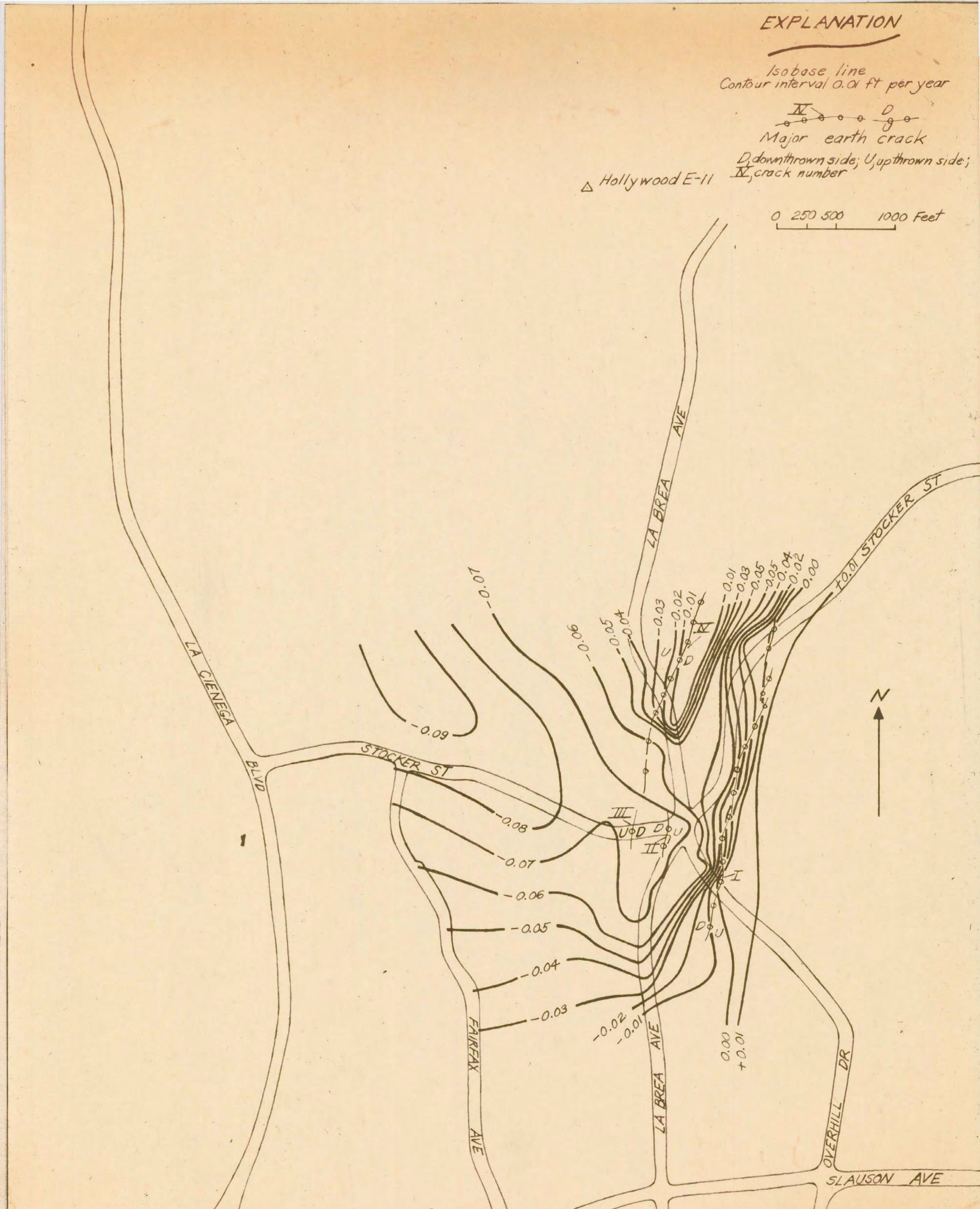

Figure 12.--Map of north-central section of Baldwin Hills showing distribution of major surface cracks and approximate pattern of average annual elevation change relative to bench mark Hollywood E-11 for period 1958 to late 1960. (Based on same surveys as those of figure 11, but reinterpreted by writers.)

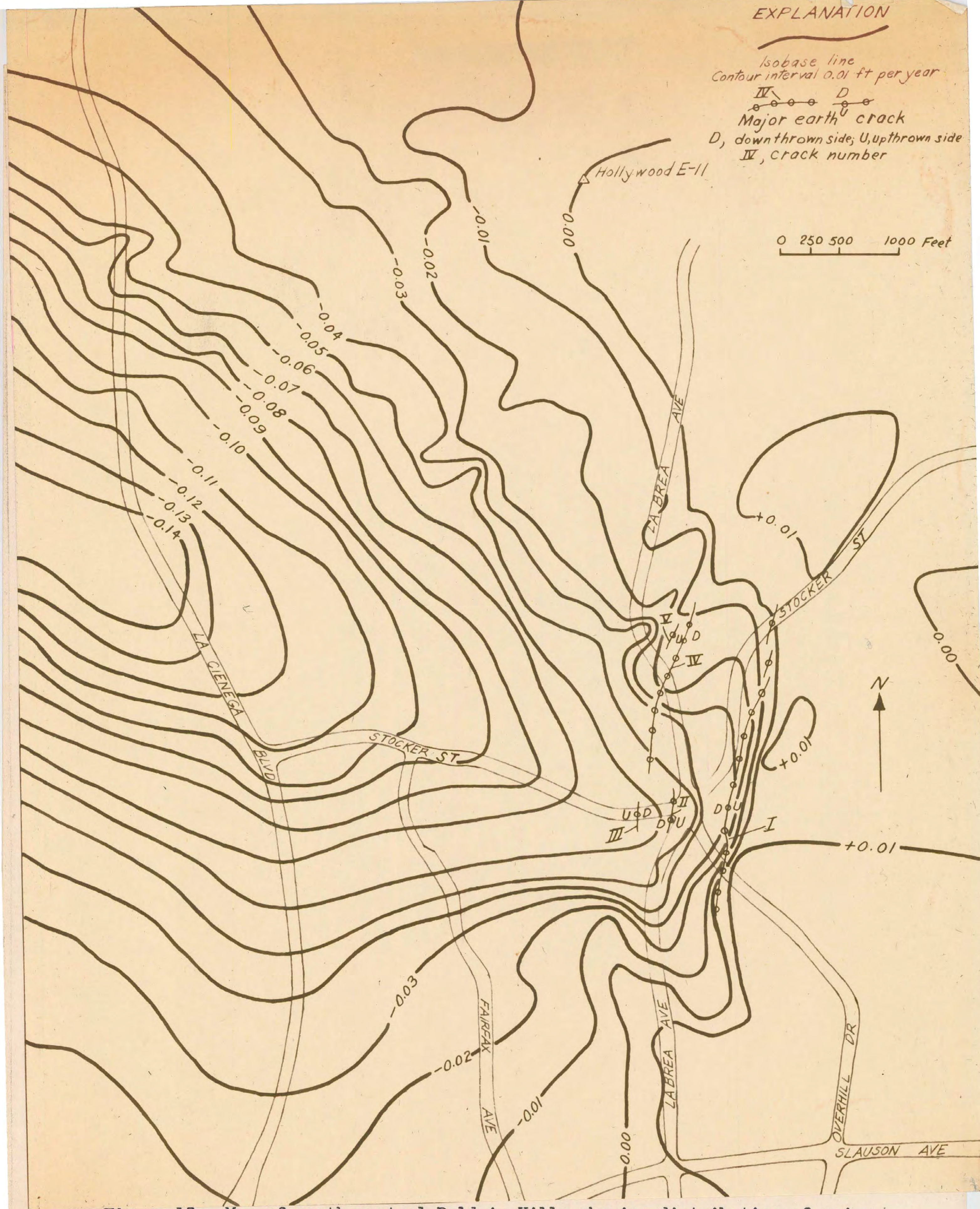

Figure 13.--Map of north-central Baldwin Hills showing distribution of major surface cracks and approximate pattern of average annual elevation change relative to bench mark Hollywood E-11 for period 1958 to 1962.

Pl. 3

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