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April 29, 1974

Mr. Philip J. Sterling
Continental Oil Company
6717 Lomas Blvd. N.E.
Albuquerque, New Mexico 87110

Dear Mr. Sterling:

With reference to your joint venture invitation at Cerrillos, New Mexico, Essex would be interested in obtaining more information. I am planning to attend the New Mexico Geological Society Symposium in Socorro May 23 and 24, and would like to spend Wed., May 22 reviewing the data in Albuquerque and possibly at Cerrillos, if this would fit your schedule.

Yours truly,

J.K. Jones
Chief Geologist

ESSEX INTERNATIONAL, INC.

JKJ:td

GSA S. P. 76, 1963, p. 296

Geology of a Primary Disseminated Copper Deposit Near Cerrillos, New Mexico

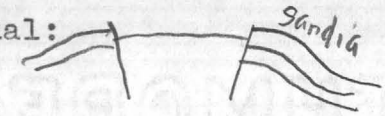
[redacted]

Cerillos

Cerillos Lead District, N.M. N Central N.M., between Albuquerque & Sta. Fe, on ~~broad crest~~ E flank of New Mexico arch, and on S extension of Sangre de Cristo Mts. Rocks oldest ss, sh, Jura-Trias. Small exposures Fort Benton sh/Dakota (base of Upper K). Fort Pierre middle Ku, 1000' sh, ss.

Madrid Coal form. Ku, 1000' plus. Lower 300', coal seams, sh. Upper, massive ss.
Galisteo sands Laramie? uppermost Cret.
Santa Fe marl group, Loup Fork upper Miocene, to recent.

Douglas Johnson, Geology of Cerillos Hills, N.M. (Columbia) School of Mines Quarterly, 24, 1903, Pt I. General Geology, 303-350, 456-500 says: " Along the eastern border of the Cerillos district erosion has removed the Sta. Fe marls, exposing red sandstone, dipping east. The thickness is probably 1500' to 2000'; the upper limit is not seen because prior to the deformation of the Sta. Fe marls there was a long period during which the region was elevated, peneplained, reelevated, and again subjected to erosion. This erosion period probably dated back to the close of Laramie time, the great upheaval which tilted and elevated these beds ~~xxxx xxx~~ being the same which inaugurated Tertiary conditions. This uplift resulted in much faulting of the beds. Along several of these great N-S strike faults the beds on the downfaulted side are turned up until they stand vertical."

Except where humped up by laccoliths the pre-Sta. Fe beds all dip E 15-20°. E flank of great Sandia uplift (part of N.M. Arch) 30 miles to SW. (Sandia is a monoclinal uplift on E side of great Rio Grande graben; as usual: 

Johnson: this uplift has results in a great series of N-S faults. Sandias graben flt zone shown on map for over 100 mi. Disp. 4000' plus. Opposite fault (graben) traced for 25 mi. Tertiary or later plugs and/or necks, N end of graben, radial dikes.

Lacco hills of which Cerillos is northernmost along N-S line, all probably along one of the great N-S fractures. Fracture died out before reaching the surface, so the lava spread laterally and arched overlying beds to form great laccoliths. (Authors of Ore Deps. of New Mexico think Cerillos "andesite" is monzonitic and early Tertiary; this is evidence for Laramide age of at least the inception and very considerable development of the great central N.M. north-south flts. and therefore for the great N.M. arch.

This of course is just what I ta ked about the other day;but ~~xxxx~~ at that time I had not read this paper for years.

Jura-Trias and Cret.beds dip E in general,but are tilted in all directions close to local Cerillos intrusions.

Radiating outward from Cerillos hills (~~xxx~~ 3 merged intrusions of slightly differing ages) is a system of vert.dikes.Intrusive sheets, mostly in beds dipping sha ply away from the laccolith.

Drag openings.

Ore Deposits: Lead-silver and zinc ores,another indicationof Laramide age for the intrusions. Along sheeted zones a little E of N;connected by Johnson with continued activity of Sandia uplift.Some are true fissure veins.

Structure is from 2 phases of deformation: (1) general Sandia uplift;region on E flank.2. Laccolithic Cerillos uplift imposed. The N-S fracture system consists of antithetic faults rising from the Sandia uplift;the partial radial system,from the Cerillos uplift.

This illustrates effect of preexisting flaws on a later deformation: composite lacco.elongated N-S;S of it all N-S dikes and fractures;no radial.Radial system to W and E where N-S system less developed. Radial system suppressed where they would make a small angle with older N-S breaks. On W and E,radial direction would be nearly at 90° with N-S so radial fractures formed.

Laccolith invaded the Madrid and Pierre shales,which grade into one another;as Johnson said, fissure stopped going up beneath these shales.

Figure 16 illustrates this principle;it combines four clay experiments by Ekkerkamp(1939, Figs.2,3,4,5) which deal with the effect of preexisting notches cut in a clay cake on the pattern of tension fissures produced by arching by vertical force,and consequent stretching of the arched cake. While the experiment involved arching and not doming,combining the four experiments reproduces radial fissuring around one quadrant of a dome, and shows the effect upon the fracture pattern of a parallel set of preexisting notches or old flaws.

Where the radial fractures trend at right angles to the older structural grain the latter has practically no influence on them. As the radial fractures swing around and begin to approach the trend of the older flaws they adapt themselves increasingly to these preexisting planes of weakness. A field example of this process is furnished by the Cerillos Hills mining district, New Mexico.

Cerillos Hills District, New Mexico

Sources.-

Douglas Johnson(1903),Geology of the Cerillos Hills,New Mexico, School of Mines Quarterly(Columbia),vol.24,Pt.I, General geology,p.303-350, 456-500.

W.Lindgren, L.C.Graton, C.H.Gordon(1910), Ore deposits of New Mexico, U.S.Geol.Survey Prof.Paper 68, p.57-58,60,163-167.

The minor silver-lead-zinc district of Cerillos Hills lies in north central New Mexico,east of the Rio Grande and on the eastern flank of the Corona or New Mexico arch, a broad uplift that marks the southward extension of the narrow and very high Sangre de Cristo uplift (Plate 1). A series of graben follow the crest of the arch, some of which define the valley of the Rio Grande,although the largest graben,that of the Tularosa Basin,lies east of the river.

The nature of the forces producing the New Mexico arch and its accompanying structural features is discussed by Lindgren, Graton and Gordon (1910, p.25-26). After submergence of the region at the close of the Mississippian sedimentation went on continuously until the close of the Cretaceous. At the start of the Tertiary epeirogenic uplift set in, accompanied by orogenic movements whereby the principal mountain ranges, rising above the growing continent, began to take shape.

Thus along the southward prolongation of the Colorado Rockies

"...the sediments were domed and then cut by vertical faults, along which subsidence took place...South of Glorieta, where the Rocky Mountains proper dip below the Cretaceous sediments, the beds were subjected to stresses which produced monclinal blocks with more or less pronounce fault scarps. The principal disturbances probably outlined the present valley of the Rio Grande and are marked by a series of sharply accented north-south ranges of apparently tilted blocks, such as the Sandia, Manzano, Oscura, San Andreas, and Organ ranges on the east side and the Nacimiento, Limitar, Magdalena, Cristobal, Caballos, and Cuchillo Negro ranges on the west. Some of the scarps face east, others west. Here also the apparent tilting may be the result of doming, faulting and subsidence." (Lindgren, Graton and Gordon, 1910, p.25).

Of the fault-block ranges on the east side of the Rio Grande Valley, The Sandia, Manzano and Oscura have their fault scarps on the west, facing the graben valley and the axis of the arch. The San Andreas-Organ block has its scarp on the east, but the scarp faces the Tularosa Basin graben.

West of the axis of the New Mexico arch the Nacimiento scarp faces west but the Limitar scarp faces east toward the axis of the arch, as does that of the Magdalena Range, with a scarp on the west side as well

While the Cristobal and Caballos Ranges lie east of the Rio Grande they lie west of the arch axis and their scarps face east, the normal faults reflected by the scarps dipping, like most of the others mentioned, toward the axis of the arch in the manner of those shown in Figure

4A. The New Mexico arch is therefore characterized by a series of major longitudinal faults, most of which dip toward the arch axis with the downthrown blocks toward the crest of the arch. Where two such faults oppose each other a graben lies between them;most of the graben lie along the crestal portion of the arch. The fault-blocks associated with these faults are tilted for the most part away from the arch axis,down the flank of the arch. The faults are mainly typically antithetic (Fig.4A). If the notions of H.Cloos are valid (p. ~~8-9~~ 12-13) formation of the antithetic faults and initial sinking of the graben accompanied the uplift that formed the New Mexico arch.

As shown in Figure 14 the Cerillos Hills lie on the eastern or dip-slope flank of the Sandia uplift. The Santa Fe marl beds of relatively recent age cover much of the area,obscuring much of the structural pattern under discussion (Fig. 17A). The rocks below this cover consist of Upper Cretaceous shale and sandstone totally about 3000 feet in thickness. The formations, Jura-Trias sandstone and shale,that underlie the Cretaceous strata are exposed in the extreme western part of the mapped area.

All pre-Santa Fe beds dip east at 15°-20°,except where disturbed around the margins of laccoliths (Fig.17A). According to Johnson(1903, p.457) the Sandia-Manzano uplift produced a series of great north-south fractures (Fig.14B,cross section of Sandia uplift), including that along the western edge of the range and many less conspicuous but similar faults.

The group of laccoliths of which that of Cerillos Hills forms the northernmost member lie along a north-south line which corresponds in all probability to one of the north-south tension fractures. The frac-

ture presumably died out before reaching the then surface;it was probably dissipated in the soft shale overlying the competent Jura-Trias and basement rocks. Monzonitic lava ascending the fracture spread laterally in the softer rock above the top of the fracture and formed a series of laccoliths which domed their cover. Intrusion took place in several stages. According to Johnson (1903,p.456) the main laccolith of Cerillos Hills consists of an earlier "hornblende andesite" on the east,and a younger "augite andesite" on the west. Graton et alii(1910, p.165-166) found a variety of intrusive rocks present, with the dominant type monzonite porphyry.

A system of nearly vertical monzonite porphyry dikes radiates from tl Cerillos Hills laccolith in the southwest portion of the mapped area. They seem lacking in the southeast portion;the cover of Santa Fe marl conceals the northern portion of the laccolith and the invaded rocks there.

Where the dikes,in radiating like the spokes of a wheel,swing from nearly east-west, on the north, to due south in the area south of the laccolith, their strikes jump suddenly from S70°W to S20°W. Dikes with the latter strike occur in other than radial relations to the laccolithic focal mass (Fig.17A).

A system of basalt dikes follows the S20°W trend almost exclusively. This system is so widespread as to preclude any radial relation to the laccolith. The basalt dikes are younger than those of monzonite porphyry.

Innumerable veins ,most of which follow the S20°W strike,lie mostly in the laccolith;some cut across the contact into the adjacent Cretaceous baked shale. The veins,which are narrow,are mainly mineralized sheeted zones.They carry spotty silver-lead-zinc ore in a quartz-cal-

cite gangue, with occasional dolomite, tourmaline or ankerite. Metallic minerals consist of argentiferous galena, sphalerite, chalcopyrite and pyrite.

The strike of the Cash Entry vein, N67°E, differs radically from that of the bulk of the veins and suggests a radial relation to the center of the southern, semicircular portion of the laccolith (Fig.17A). According to Lindgren et alii(1910, p.167) the Cash Entry vein formed by raplacement of a sheeted zone in the monzonite porphyry of the laccolith and alongside a syenite dike.

Tectonic Analysis of Cerillos Hills District.- It seems logical to suppose that the north-south fracture system, regional in distribution, resulted from the Sandia uplift, and that the local, partly radial system originated through domical stretching of the cover above and around the Cerillos Hills laccolith. Johnson believes that most if not all the uplift forming the Sandia Range took place before the laccolithic intrusion. The laccoliths of the region look as if they had intruded strata already dipping to the east; further, they lie along a north-south line which presumably reflects a fault or fissure produced by the Sandia uplift. In detail, the Cerillos Hills laccolith is elongated north-south and its western margin is much steeper than its eastern (Fig.17B), suggesting control of its emplacement by a north-south fracture.

Cross (1894, p.236), cited by Weed(~~1898-99~~ 1900, p.391-392, Fig.48) discusses the origin of assymetric laccoliths with steep contacts along one side, and ascribes the shape to the presence of a line of weakness formed by axial tension, to a preexisting fracture of any sort, or to resistance offered by the side of an earlier intrusion. Cross's cross-section through the Mount Marcellina laccolith, reproduced by Weed as his Fig148, shows the steep side of the laccolith bounded by a normal fault dipping steeply away from the laccolith. Applying this notion to Cerillos Hills,

the corresponding fault there would strike roughly north-south and dip steeply west, toward the axis of the Sandia uplift. Such an attitude would be that of a longitudinal tension fracture or antithetic fault associated with a north-south uplift and lying east of its crest (Fig.4A).

If the north-northeast fracture system of the Cerillos Hills region is a result of the main Sandia uplift, the Ekkernkamp notching experiment (Fig.16) suggests that intrusion of the laccolith and formation of fractures related to the laccolith could have taken place after the regional Sandia uplift was complete. West of the laccolith,where radial fractures related to it would trend west and make a highly obtuse angle with preexisting north-northeast fractures,such radial fractures would form freely and without deflection. This is the case. Toward the south, where the radial spokes approach in trend the north-northeast fracture set,the latter would "take over" and enforce just the sudden swing in strike that is shown by the radial fractures,which change from S70°W to S20°W in one swoop.

Time relations of various dike types and of the veins tell,however, a less simple story. The sequence of critical events at Cerillos Hills may have been somewhat as follows.

1. Start of the Sandia north-south uplift;development of a major north-south fault along its eastern flank;intrusion of monzonitic magma along this tensional fault. The soft, yielding Cretecaous shale stretched during arching by flow;underlying brittle rocks cracked. The Cerillos Hills fault made in the brittle rocks but was extinguished in the shale above them.Magma ascending the fault was halted by the shale and forced to spread laterally to form laccoliths.

2. The Cerillos Hills laccolith is composite and shows evidence of repeated intrusion within the same relatively small area and presumably under the same tectonic conditions. After the first intrusion, continued uplift of the Sandia elongated half-dome would maintain tensional pull on the walls of the feeding conduit.

The doming cover above the growing laccolith stretched and broke into radial tension fissures. Monzonite porphyry dikes invaded these radial fissures,but it is highly significant that they intruded fissures of the regional north-northeast system as well;for if tension was needed to maintain radial fractures permeable to dike invasion, the same applies to the fractures of the regional system and the most logical source of the tension is continued uplift of the main Sandia Range.

Effects of regional uplift upon the Cerillos Hills fracture pattern might continue to be felt after consolidation of the laccolith had put a stop to laccolithic doming. Ekkernkamp (1939,my Fig.9) produced a radial fracture pattern by doming a clay cake in which a hard kernel was inserted (p.21-22). Similar doming by Welles (p.5, Fig.3C) produced 6 or 7 local radial fracture sets,arranged about small hard lumps in the clay. The resistant Cerillos Hills laccolith corresponds to the hard lumps in the experiments, the enclosing shale to the yielding clay.

If these experimental analogies are valid,radial fractures surrounding hard plugs in softer material might be products of regional uplift rather than merely local phenomena connected with the plug alone.

3. Laccoliths produce radial fractures in their covers and surroundings, but not within themselves,since when they solidify and become able to fracture the pressure to bring about doming ceases. The hard

lumps that become foci for radial fracturing in experimental doming are not themselves fractured. It is their resistance to any kind of internal deformation that brings about the intensified concentric stretching around them which produces the radial fractures. The resistant lump used in the Ekkernkamp experiment is however too resistant to represent a prototype in nature. No rock mass of the size of the Cerillos Hills laccolith could resist fracturing under the strain of the forces producing the regional Sandia uplift. The laccolith was intensely fractured, most of the fractures pertaining to the regional north-northeast system.

The fractures, most of which were mineralized to form the dominant vein system of the district, are sheeted zones of the type shown by Balk to be tension joints (p. ~~10-11~~ 14-15).

These short and discontinuous tensional sheeted zones within the laccolith could hardly have furnished trunk channels for the mineralizing solutions. The postulated north-south tension fissure or antithetic fault up which the monzonitic magma presumably travelled, probably carries a neck of intrusive rock beneath the laccolith extending downward at least to the competent strata below the shale series. Within the competent rocks the tension fissure could by itself have stayed permeable enough to furnish a trunk channel for ore solutions; above the competent basement, within the shale, solutions may have followed upward the contact of the intrusive neck.

4. A final reopening of north-northeast fractures, and of one or two radial fractures, to receive basalt dikes. This reopening may have been the result of a Pliocene or later renewal of the Sandia uplift. Presumably the monzonitic intrusion and the metallization took place in much earlier Tertiary time.

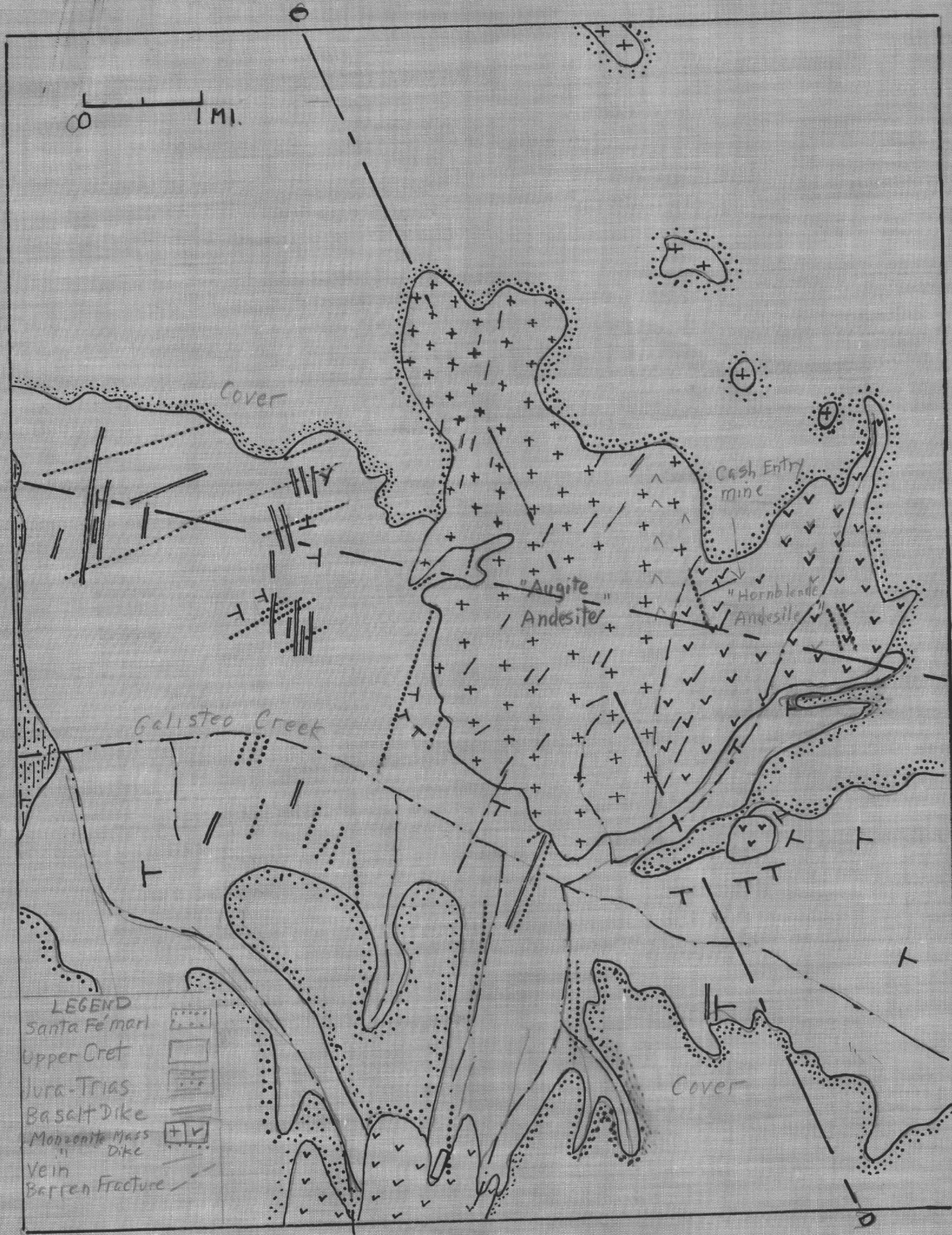


FIG. 17-A.
Cerillos Hills

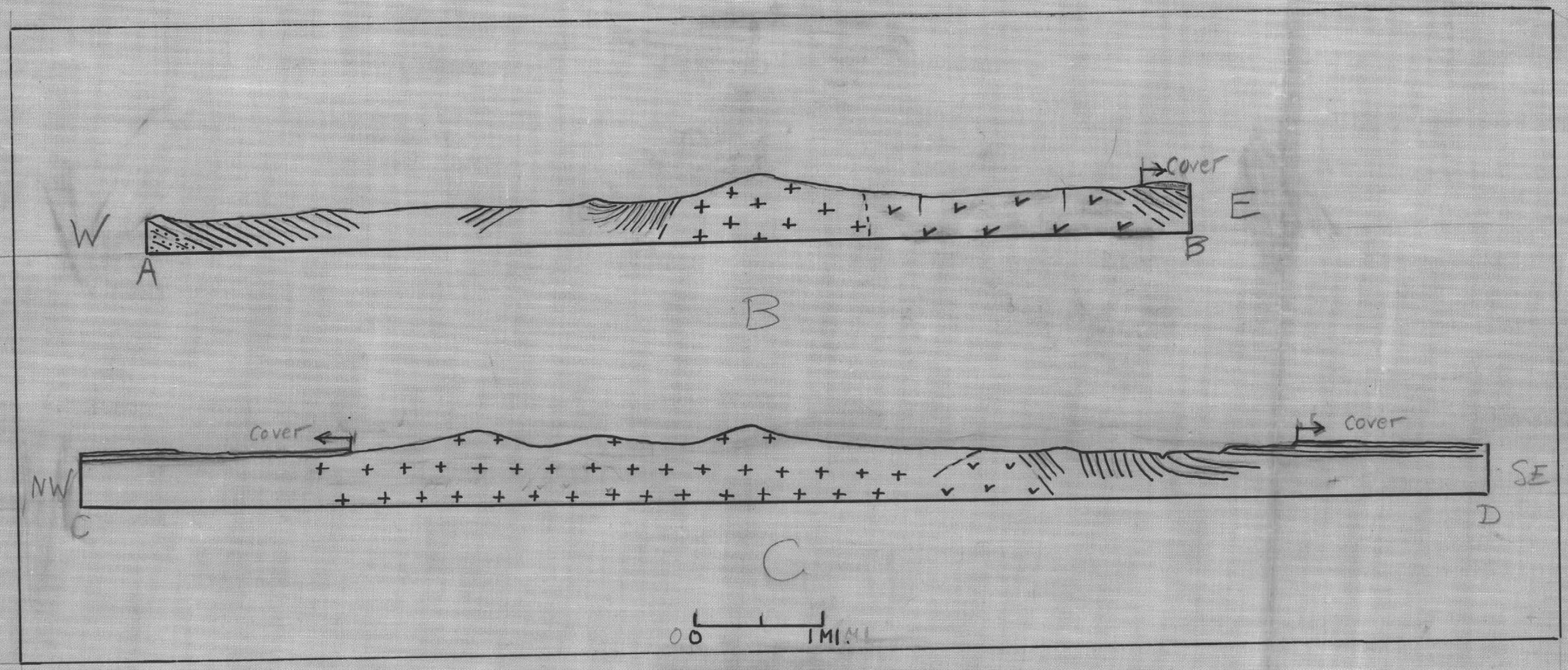


FIG 17

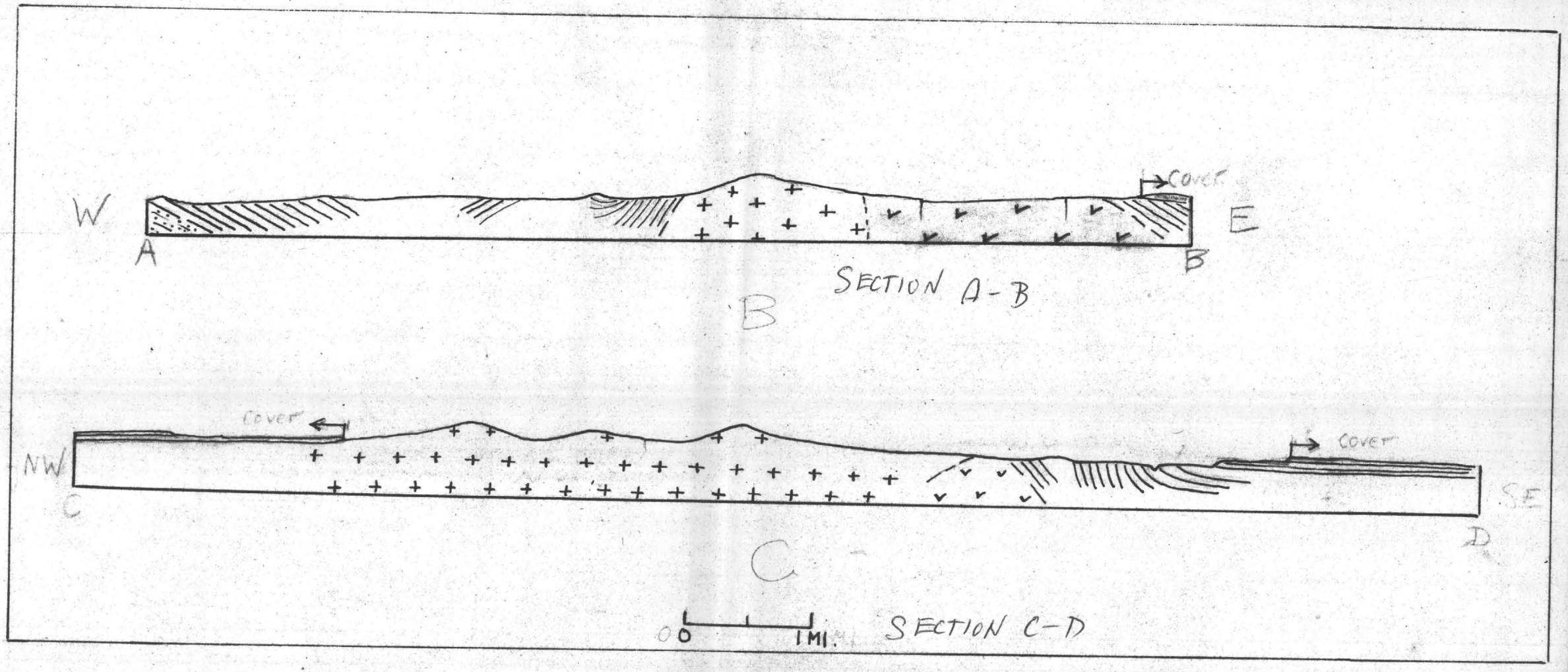


FIG 17

This type of deformation has long been recognized,for example by Spurr (1912, p.449-450; 1916, p.615,621) and by Darton(1928A).Darton's brief note on the subject merits quotation:

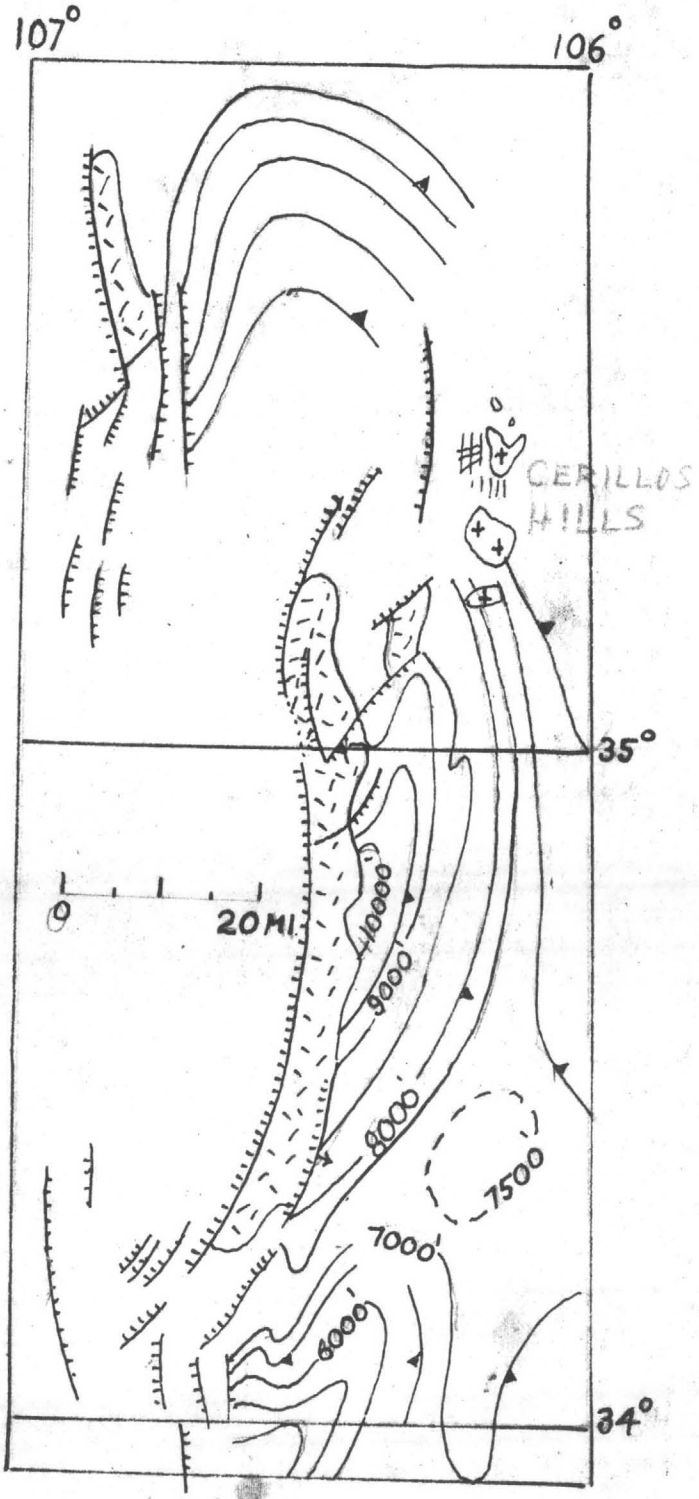
"In the study of many parts of Arizona and New Mexico data have been obtained for the representation of the larger structural features by contour lines at the top of the Kaibab and Chupadera limestones. These lines bring out the fact that there are alternate zones of crumpling and block-faulting giving rise to basin-range ridges and broad plateaus. In New Mexico especially there are large elongated domes which are faulted along their higher parts but overarch more or less completely at either end. This type is to be called the 'Sandia' structure from the Sandia Mountains,where it is well exhibited."

44 Figure 14A is a plan and Figure 14B a cross section of the Sandia uplift, New Mexico. The uplift is discussed in the section on the uplift, New Mexico. The uplift is discussed in the section on the Cerillos Hills mining district (p.55-62).

The so-called Mono wedge at Ophir(Figs.12A, 13A-B) is a minor but highly significant feature associated with the Ophir dome. The wedge is formed by two radial fractures that join to make a V,open on the north,in plan. The wedge is shaped like the stern of a yacht,the fractures joining on dip to make a "keel" plunging northward. Beds within the wedge have been dropped 700 feet vertically with respect to those surrounding the wedge. Striations on the bounding fault are everywhere normal to the "keel" (Gilluly, 1932, p.).

Gilluly offers several mechanical explanations for the wedge but seems satisfied with none. The wedge is not difficult to account for on the assumption that the Ophir half-dome swelled radially,i.e. it grew upward and outward from a focus of doming,like an inflated balloon. A given area of the surface of a balloon expands and in expanding moves radially away from the center of the sphere.

The wedge was much like a loose brick in the domical roof of a furnace. Just as the furnace dome,expanding under heat would tend to move past the loose brick and perhaps cause it to fall out,so the Ophir dome,rising and expanding by "flow" would tend to leave the Mono wedge behind,



PLAN, SANDIA UPLIFT, N.M.

LEGEND

Early Tertiary Intrusive

Precambrian

Structural Contour 8000

Fault

SANDIA UPLIFT & CERILLOS HILLS

FIG 14

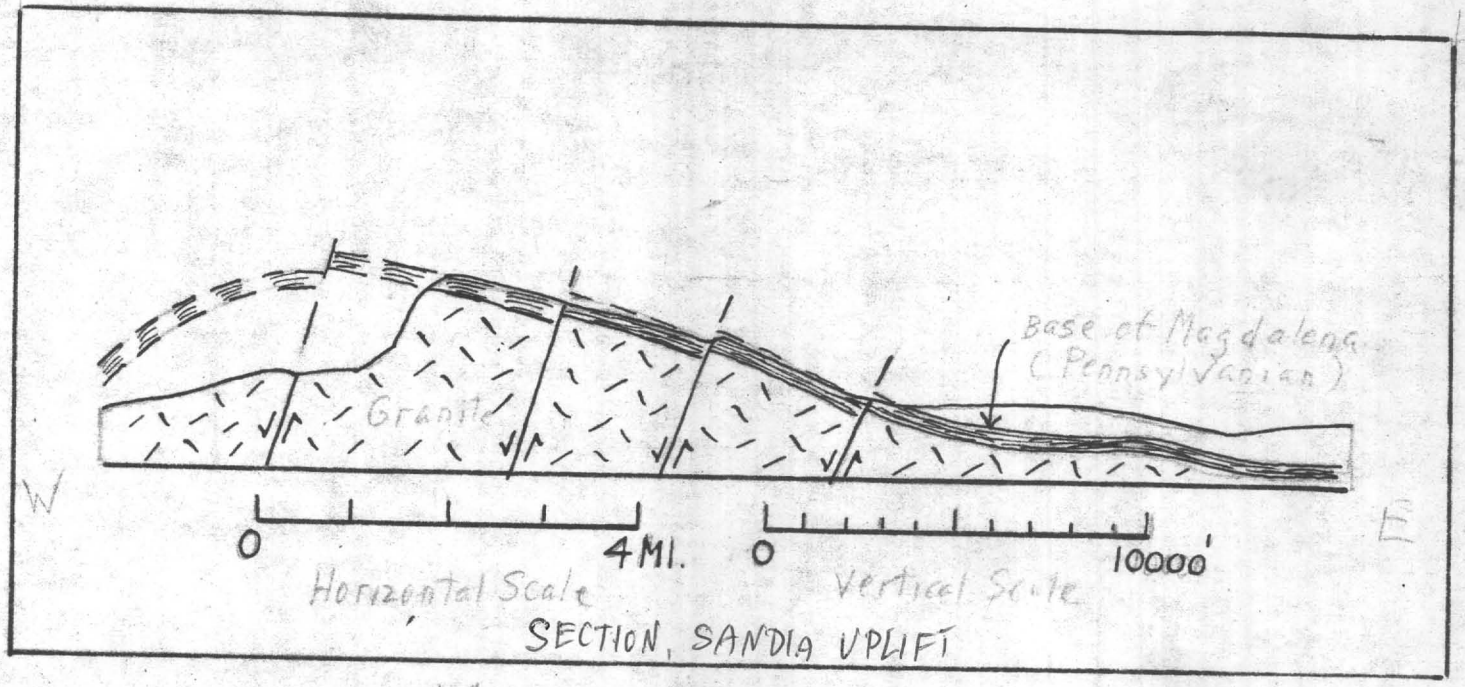


FIG. 14 B

After Darton (1928, Fig. 23, Sec B-B)

SANDIA UPLIFT

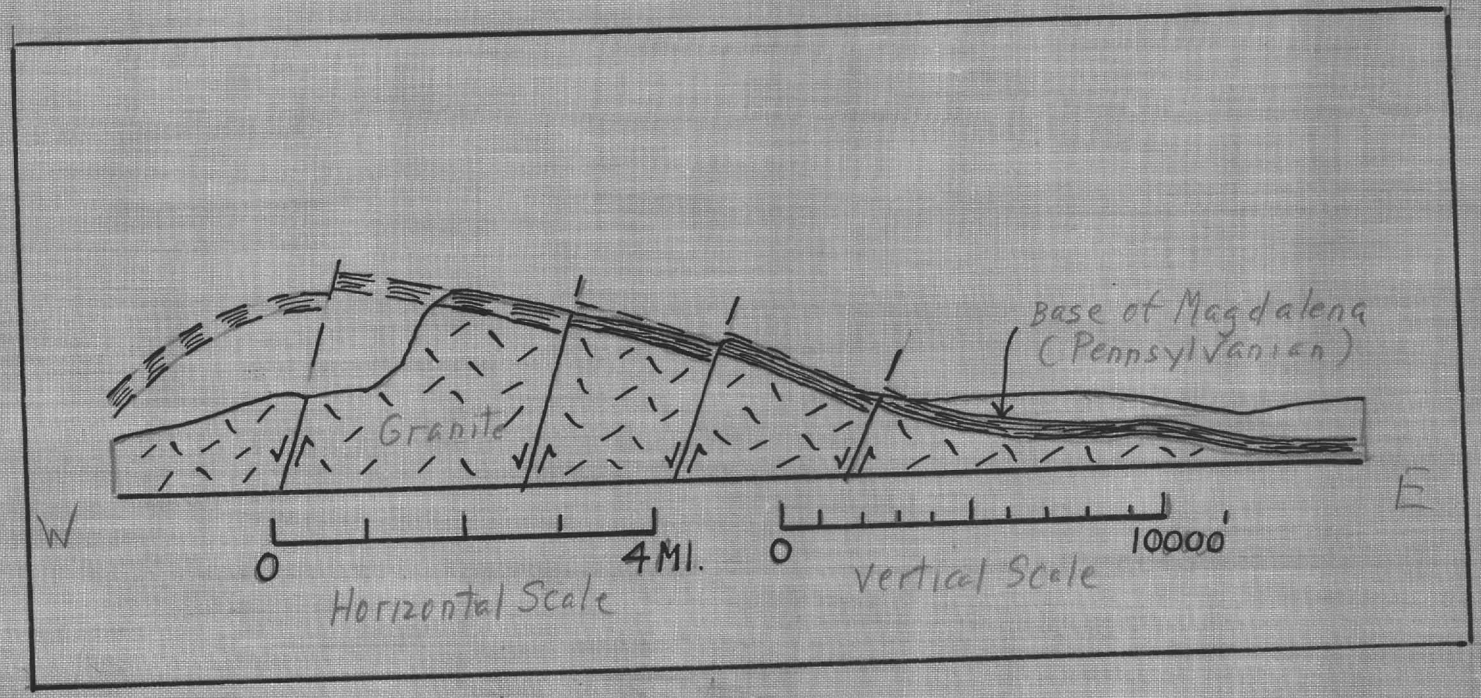
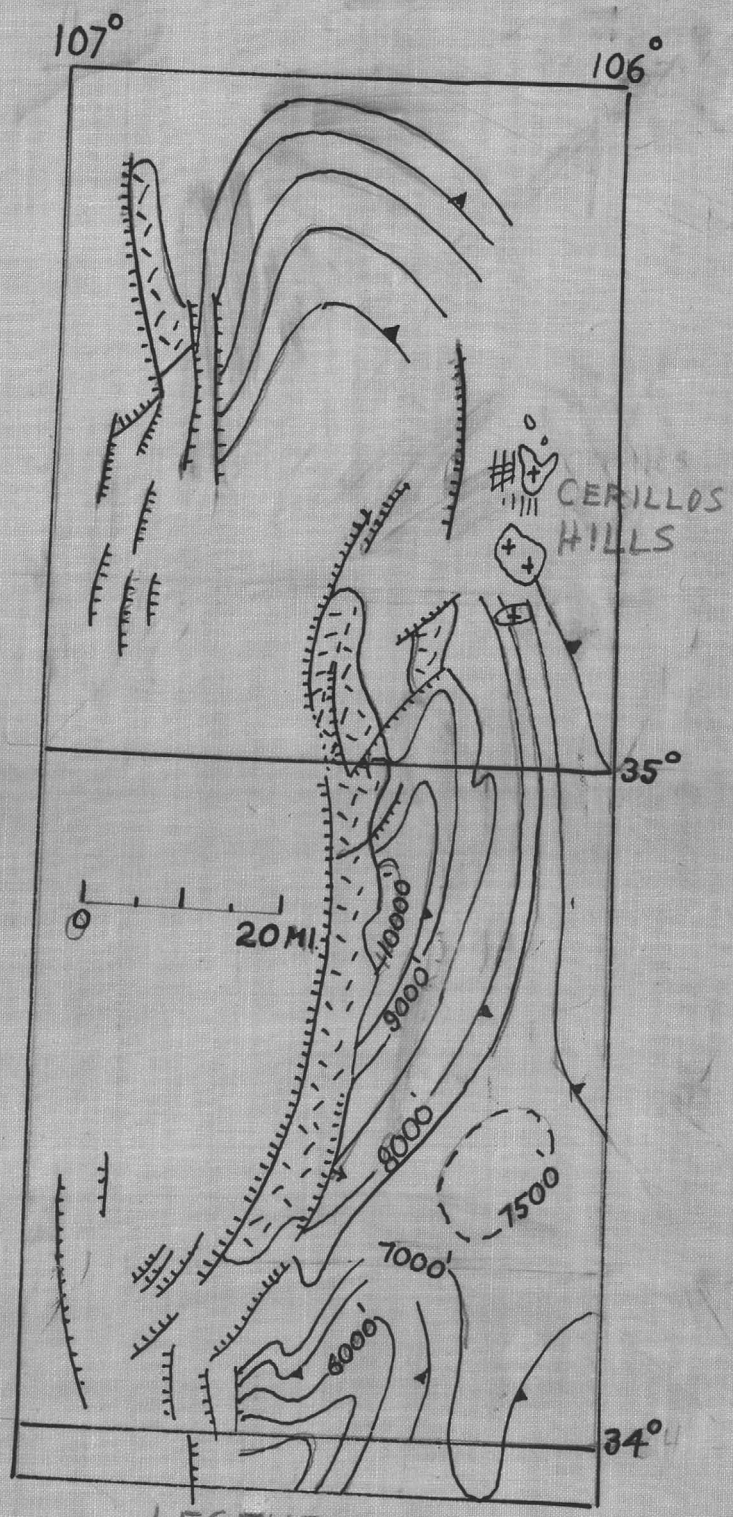


FIG. 14 B
After Darton (1928, Fig. 23, Sec. B-B')
SANDIA UPLIFT



LEGEND

Early Tertiary Intrusive: (+)

Precambrian:

Structural Contour: 8000

Fault: U D

SANDIA UPLIFT
& Cerillos Hills

FIG 14

SOME MINING DISTRICTS ASSOCIATED WITH STRUCTURAL DOMES

I Simple Domes,no evidence of compression.

I-A. Fissure Deposits

Cerillos Hills, N.M. Douglas Johnson, Geol.of the Cerillos Hills, N.M. School of Mines Quarterly (Columbia) vol.24,1903,:173-246;303-350,456--500.vol.25, 69-98.

CR Jura-Trias.red beds. Ku Benton,Pierre,shale,ss. Ku Fox Hills Shale,coal seams,upper part massive ss.

On E flank Sandia uplift.This uplift accompanied by great series of N-S fractures.Recent volcanic cones along N-S line.

Cerillos Hills northernmost member of series of laccoltic hills alng N-S line. These lacoliths have superimposed domical structures on the eastward monocline.

Radial system of dikes around Cerillos multiple lacolithic dome.

Ore Deposits of New Mexico, W.Lindgren, L,C,Graton,C.H.Gordon,USGS PP 68,1910,166-167. Many but small veins,chiefly in monzonite plug.Radial in NE quadrant Sheeted zones,Balk tensio joints. Gangue qtz.,cal-. Cash Entry mine in NE quadrant,strike ENE. Replacement vein along sheeted zone following syenite dike.Ankerite,qtz gangue.PbS,yellow ZnS, ccpy -/ Silver.

Map shows general N-S fracture system allied to Sandia uplift,with partial radial system connected with Cerillos domical uplift. Latter probably superimposed on former:laccolithic mass elongated N-S,W flank,beds vert steep as if giverned by N-S flt. Filling of N-S fractures with dikes and veins cutting the lacco suggests resumption of Sandia uplift.

However, see Magdalene Ekkernkamp: Zum Problem der aelteren Anlagen in Bruchgebieten. Geol.Runschau, vol.30,Heft 7/8,1939,713-764, Clay experiments, controlled deformation acting on notches representing preexisting fractures.. Tendency toward radial fractures would be inhibited where they would make a small angle with older N-S fractures:renewed train would use these. Only radial are E and W of the uplift,where the angle was too great,so radial fractures were formed. But renewed uplift along Sandia lines would not reopen N70 E and W radial fissures,but only N-S fractures.

No master fracture - no important OBS.