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Gary Christenson

LIQUEFACTION GENERATED BY THE 1983 MOUNT BORAH, IDAHO, EARTHQUAKE

by

T. L. Youd, E. L. Harp, D. K. Keefer, and R. C. Wilson

U.S. Geological Survey

Menlo Park, California

Introduction

A magnitude 7.3 (M_s) earthquake struck south-central Idaho on October 28, 1983, and generated major earthquake effects including a 21-mi-long fault rupture, building damged in several communities in southern Idaho, landslides and rockfalls over a wide area, and numerous liquefaction effects. The latter effects included sand boils, fissures, lateral spreads, and buoyant rise of a buried pump house; these disturbances disrupted roadways, pastures, and two buildings. ~~All the liquefaction effects were within 23 miles of the fault rupture.~~ In search of liquefaction effects, We examined all localities of reported damage in the epicentral area, drove upon nearly all of the major roads within 40 miles of the fault rupture, and made reconnaissance flights over the area in a light plane. In this report, we describe the liquefaction effects, plot their locations on a map, and compare their distribution with past occurences.

Geologic and Hydrologic Setting

Liquefaction effects generated by the 1983 earthquake developed only in the intermountain vallies surrounding the Lost River Range (Fig. 1). These vallies are filled with alluvial, fluvial, and glacial sediment to varying depths (McIntyre and Hobbs, 1978; Nelson and Ross, 1969; Rember and Bennett, 1979a, 1979b). The youngest sediment in the vallies are channel and floodplain deposits of late Holocene age. These young fluvial deposits lie along the courses of the many rivers and creeks that drain the intermountain vallies. Alluvial fan, glacial, and fluvial deposits of earlier Holocene and late Pleistocene age flank the young fluvial deposits and drape up the margins of the vallies. Most liquefaction effects developed in the late Holocene deposits, but some effects also developed in older sediment.

Artesian conditions beneath the vallies generate numerous springs and seeps and leads to high ground water conditions beneath much of the lower areas including large areas covered by wet marshes. Nearly all of the liquefaction effects occurred in these areas of high water table. Some lateral spreads, however, extended into areas where free ground water is tens of feet deep.

Big and Little Lost River Sinks

Because of high rates of sedimentation and high ground water levels in the Big and Little Lost River Sinks, conditions commonly associated with high liquefaction susceptiblity, a search was made for liquefaction effects in those areas (Fig. 1). These are areas where waters from the two Lost Rivers deposit sediment as they seep into the valley floor. We did not see any liquefaction effects at the localities we visited nor hear of any effects from several residents that we interviewed. The Sinks lie 50 to 60 mi southeast of the southeast terminus of the fault rupture.

Big Lost River and Thousand Springs Vallies

We checked the Big Lost River Valley for liquefaction effects begining at Arco and working northwestward (Fig. 1). About 1 mi southwest of Leslie, fissures up to 2 in wide disrupted the pavement of Highway 93 over distance of 500 ft. The fissures were parallel with the road and effected only the outer 5 ft of pavement and adjacent sholder on both sides of the road. A railway embankment parallel to the highway contained similar but smaller fissures. The highway and railroad at this locality crosses a marsh on 3- to 5-ft-high embankments. No fissures were found in the natural ground on either side of the highway and railroad. Apparently the weight of the fill along with weakening of the underlying soil caused the displacements that generated the fissures and the brittleness of the pavement and sholder led to their development and preservation. These fissures were 23.5 miles from the fault rupture, the farthest apparent liquefaction effect from that rupture. For comparison, the collapse of an exterior brick veneer wall of a church about 0.5 mi southeast of the damaged highway was the farthest collapse of a building component in the Big Lost River Valley during the earthquake, and approximately marked the outer bound of the zone of intensity 7 on the Modified Mercalli scale.

Fissures similar to those southeast of Leslie developed in most roadways where they passed over marshy areas in the Big Lost River Valley above Leslie. In the vicinity of Mackay, we noted three zones fissures on Highway 93 and several other zones on county roads as marked on Fig. 1. In general, the fissures became wider and more disruptive with distance up the valley. For example, the fissures in Highway 93 about 3 mi northwest of Mackay and 12 miles from the fault rupture were as wide as 4 in and disrupted the roadway sufficiently to impede traffic. Near this area, sand boils with deposits as large as 2 ft in diameter erupted in the flood plain of the Big Lost River; these are the only sand boils we saw south of Mackay Reservoir.

Along a two-mile stretch of the Big Lost River extending upstream from Mackay Reservoir, gravel and sand bars in the channel liquefied producing ground fissures up to 1 ft wide and sand boils with deposits upto 6 ft in diameter. A man who happened to be fishing on the Big Lost River at this locality at the time of the earthquake and gave the following account to Frank Baldwin, National Earquake Information Service, of what he saw.

"I was standing on a gravel sand bar when the quake struck. Cracks appeared in the bar and began to gurgle water. Then three or four water spouts with 3 to 4 inch holes opened up and water shot up to 3 feet in the air. The gravel bar shook like a marshmallow and it was very difficult to stand. Some of the water spouts spewed black water; others spewed clear water." When the man waded out to the bar, the water was about calf high. After the shaking ceased, he waded back to the bank and found the water to be waist high. He estimated the water had risen nearly 10 inches. Upon reaching higher ground, although still in a marshy area, he could see numerous nearby water spouts.

The above account indicates that liquefaction, fissuring, and eruption of sand boils must have occurred very early in the ground shaking since the observer notes these events before he descrubes the severe ground shaking. Also, the sand boils must have continued to flow for some time after the snaking ceased while the man waded back to the river bank, relaxed, and then saw numerous water spouts still flowing.

About 3 mi northwest of Makay Reservoir and 6 mi southeast of the southern terminus of fault rupture a lateral spread developed on a low terrace near the Big Lost River (Site 1 on Fig. 1). A curved zone of fissures and sand boils marked the head of the spread, and passed beneath a house, barn, and adjacent ranch yards (Fig. 2). The fissures were as wide as 1 ft with scarps as high as 1 ft. Sand boil deposits, as wide as 8 ft., were composed of gravelly sand with pebbles up to 1 in diameter. Grain-size distribution curves for samples from two sand boils at this site plus curves for samples from sand boils at other sites are given in Fig. 3. The foundation of the house was constructed of small spread footings with wood pillars beneath the interior of the structure and a perimeter footing with concrete-block wall around the exterior. The foundation was fractured and split apart several inches, primarily under the back part of the house by the horizontal displacement. Fig. 2B shows the back wall of the house in which about 5 in horizontal slip occurred between blocks in the foundation. The wood-frame superstructure remained intact and essentially undamaged, although it was slightly distorted due to differential settlement. Nearly all of the the horizontal displacement was absorbed by the slippage that occurred in the perimenter foundation; the spread footings and wood pillers were only slightly distorted by the horizontal displacement and upto perhaps a few inches of differential settlement. The floor slab in the garage, which is attached to the house, was also fractured and pulled apart a few inches and the garage walls distorted by the by the displacement.

Eastward from the house, the fissures passed beneath a steel-frame barn with a dirt floor. The fissures gave the floor the appearance of having been plowed (Fig. 2C). The horizontal displacement widened the doorway by about 1 ft at the base and distroted the frame. The fissures continued eastward from the barn where they disrupted roadways and passed beneath a haystack yard. A wire fence enclosing the yard was pulled apart by 30 in.

About 50 ft behind the house, a water tank and pump were housed in two separate, but adjacent concrete boxes that extended from about 2 ft above to about 4 ft below ground surface. Liquefaction during the earthquake caused the box containing the pump to buoyantly rise 3 in while the more heavily loaded box, containing the filled water tank, remained in place (Fig. 4).

Additional sand boils erupted and fissures formed in the general area surrounding the lateral spread noted above. North of the spread in the floodplain of the Big Lost River, the pavement of Parsons Creek Road was disrupted by fissures and ground settlement over a distance of about one mile. Sand boils with deposits up to 3 ft in diameter erupted at a few localities along the sholder of that road. Southwest of the spread for a distance of about 0.5 mi, sand boils with deposits up to about 6 ft diameter erupted at sporadic locations in the fields. Sand boils also erupted in the corrals and yards of a ranch about 0.5 mi southwest of the lateral spread, but there was no damage to buildings and other structures at that location. All of the effects noted at this site (Site 1) were located within Section 30, T 8 N, R 23 E.

Highway 93 settled and cracked over a distance of about 200 feet where the roadway crosses a section of marsh 1 mile southeast of the intersection of Trail Creek Road (about 1.5 miles southeast of the fault rupture). About 6 in of differential settlement occured across segments several feet wide at each end of the disturbed zone. Fissures up to 3 in wide fractured the pavement at several places. We saw no fissures or other ground effects in the natural ground on either side of the highway.

A 1.5-mi-long rather continuous zone of fissures extended northwestward from near Trail Creek Road along the alluvial fan fronts on the east side of Thousand Springs Valley (Fig. 5). The fissures were caused by lateral spreading of distal ends of the fans toward the valley bottom. The zone of fissures was as wide as 250 ft and was about 1 mi east of the southern segment of fault rupture (Fig. 1). The fissures usually developed in subparallel sets with individual cracks roughly paralleling the fan front (Fig. 6). Individual fissures were as long as 1,000 ft and open to depths as great as 10 ft. Separations were as great as 2 ft, but due to collapse of material into the fissures, they were open as wide as 4 ft at several localities. At some localities along fan-marsh interface, which forms the downslope bound or toe of the zone, segments of marsh sod were thrust outward over the marsh by the spreading movement. The thrusting generated buckels and scarps in the marsh sod as high as 4 ft (Fig. 7). Sand boils erupted at several localities along the fan-marsh interface and at a few localities on the fissured surface. Sand boils were more common at mouths of draws where the ground slope is more gentle than along steeper fan fronts. Small, permanent springs also flow out of margins of the fans in several places.

The apparent cause of the lateral spreading was liquefaction of a subsurface sediment layer. The eruption of sand boils at several places along the toe and on the spread are evidence of this phenomenon. The sediment deposited by the sand boils in all observed instances was silty fine sand (Fig. 3), indicating that the layer that liquefied is composed of approximately equally fine grained material. That material is finer grained and better sorted than the fan material exposed in fissures. The fan material is rather poorly sorted and contains both finer particles (clay-size) as well as coarser sand, gravel, and cobble size particles than the sand boil deposits.

Highway 93 traversed the zone of lateral spreading noted above for a distance of about 2,000 ft between at a point 1.2 mi northwest of the Trail Creek Road and Whiskey Springs (site 2). Across most of this zone, 4 ft wide and 10 ft deep fisures marked the head of the lateral spread and up to 4 ft high buckles and scarp marked the toe (Figs. 7 and 8). The fissures at the head, about 100 ft above the highway, splayed out, diminished in size, and curved back toward the highway on both ends of the 2,000-ft-long zone. The road pavement across the section was disrupted in numerous places by fissures, scarps, and offsets with dimensions as large as 5. Fissures in the sholders and barrow pits along the road, however, were as wide as 16 in. Roughened pavement caused by these fissures and scarps slowed the flow of traffic and created some rather hazardous driving conditions, but did not block the roadway. The roadway and underlying ground were also also displaced at least 4 ft downslope across the middle part of the section. This displacement created a gentle concave curve in the road (Fig. 9). Sand boils erupted along cracks in the barrow pit on the up hill side of the road, on the alluvial fan surface between the road in the marsh, and along the toe of the spread.

North of Whsikey Springs on the east side of Thousand Springs Valley (site 3); fissures on the alluvial fan fronts diminished to sporadic zones of ground cracks; however, hundreds of sand boils erupted along a 3-mi-long zone of fan front (Fig. 10). At one locality which we traversed on foot, we observed more than a hundred sand boils with deposits ranging from 0.5 ft to 8 ft in diameter in a 1,500 ft long zone that extended 300 ft upslope from the marsh. The area traversed lies east of Chilly Road along the northern edge of Section 20, T 9 N, R 22 E. The sand boils in the zone were scattered with spacings between boils generally being greater than 100 ft. Only a few scattered small fissures developed within this zone.

We saw no sand boil deposits or fissures on marsh grasss in the Thousand Springs Valley other than those near fan fronts, and many of those erupted through cracks in the sod at the toes of lateral spreads. Because of the high water table and generally thick section of late Holocene sediment in those areas, liquefiable material should be abundant. Two possible reasons for the lack of sand boils and fissures are: (1) The sediment may be too fine grained to liquefy; (2) the thick mat of roots in the grassey sod that covers the marshes may have acted as a filter inhibiting sediment from erupting to the ground surface in boils and formed a ductile surface that stretches instead of cracks. The latter explanation seems the most likely to us.

We drove a 5-mi-long segment of the Big Lost River extending southeastward from near the intersection of the Trail Creek and Parsons Creek Roads. We observed a part of the floodplain and frequently the river channel as we drove this distance; in addition, we walked across the floodplain at several scattered localities. We did not see any sand boils or ground cracks, and conclude from this sample that no significant liquefaction effects occurred in this segment of the river. All of this section of river lies between 2 and 4 mi from the southern terminus of the fault rupture. The floodplain material in this section is generally gravelly and cobbly with vaneers of sand and silt overbank deposit away from the channel and sporadic thin sand bars near the channel. The probable reason for the lack of effects in this area is that the sedeiment may be too coarse and well drained to liquefy or at least produce surficial liquefaction effects. We also checked the floodplain of the Big Lost River at several localities along Trail Creek Road in the Thousand Springs Valley and in White Knob Mountains to the southwest, and found no surface evidence of liquefaction.

Some of the most spectacular effects of the earthquake were violent eruptions of huge sand boils and springs in a 1-mile long northwest trending zone that cut across the eastern tip of Chilly Buttes (site 4). The sand boils on the valley floor reportedly spewed water and sediment up to 20 ft into the air for several hours after the earthquake. This action flooded part of the Thousand Springs Valley, spread hundreds of cubic yards of sediment across the ground surface in the vicinity the outbursts, and pocked the surface with craters (Fig. 11). Where the zone cut across the tip of Chilley Buttes, springs gushed out of the hill side as high as 50 ft above the valley floor. These springs washed sediment from the hillside, cut gullies, and blocked a ranch road and irrigation ditch. Two authors (Keefer and Wilson) mapped the area noting widths and depths of craters and delineating the areas covered by sediment (Fig. 12). They counted craters larger than 2 ft in diameter and measured 10 with diameters greater than 20 ft and depths greater than 5 ft. The largest crater had a diameter of 50 ft and a depth of 20 ft. (Dave and Ray correct the numbers given and fill in the blanks, or revise to better state what happened/ Les.) At least one crater existed before the earthquake and was deepened by the outburst of water during this event. That crater was apparently was created by a similar eruption of water during a previous earthquake, possibly the 1956 Hebgen Lake, Montana, event. The quanty of water expelled and the fact that eruptions developed high on the hillside of Chilley Butte indicate that the source for the water that flowed out of the boils and springs was a deep aquifer that was either pressurized or the confining cap fractured by earthquake actions. More information on the outbursts near Chilley Buttes and increases in spring flow in other parts of the Thousand Springs Valley is given in the chapter on Ground Water Hydrology in this report.

Although the soil in the vicinity of these huge sand boils certainly liquefied during the earthquake, the cause of liquefaction was not compaction of shallow sediment, the usual cause of soil liquefaction, but rather upward flow of water from a deep aquifer. The usual techniques applied by geotechnical engineers to evaluate liquefaction susceptibility, therefore, do not apply in this instance.

Warm Springs, Salmon, and Pahsimeroi Vallies

We drove Highway 93 to Challis viewing the floodplain of Warm Springs Creek, which is unwooded and clearly visable along most of this route. In addition, we walked the floodplain at several localities where conditions appeared favorable for liquefaction to occur. We found no liquefaction effects in that area.

We checked the floodplain of the Salmon River at several localities between Challis and the Pahsimeroi Valley to look for liquefaction effects. We saw several areas where conditions appeared favorable for liquefaction to occur, but saw no effects. Most exposures of the floodplain, however are covered with gravel and cobbles indicating that the materials may be too coarse and well drained to develop surficial liquefaction effects. We also interviewed two residents who live near the river; neither had seen nor heard of any ground effects caused by the earthquake.

We checked the flood plain of the Pahsimeroi River near its confluence with the Salmon River and saw no ground effects caused by the earthquake. We then drove southeastward through the Pahsimeroi Valley, crossing the valley on each public road. These roads, not all of which are marked on Fig. 1, are 3 to 5 mi apart, and thus provide only limited access to the valley bottom and river floodplains, the areas where liquefaction would most likely occur. The areas we visually checked and the interviews we made with local residents, however, provide enough information to give the types and general distribution of effects that occurred, and indicate that we probably did not miss any damaging or extra large effects.

A few hundred sand boils erupted in a 2,000-ft-long and 500-ft-wide zone that extends eastward from Hooper Lane across a flat terrace a few hundred ft north of the Pahsimeroi River (site 5, Fig. 1). The zone is 16.5 mi north of the fault rupture. The only house on the east side of Hooper Lane lies within the zone of sand boils; the house was undamaged eventhough several boils erupted within a hundred of feet of the structure. A few boils also erupted in a field west of the house across Hooper Lane. The largest sand boil deposits were about 6 ft across; most deposits, however, were about 2 ft across; and the smallest contained only a few thousand grains of sand (Fig. 13). All of the deposits were composed of medium-grained white sand. In many instances the sand boils erupted along small fissures that were as wide as 4 in. These fissures formed an arcuate pattern that seemingly outlined a latteral spread with incipient southward movement. Immediately south of the zone of sand boils, the ground surface drops to a 4-ft-lower terrace which is covered by marsh grass. Not a single sand boil that we could see erupted through the grassy surface, although several sand boils erupted near the northern margin of the terrace and a few erupted within a small stream that flows across the terrace. This observation is consistent with the behavior noted in the Thousand Springs Valley and further suggests that thick marsh grass inhibits the eruption of at least small to moderate size sand boils.

The owner of a ranch located south of the Pahsimeroi River and about 0.5 mi east of Hooper Lane reported that a number of sand boils, perhaps as many as 100, erupted in his fields. He described their size as small, each containing "two or three buckets full of sand." These sand boils were about 15 mi north of the fault rupture. The rancher had not observed any increases in the flow of springs on his ranch, but noted that his well flowed turbid water for a few days following the shock.

Southeastward in the Pahsimeroi Valley from the ranch noted above, we did not see nor hear of any ground effects attributable to liquefaction. Our reconnaissance included field checks of several likely sites as well as visual observations from the public roads and interviews with several ranchers. One rancher whose property is near the confluence of Goldberg Creek and the Pahsimeroi River reported that springs in his area had increased their flow, including the one near his home from which the ranch takes its culinary water.

Distribution of Liquefaction Effects

Most of the liquefaction effects described above developed in lowland areas along rivers draining the vallies surrounding the Lost River Range. Geologic maps of the region indicate that materials in these lowlands are late Holocene fluvium (McIntyre and Hobbs, 1978; Nelson and Ross, 1969; Rember and Bennett, 1979a, 1979b). Thus, most of the liquefaction developed in late Holocene sediment.

The notable exception to the above conclusion is the sediment that liquefied beneath and caused lateral spreading of alluvial fans in the Thousand Springs Valley. The materials in the fans are mapped as old alluvium of late Pliestocene and Holocene age (eg. Nelson and Ross, 1969). The finer grained layer that liquefied beneath the fans must be equally as old or older than the overlying fan deposit. Only the distal ends of the fans, where deposition is slowly but activly occuring, was affected by liquefaction. The materials in these areas are amoung the youngest in the fan and thus would be of Holocene, and possibly even late Holocene, age. Because fluvial sedimentation also actively occurs on the marshy valley floor in front of the fans, the sediment being covered at any point in time is only slightly older than the material in the cover. Thus, we conclude that the sediment that liquefied beneath the fans is also of Holocene, and possibly late Holocen, age.

Although much of the ground surface in the vallies near the epicentral area is covered by old alluvium of late Pleistocene to Holocene age, including some areas with high ground water, we neither saw nor heard of liquefaction effects other than those previously described along the fan fronts.

The restiction of liquefaction to saturated Holocene (mostly late Holocene) sediment of fluvial origin is consistent with experience during past earthquakes. Based on field observations, this type of sediment is classed among the most susceptible materials to liquefaction (Youd and Perkins, 1978). The lack of liquefaction in the older alluvium also is consistent with behavior in other parts of the world. Sediments of this age, late Pliestocene and early Holocene, generally have low to moderate susceptibility to liquefaction. In particular, alluvial fan deposits, which make most of the older alluvium, have shown high resistance to liquefaction (Youd and Perkins, 1978).

The distance from the fault rupture to the farthest localities where liquefaction occurred is much smaller for this earthquake than would predicted from worldwide correlations. The fissures in Highway 93 near Leslie, 23.5 mi from the fault rupture, are the most distant effects attributable to liquefaction. That distance is only about half the possible maximum distance expected for M_s 7.3 earthquakes according to the curve given by Youd and Perkins (Fig. 14). This more rapid attenuation of liquefaction effects with distance, however, is consistent with Modified Mercali Intensity which also decreased more rapidly with distance than would generally be expected.

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Figure Captions

Fig. 1.--Map of region investigated showing geographic features and locations of effects associated with liquefaction.

Fig. 2.--Structures at Site 1 damaged by lateral spreading: (a) damaged house with sand boil deposit on front lawn; (b) foundation at back of house where slippage of 5 in between blocks accomodated lateral displacement that occurred beneath structure; (c) Steel framed barn that was astride fissured zone and pulled apart at the base by about 1 ft.

Fig. 3.--Grain size distribution curves for samples taken from various sand boil deposits.

Fig. 4.--Concrete boxes housing well pump and water tank; the lighter box containing the pump buoyantly rose 3 in due to liquefaction of surrounding soil.

Fig. 5.--Map showing approximat~~ion~~ locations ~~and dimensions~~ of fissures geneated by lateral spreading of distal ends of alluvial fans in the Thousand Springs Valley.

Fig. 6.--Oblique aerial photo of fissures along alluvial fan fronts mapped on Fig. 5.

Fig. 7.--Buckled and overturned sod in toe of lateral spread mapped on Fig. 5. This disruption occurred below damaged section of Highway 93 where fissures above highway and lateral displacement of highway was greatest.

Fig. 8.--Aerial view of lateral spread south of Whiskey Springs that damaged Highway 93 and produced the buckling shown in Fig. 7.

Fig. 9.--Displacement of Highway 93 south of Whiskey Springs due to lateral spreading.

Fig. 10.--Sand boil typical of those that erupted on alluvial fan surface in a 3-mile-long zone north of Whiskey Springs. The material in the sand boil

deposit is better sorted than the material in the fan.

Fig. 11.--Aerial view of craters near Chilley Buttes which were caused by violent expulsion of water from a deep aquifer and which spewed water and sediment tens of feet into the air while eroding the craters.

Fig. 12.--Map of Chilley Buttes area showing craters, areas covered by ejected seciment, and flooded areas.

Fig. 13.--Sand boil deposit typical of hundreds that occurred in a 1,500-ft-long zone in the Pahsimeroi valley.

Fig. 14.--Distance to farthest significant liquefaction effect versus earthquake magnitude (M_s) for past earthquakes (after Youd and Perkins, 1978) with data from 1983 Mt. Borah Idaho event.

Fig. 1

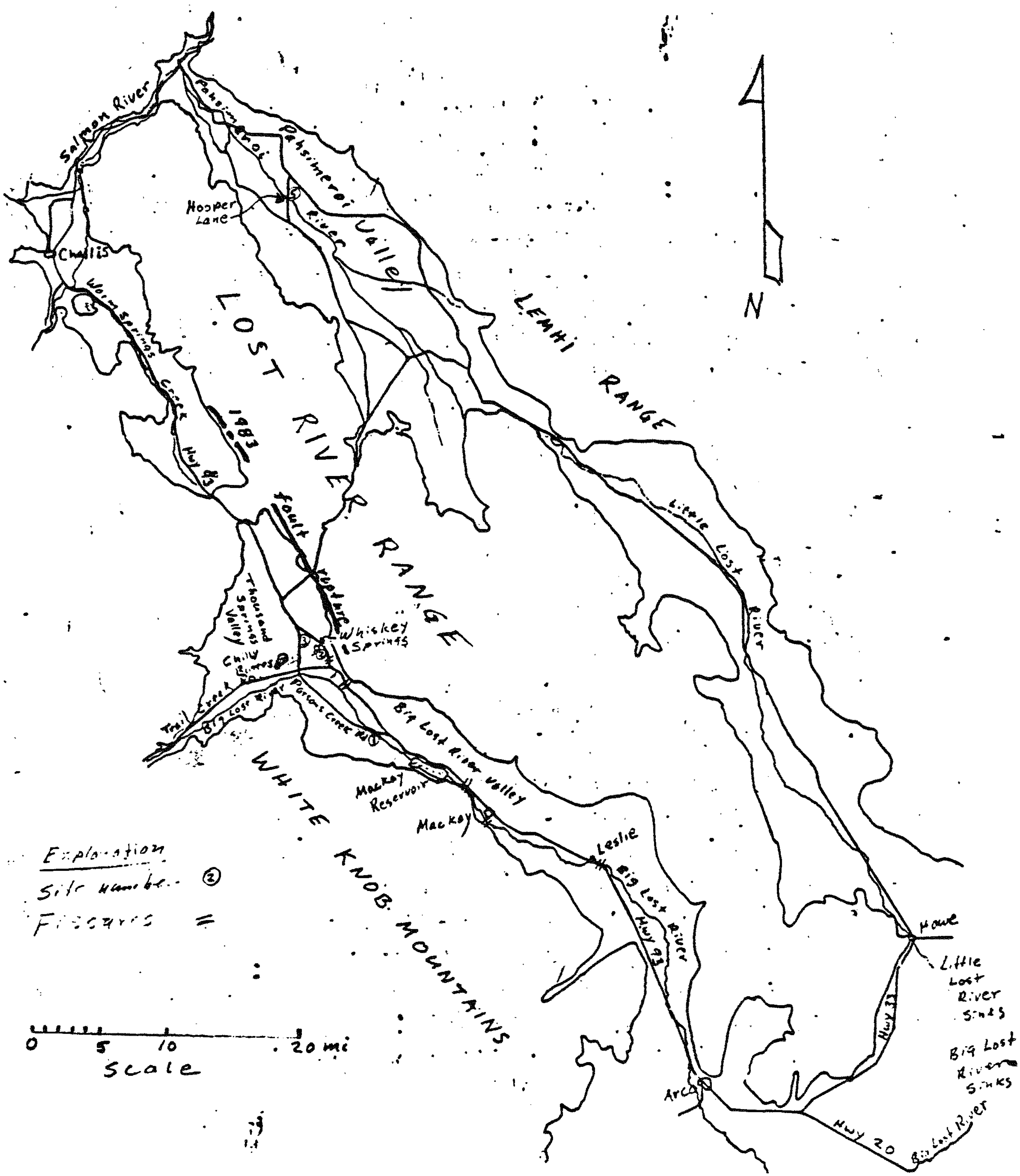


Fig. 1.--Map of region investigated showing geographic features and locations of effects associated with liquefaction.

Fig. 2(a)

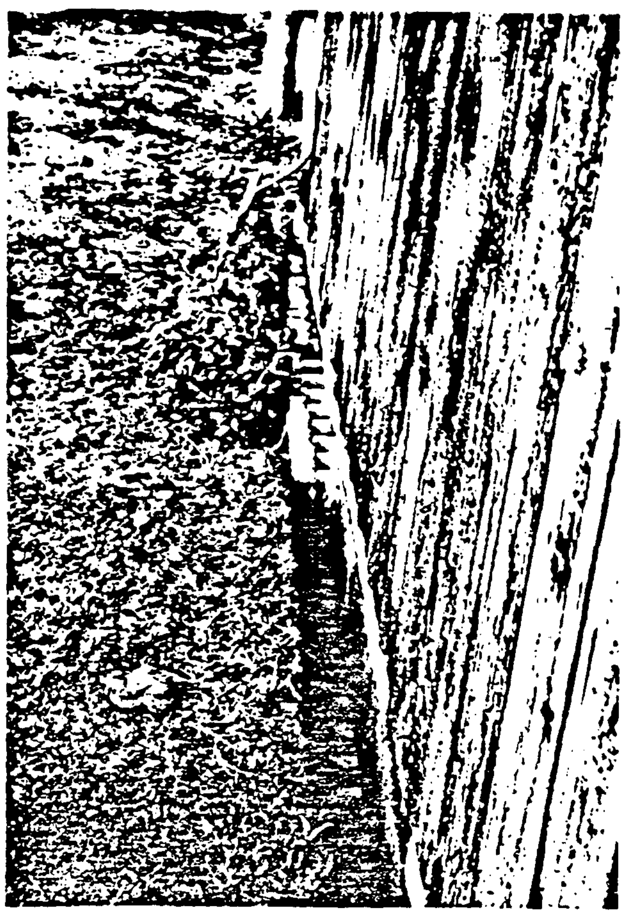
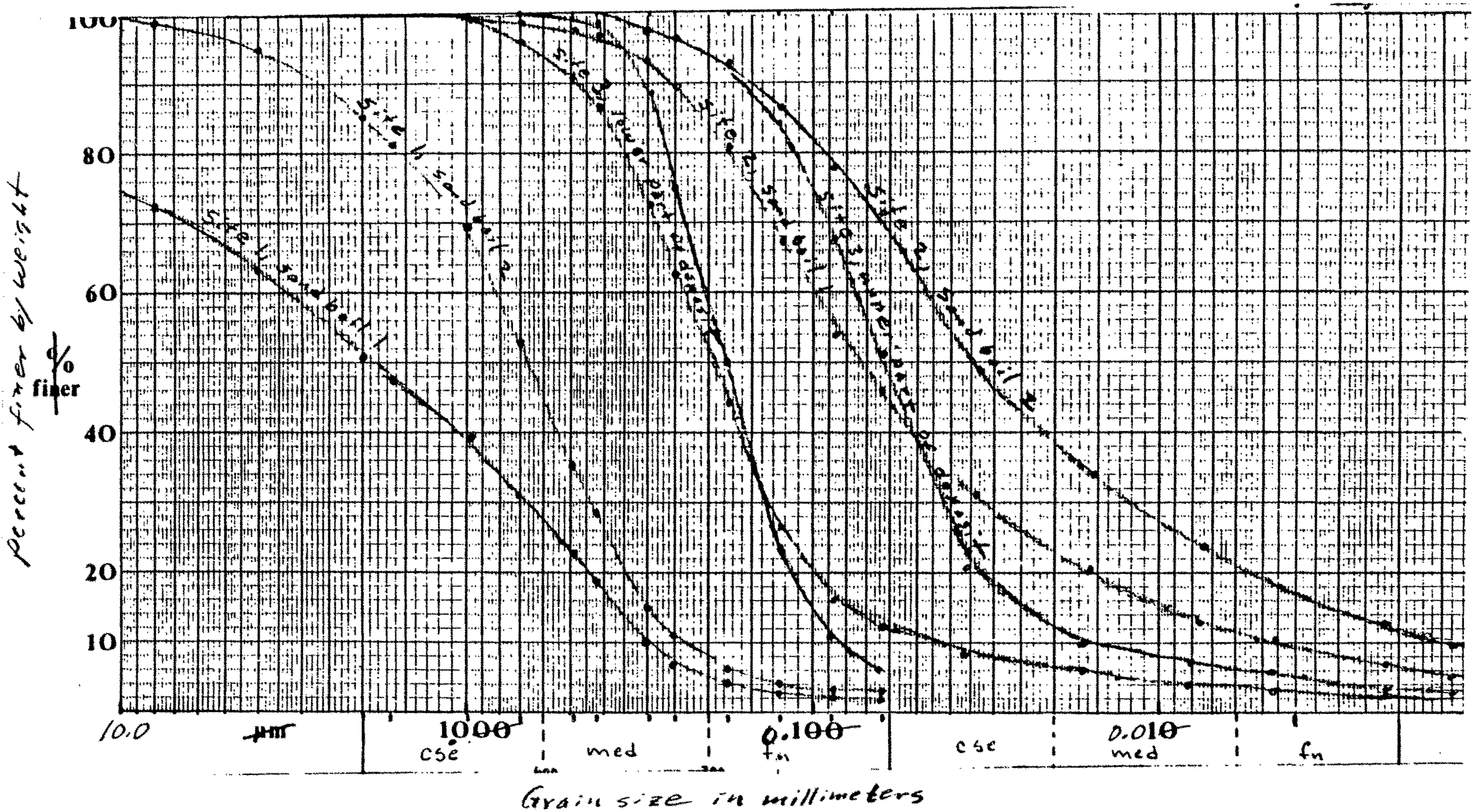


Fig. 2(b)

Fig. 2 c)

Fig. 2.--Structures at Site 1 damaged by lateral spreading: (a) damaged house with sand boil deposit on front lawn; (b) foundation at back of house where slippage of 5 in between blocks accomodated lateral displacement that occurred beneath structure; (c) Steel framed barn that was astride fissured zone and pulled apart at the base by about 1 ft.



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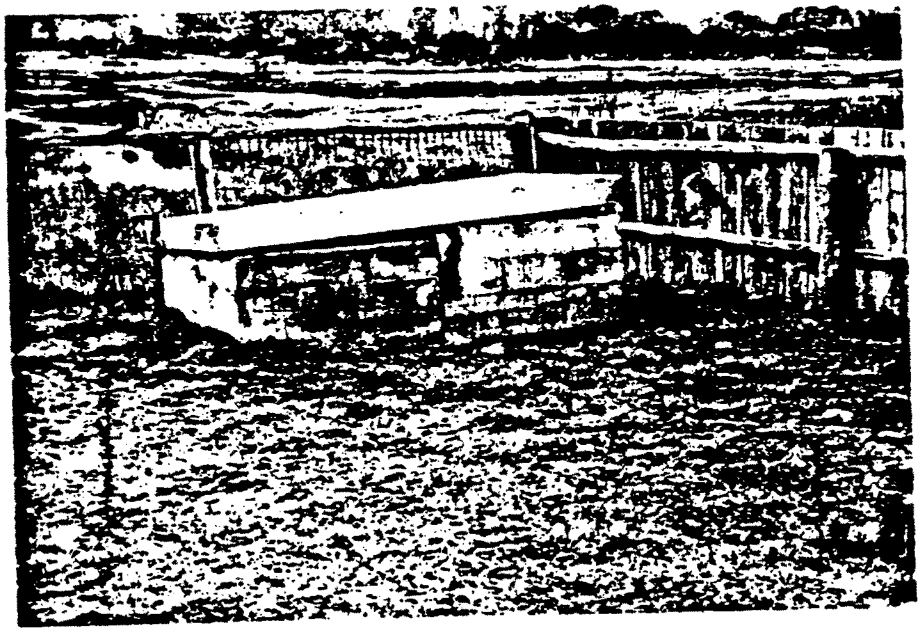
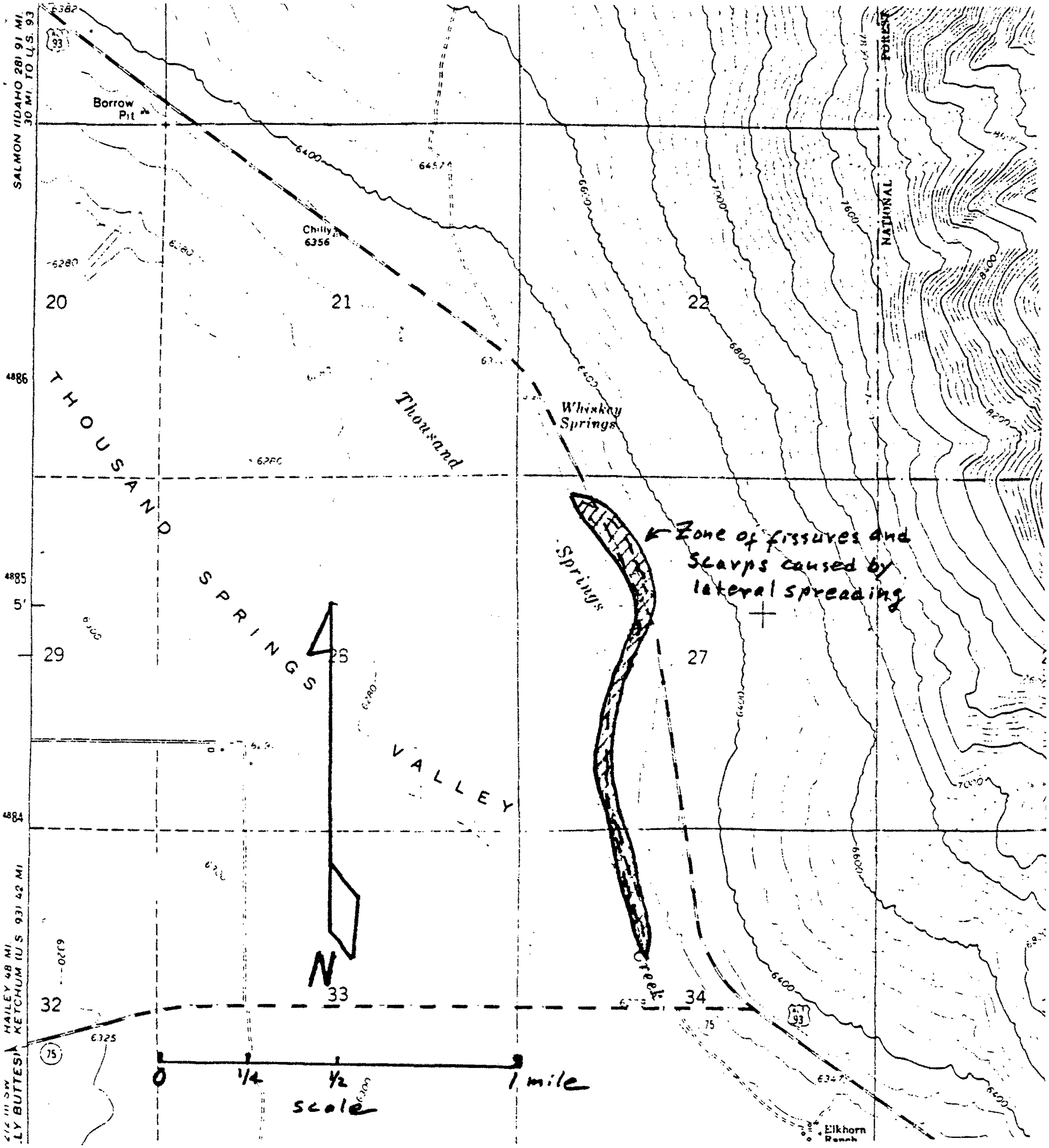


Fig. 4.--Concrete boxes housing well pump and water tank; the lighter box containing the pump buoyantly rose 3 in due to liquefaction of surrounding soil.



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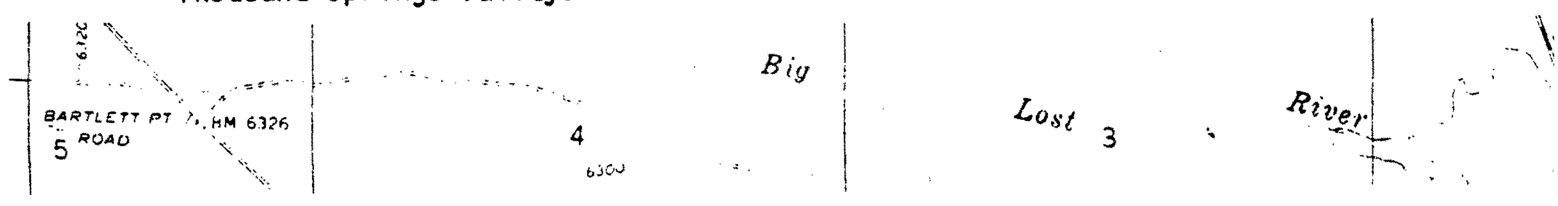

Fig. 6.--Oblique aerial photo of fissures along alluvial fan fronts mapped on Fig. 5.

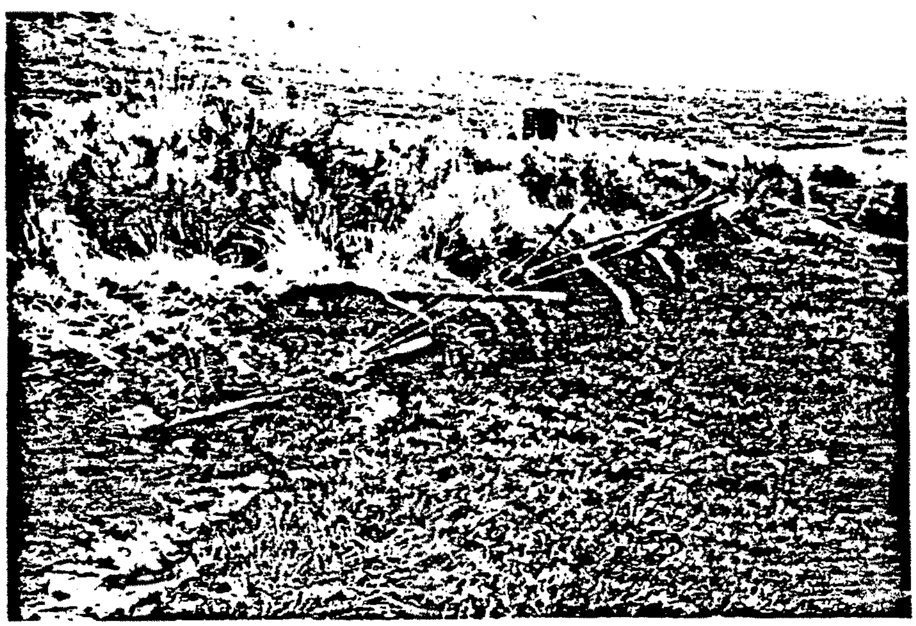

Fig. 7.--Buckled and overturned sod in toe of lateral spread mapped on Fig. 5. This disruption occurred below damaged section of Highway 93 where fissures above highway and lateral displacement of highway was greatest.

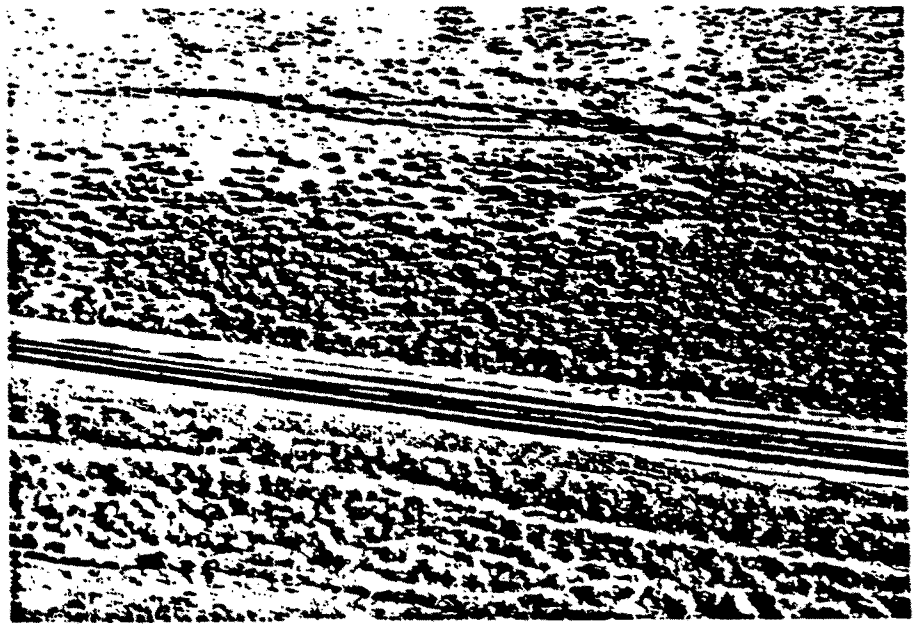

Fig. 8.--Aerial view of lateral spread south of Whiskey Springs that damaged Highway 93 and produced the buckling shown in Fig. 7.

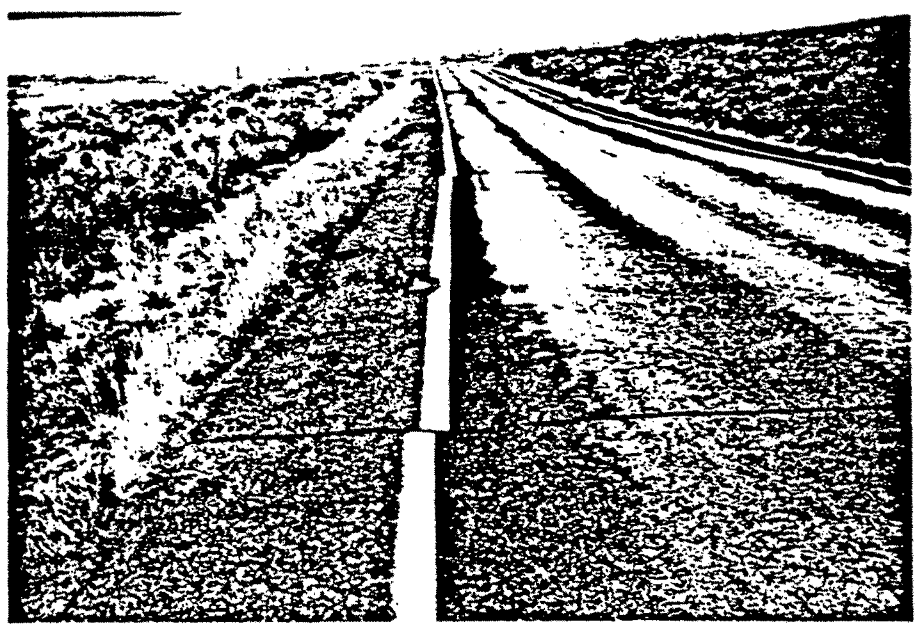

Fig. 9.--Displacement of Highway 93 south of Whiskey Springs due to lateral spreading.

Fig. 10 deleted

Fig 11(a)

Fig. 11.--(a) Aerial view of craters near Chilley Buttes which were caused by violent expulsion of water from a deep aquifer and which spewed water and sediment tens of feet into the air while eroding the craters. (b) Ground view ~~of one of the craters~~ showing walls and blanket of ejected

Fig-12

Topography to be added later by Dave and Ray —

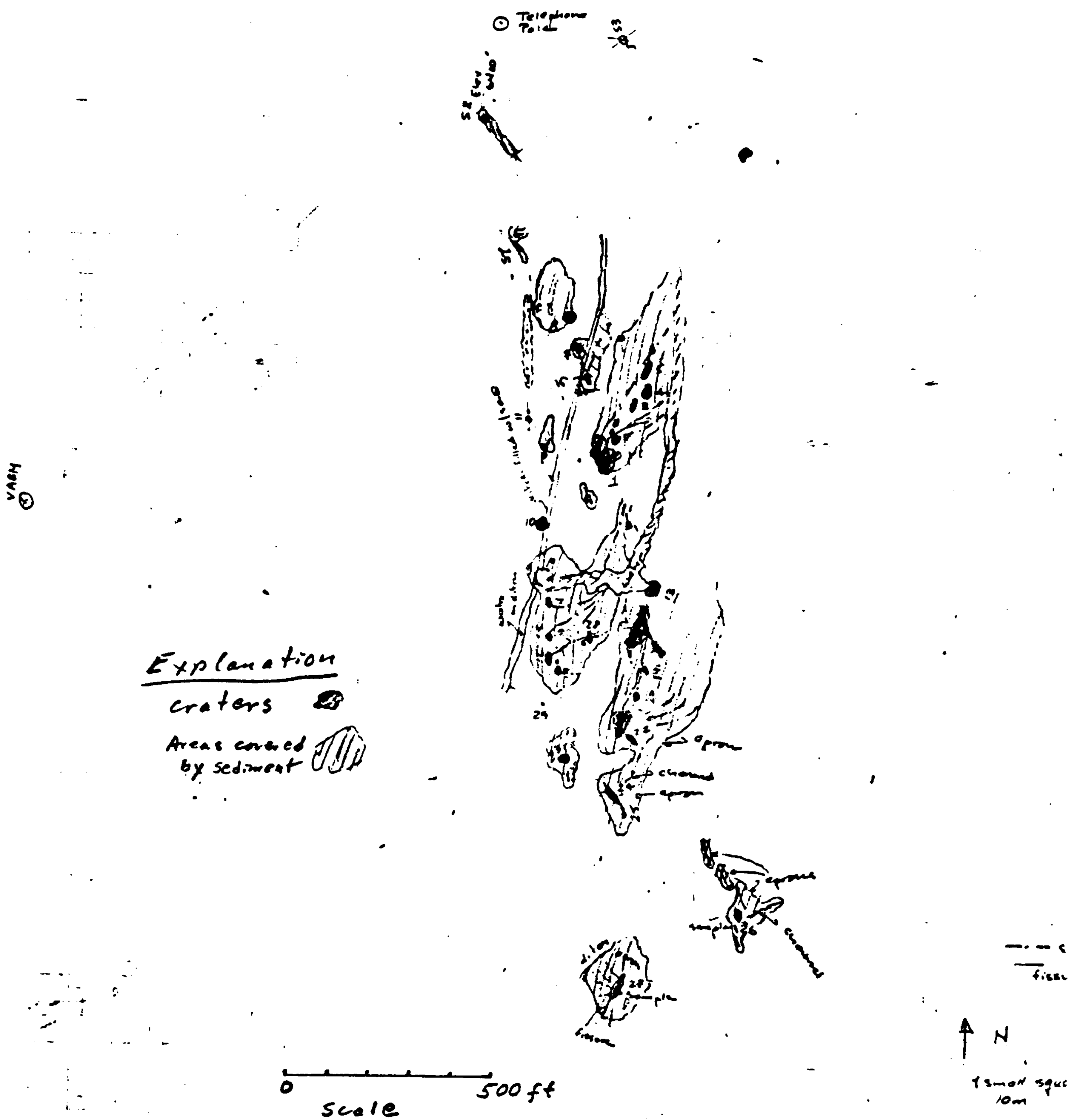

Fig. 12.--Map of Chilley Buttes area showing craters, areas covered by ejected sediment, and flooded areas.

Fig. 13.--Sand boil deposit typical of hundreds that occurred in a 1,500-ft-long zone in the Pahsimeroi valley.

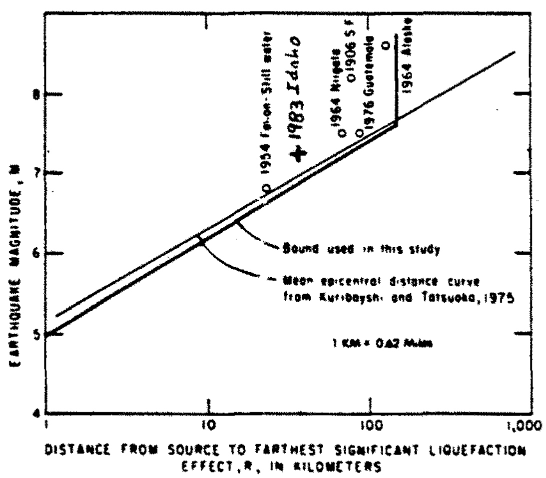

Fig. 14.--Distance to farthest significant liquefaction effect versus earthquake magnitude (Ms) for past earthquakes (after Youd and Perkins, 1978) with data from 1983 Mt. Borah Idaho event.