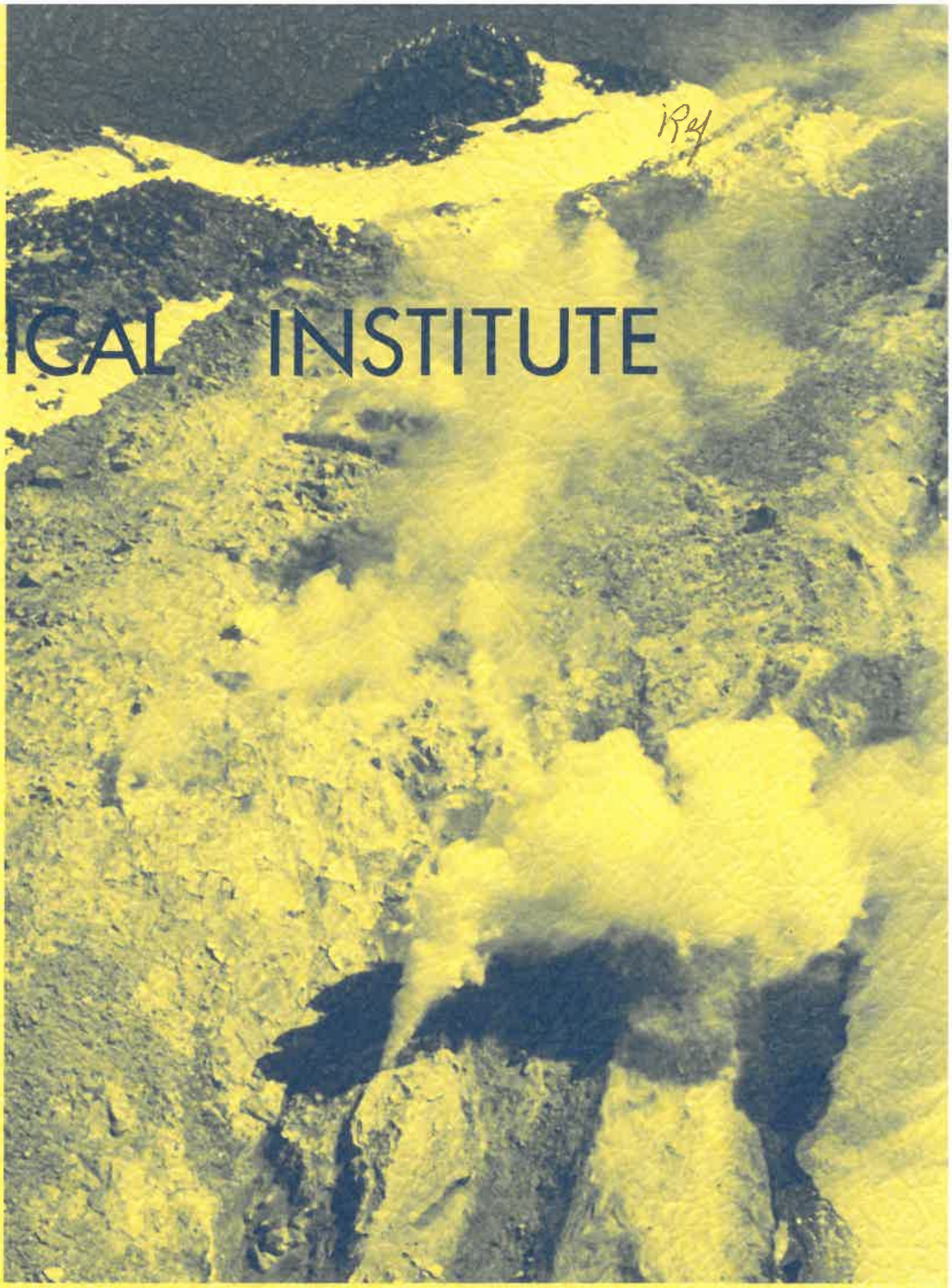

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A GEOPHYSICAL RECONNAISSANCE OF PILGRIM SPRINGS, ALASKA

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Report Approved By

K. B. Mather
Keith B. Mather
Director

ABSTRACT

A geophysical survey of Pilgrim Springs, Alaska, including seismic refraction, geomagnetic, microseismic background and water temperature studies indicates that the springs deserve further exploration as a potential geothermal resource.

Seismic profiling indicates possible Tertiary reservoir rocks or hydrothermally cemented cap rock at a depth of 205 ft.

Subsurface probes detected water temperatures up to 80°C, and local temperature inversions caused by the mixing of spring and groundwater and convective circulation in coarse, permeable sands.

Less diluted spring water, when sampled at depth, will probably be more saline and silicious than that previously sampled at the surface; and estimated reservoir temperatures, based on geothermometry, will probably be increased.

A modest exploration program, involving additional geophysical and geochemical studies and the drilling of a test hole, is recommended.

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INTRODUCTION

Location and History

Pilgrim Springs is located approximately 40 miles north of Nome, in the southwest corner of the Bendeleben (A-6) Quadrangle (figure 1).

Before the arrival of the white man, the Eskimo name for Pilgrim Springs was Kruzgamepa. During the height of early gold mining activity, the Springs served as a resort for residents of Nome, Solomon, Council and other mining communities, and vegetables were also raised at the springs for local markets.

Subsequently, the Catholic Church established a mission school for native children at Pilgrim Springs which was closed in 1942. At present, the springs are leased from the Catholic Church by C.J. Phillips of Nome.

Pilgrim Springs as a Potential Geothermal Resource

Although Pilgrim Springs has a previous agricultural and resort history, it has excited more recent interest as an indicator of a possible subsurface geothermal steam or hot-water reservoir.

Based on the silica, potassium-sodium and sodium-potassium-calcium thermometers (White, 1970) (Fournier and Truesdell, 1970) (Fournier and Truesdell, 1973), estimates of the sub-subsurface reservoir temperature of Pilgrim Springs have ranged from 150° to over 200°C. Previous estimates of spring water flow rates have ranged from 8 to 20 gal/min. However, data reported in this study show that earlier temperature and flow measurements must be treated with caution, due to the high permeability of the surrounding channel sands, and the mixing of spring and ground water.

A 1971 aeromagnetic survey by the State of Alaska Division of Geological and Geophysical Survey included the Pilgrim Springs area, but flight line spacing was too wide for application to subsurface interpretation at Pilgrim Springs.

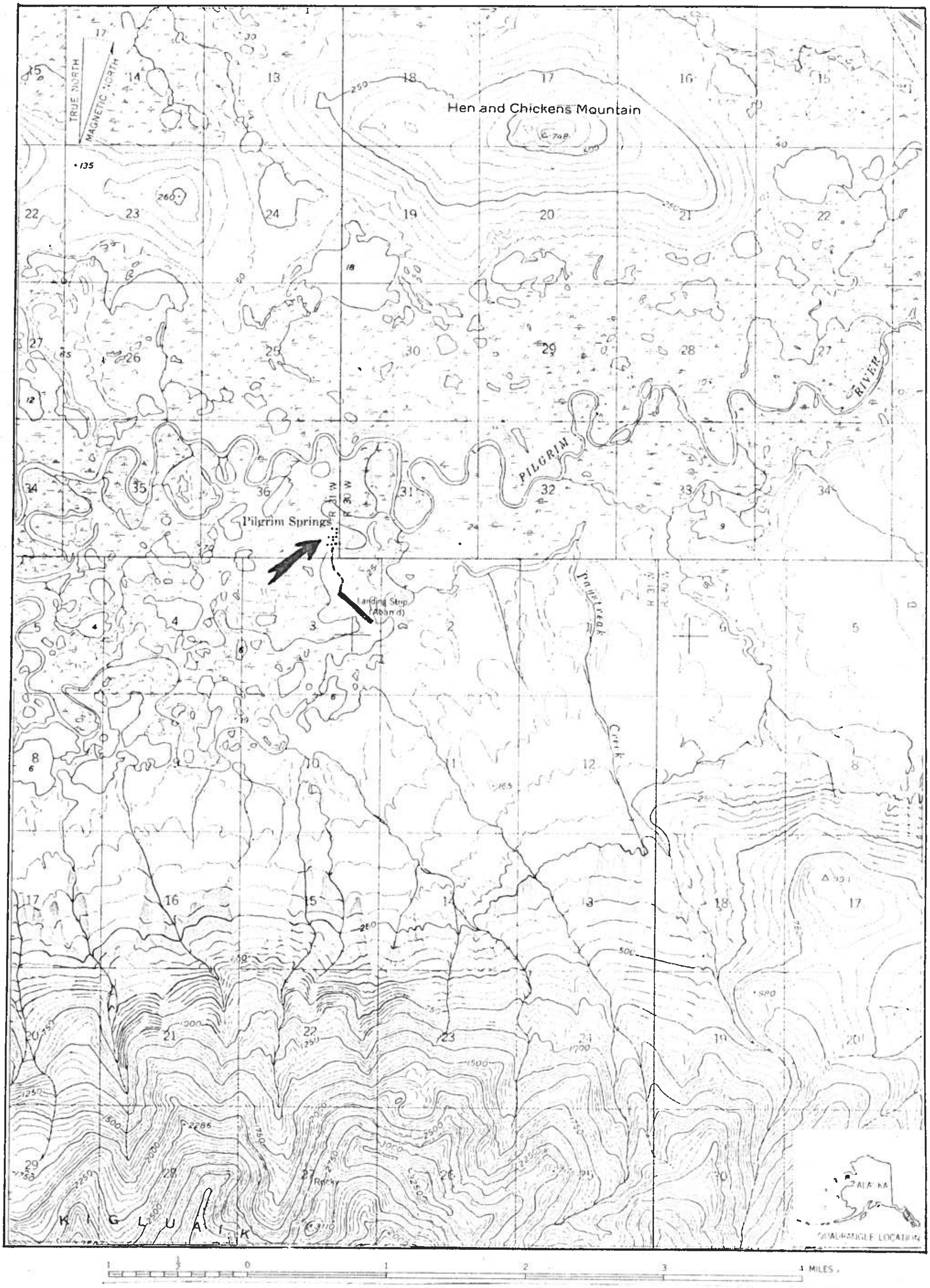

Figure 1. Location map of Pilgrim Springs, as taken from the Bendeleben A-6 Quadrangle.

Most recently, Harding-Lawson Associates of Anchorage conducted an electrical resistivity survey of the Pilgrim Springs area for Stefano and Associates, also of Anchorage, Alaska, (1974) which contributed additional data on the geophysical setting of the site.

Geologic Setting

Areal Geology: The Pilgrim River Valley is mantled by alluvial fill. Precambrian gneisses and biotite schists are exposed on Hen and Chickens Mountain, four miles north of the springs, and Cretaceous granitic intrusives cut Precambrian gneisses and schists in the hills to the south and east (Sainsbury, 1974). Miller, et al. (1972) have suggested that an extension of the Bendeleben range front fault may underlie the alluvium of the Pilgrim River Valley, and that Pilgrim Springs may be related to this fault system.

Serpentine Hot Springs is located approximately 50 miles north of Pilgrim Springs. Serpentine Spring waters are chemically similar to the Pilgrim Spring waters, as characterized by high salinity of the NaCl type (Table 1). The saline character of the Pilgrim Spring water has aroused speculation on a possible marine origin.

To the northeast, a large, lowland area centered on Imuruk Lake is covered by a very young basaltic volcanic field which ranges in age from 3.5 million year old basal volcanics, to very young flows which may have been erupted as recently as a few hundred years ago (D.M. Hopkins, unpublished data).

Site Geology: The larger springs and associated seeps emerge from channel sands and silts in an abandoned meander loop of the Pilgrim River (figure 2). However, other seeps and patches of warm ground occur in the adjacent area as shown by snow-free ground and bright green vegetation in winter versus summer aerial photographs (figure 2).

Table 1. Chemical analysis of Pilgrim and Serpentine Springs water, as taken from Miller, et al. (1973).

Component	Pilgrim	Serpentine	
SiO_2	100	100.0	* PPM
Al	0.044	0.083	
Fe	-----	-----	
Ca	530	47.0	
Mg	1.4	0.48	
Na	1450	730.0	
K	61	40.0	
Li	4.0	4.7	
NH_3	-----	-----	
HCO_3	30.1	64.5	
CO_3	-----	-----	
SO_3	24	29.0	
Cl	3346	1480.0	
F	4.7	6.4	
Br	-----	-----	
pH	6.75	7.91	

(Analysis taken from Miller, et al., 1973)

* parts per million

Figure 2. Northeast oblique aerial photograph of Pilgrim Springs, showing abandoned Catholic mission buildings, and man-made pools and ditches. Pilgrim airstrip is at lower right. The zone of maximum upwelling follows the arcuate trace of the abandoned meander channel in the center of the photo, and the spring waters are the source for the stream which follows the old meander channel.

(Photo by R.B. Forbes)

Based on the apparent lack of subsidence and tilting of the mission buildings (with the exception of damage of uncertain origin to the greenhouse), and the absence of thermokarst pits in the cleared fields, the Pilgrim Springs area appears to be free of permafrost. The three dimensional geometry and areal extent of the thawed zone are not known.

East of the church, and on the north bank of the channel adjacent to the bathing pool, trees, stumps, and posts are tilted to the north at various angles up to 35° (figure 3). It seems unlikely that this phenomena is due to the thawing of frozen ground. The stumps are from trees which were cut before 1943, and we believe that the tilting process pre-dates the arrival of the white man at Pilgrim Springs. Tilting of the trees appears to be due to slumping to the south toward the springs, as related to sapping caused by the lateral circulation of hot spring waters in the underlying channel sands.

Geophysical Survey Objectives

In an attempt to refine previous estimates of the geothermal potential of Pilgrim Springs, we applied several geophysical survey techniques including:

(1) Seismic refraction profiling
(2) Geomagnetic profiling
(3) Microseismic background recordings
(4) Surface and subsurface water temperature measurements in springs and seeps

The results of the survey follow.

GEOPHYSICAL SURVEY

Seismic Refraction Profiling

Methods: Seismic refraction profiles were obtained along a line extending from the landing strip northward to the old mission buildings. In all, a distance of 2250 ft. was traversed, although the profile was broken up into

Figure 3a. Tree stumps tilted to the north (hammer handle is horizontal). Trees were cut prior to 1942; the year the mission was abandoned.

Figure 3b. Trees and post tilted to the north, about 100 ft. north of locality 3a.

(Photos by R.B. Forbes)

partially overlapping segments of 730, 740, and 950 ft. The end points (shotpoints) for these three segments are shown schematically in Figure 4 as AB, BC, and DE. Each profile was reversed, and the resulting travel-time curves, together with their least-square parameters, are shown as Figures 5, 6, and 7. Geophones were spaced at either 50 or 100 ft., except at the southern end of the profile, where the spacing was reduced to 10 or 15 ft. To enhance control, the last geophone location of an array was made the first geophone location of the succeeding array. Thus, in Figure 5, there are two arrivals plotted at 60, 110, and 210 ft. Shot magnitude was governed by distance to the recording array, and ranged from a single electric blasting cap for the ten-foot spaced configuration at the southern end of the line, to three pound charges of nitrocarbonitrate at both ends of the 950-foot spread. The shots were buried to a depth of about two feet. Because of the flat terrain and shallow shotholes, no delay times were applied. Recording was accomplished on a six-channel SIE seismic refraction-reflection field unit, and the photographic records were read to the nearest millisecond. Either hardwire or radio time-breaks from the blaster were recorded, depending on the distance from the shotpoint to the recording site. In some cases the radio time-break overrode the seismic signal, resulting in the loss of a data point from one channel.

Data Analysis: Each record was read individually by the two investigators, and when discrepancies were noted, the records were re-read until the results were satisfactory to both. Choices regarding the observations to be included on each individual curve (i.e., should a particular observation be included on the first or second branch of the curve, or on both?) were made by first manually plotting the curves, visually picking "best fits," and then working out the relevant parameters. Several different options for each of the curves

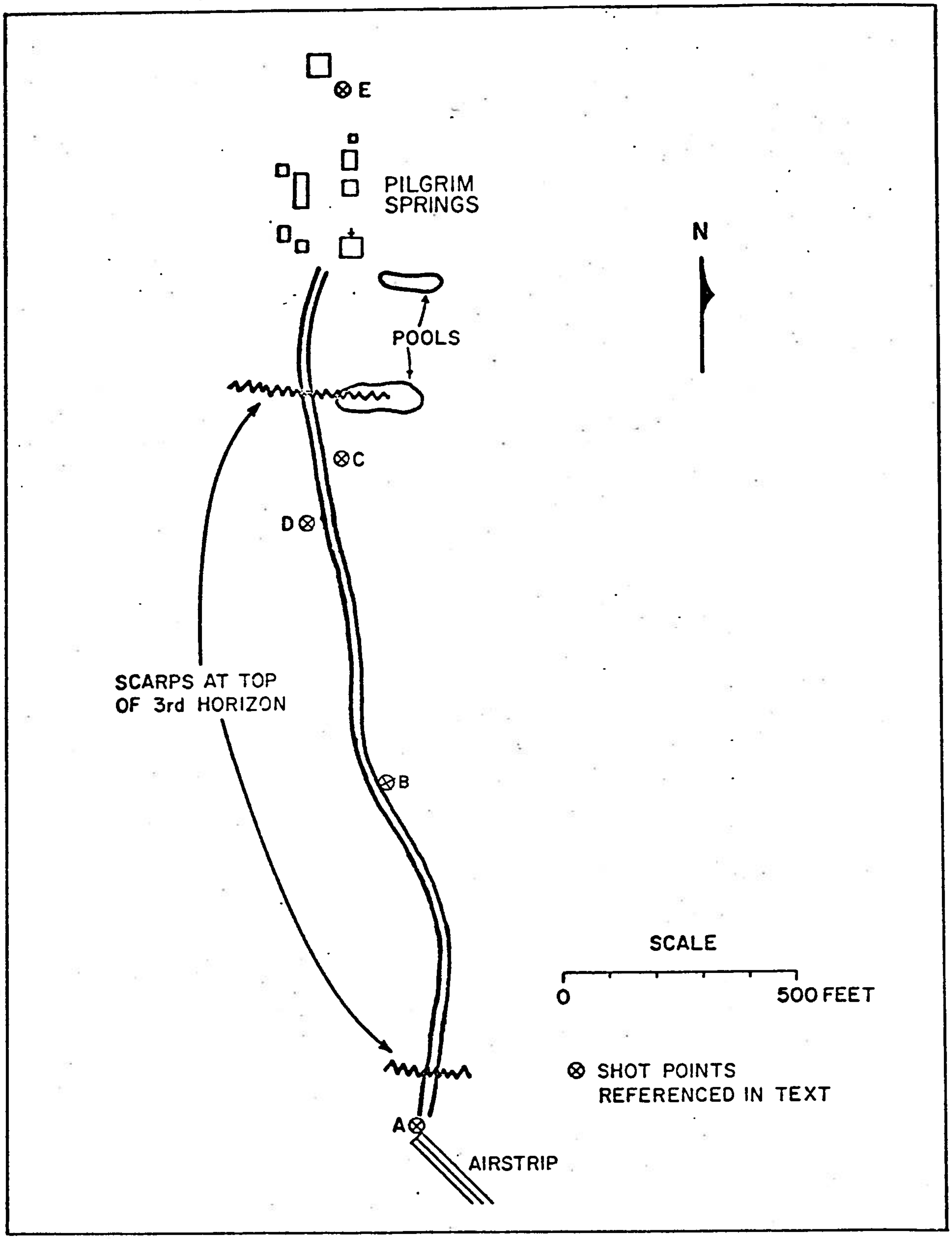

Figure 4. Location map showing shotpoints of seismic profile and subsurface breaks in slope of layer #3.

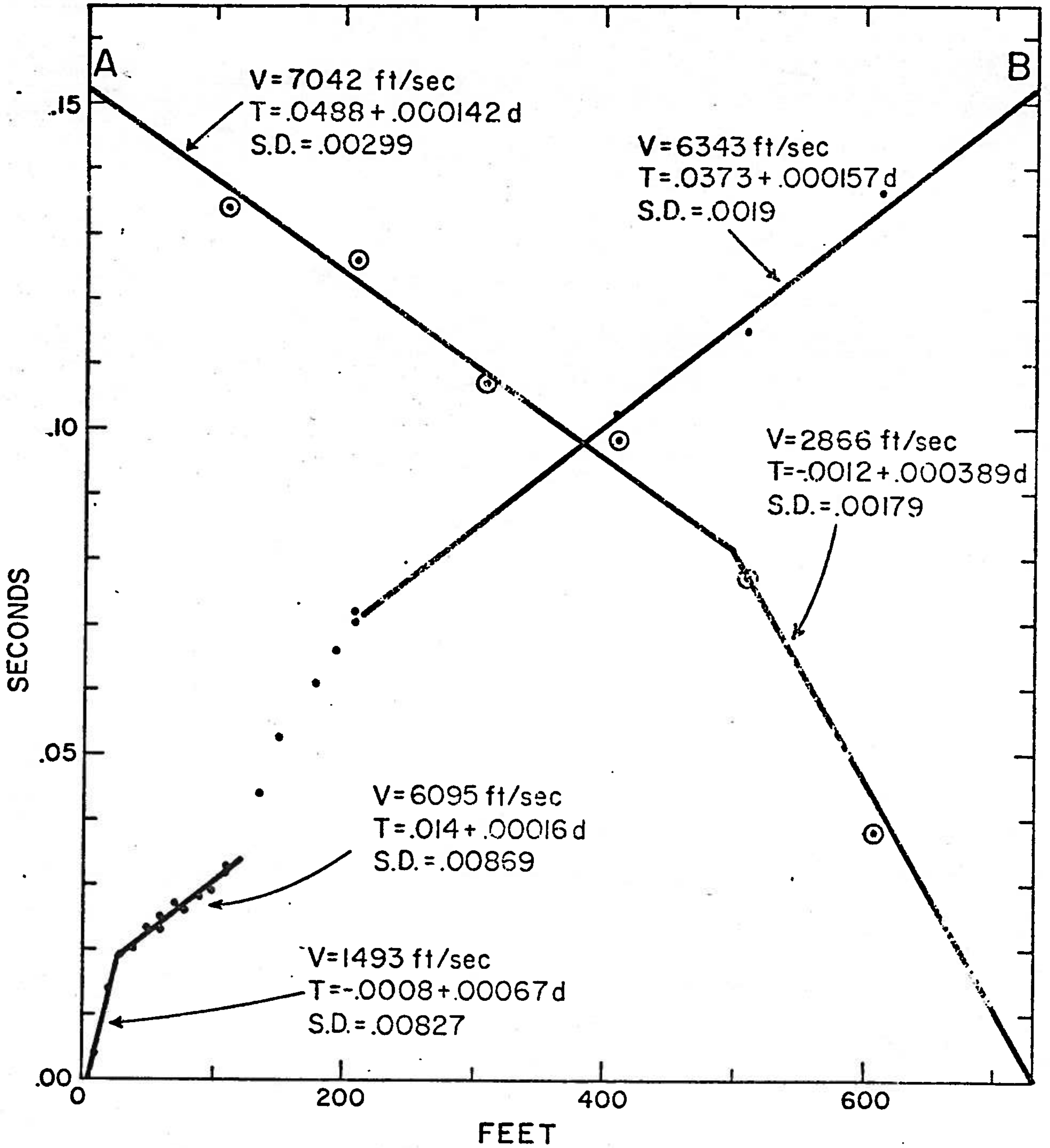

Figure 5. Travel-time curves A-B.

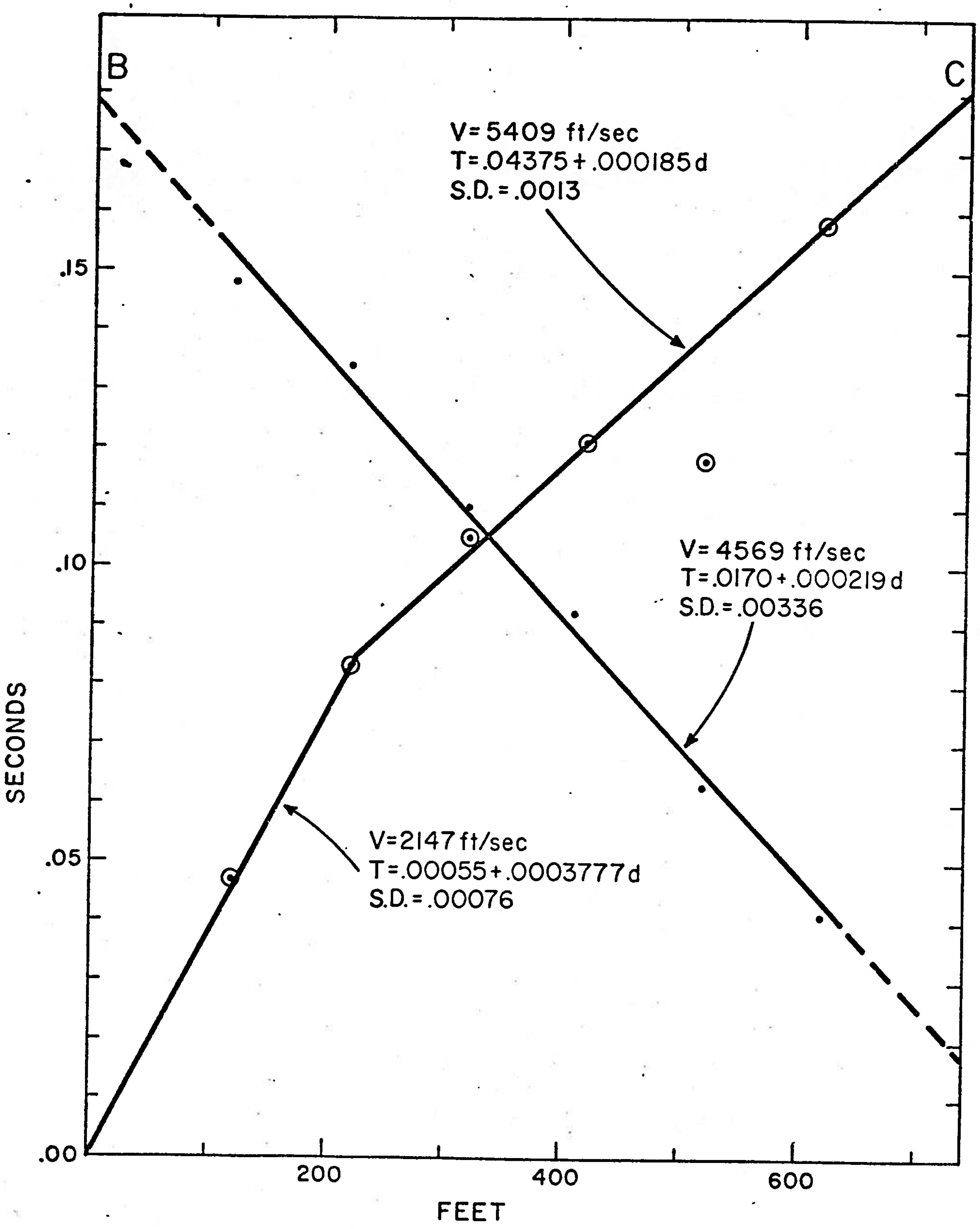

Figure 6. Travel-time curves B-C.

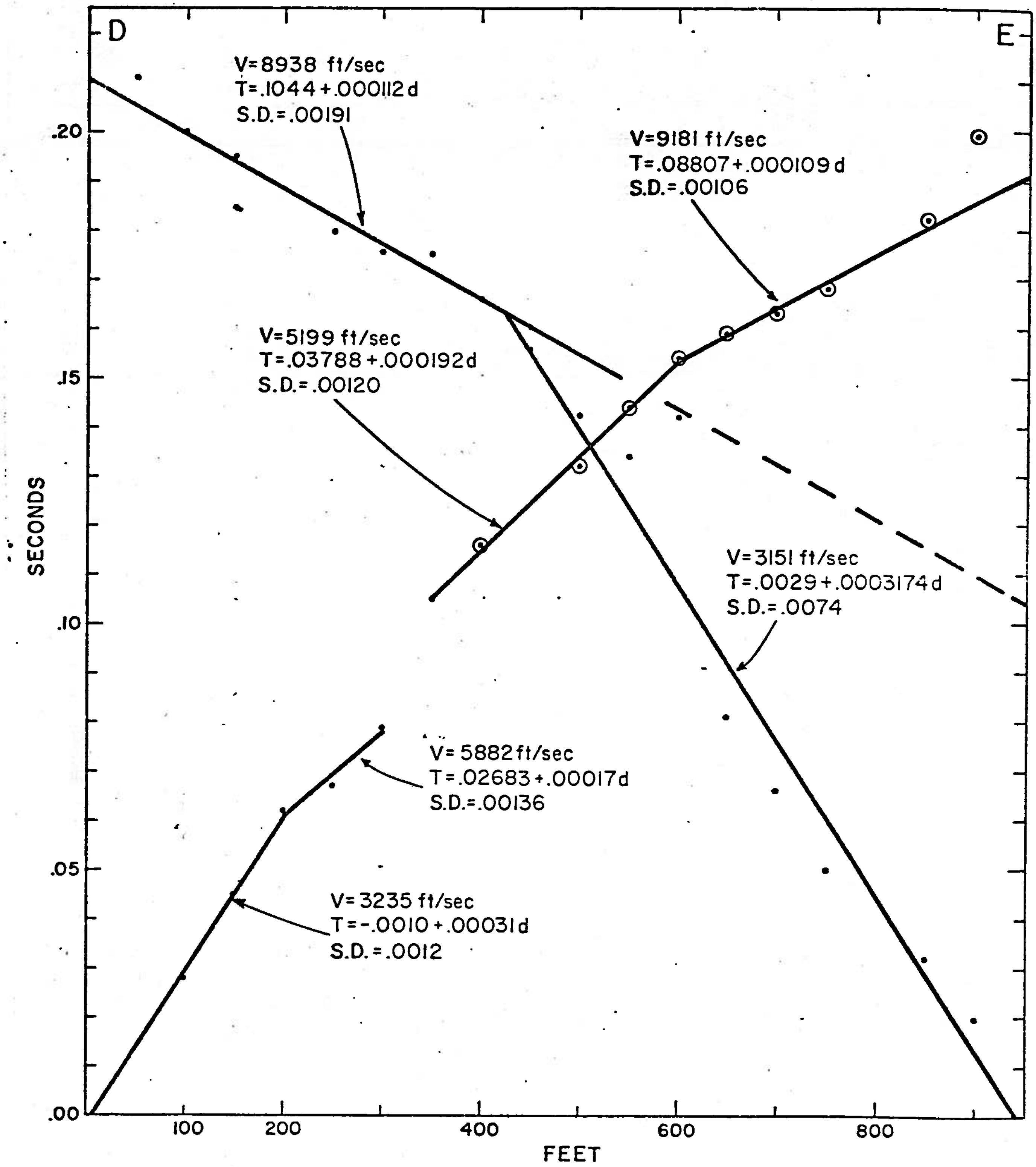

Figure 7. Travel-time curves D-E.

were investigated, and the ones which showed the greatest consistency between computed slopes and depths, and agreement between adjacent profiles were chosen. Slopes, intercepts, and standard deviations (in seconds) were then computed by the least-squares method, and summaries are given for each branch in Figures 5, 6, and 7. Figure 8 includes a cross section which seems to offer the best fit to the seismic data. It should be noted that in most cases, the velocities on Figure 8 are not exactly those computed for individual branches of the travel-time curves, but are based on interpretation of the problem as a dipping layer case.

Subsurface Interpretation: The subsurface structure of the Pilgrim Springs area appears to be laterally and vertically heterogeneous, as judged from the range in recorded seismic velocities. Some striking departures from expected arrival times were noted at individual geophones, even though adjacent phones in the array received "normal" arrivals. Moreover, these anomalies were reproducible, as shown by identical results which were recorded in four successive experiments. As an example, one geophone emplaced northwest of the church received the seismic signal from the north end of line DE 8 milliseconds later than a geophone 50 ft. more distant, and at the same time as a phone 100 ft. more distant. In another case involving line BC, the fifth geophone from the southern end received an arrival 3 milliseconds earlier than the phone 100 ft. closer to the shot. The most practical explanation of these anomalous arrivals is the probably presence of discontinuous layers of lenses of sand, silt and gravel.

In general, our data indicate that four subsurface layers are present in the section. The uppermost is the usual "weathered zone," extending to about a depth of 10 ft., which is typified by compressional wave seismic velocities of around 1500 ft/sec (well shown in the closely-spaced profile at the southern end of the refraction line).

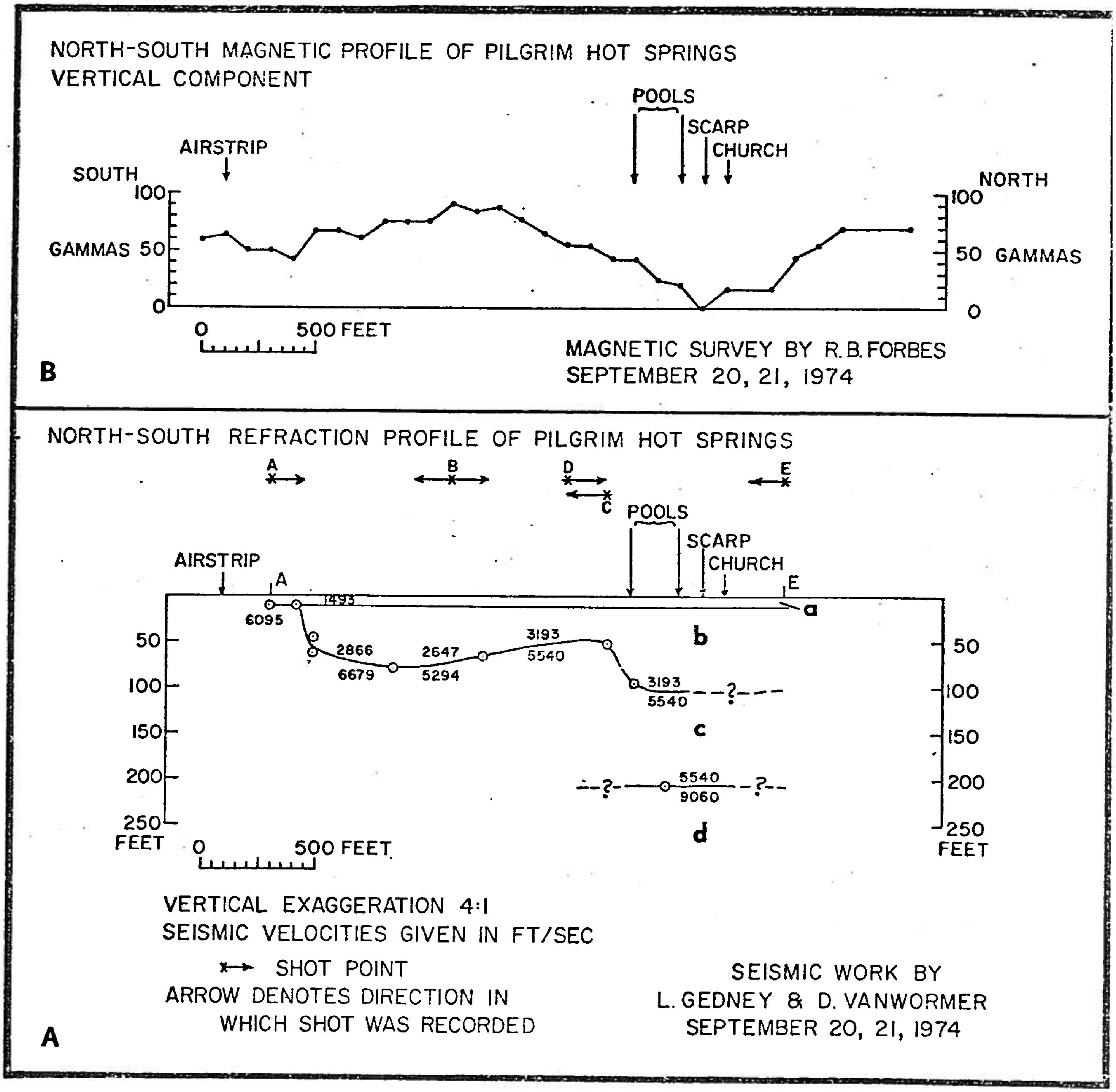

Figure 8. Subsurface section, as interpreted from seismic data (A); and magnetic profile along same traverse line (B).

The second refracting horizon, which is characterized by velocities of around 3000 ft/sec, appears to be relatively homogeneous, but varies considerably in thickness across the profile. While nearly 100 ft. thick at the north end, it apparently pinches out to the south. Most likely, this layer is composed of fluvial sediments, including sands, silts, and gravels.

The third recognizable layer exhibits a broader range of seismic velocities from around 5000 to over 6500 ft/sec. The average thicknesses for this layer is about 125-150 ft. However, the upper discontinuity is offset by two prominent breaks in subsurface relief. These breaks in slope have the appearance of normal faults, north side down (with throws of 35 and 43 ft.), although an equally good case can be made for buried river terraces or cut and fill structure in gravels. The observed velocities are representative of coarse, compacted sediments, and there is a good possibility that this layer is stream-cut glacio-fluvial gravels.

The deepest (208 ft.) discontinuity detected in the profile is defined by velocities exceeding 9000 ft/sec. Although this velocity is too low for crystalline rocks, it is within reason for poorly compacted Tertiary sediments. Unfortunately, only the northernmost (950 ft.) leg of the traverse had sufficient geophone spacing to conclusively record this discontinuity, although breaks in slope of the travel-time curves representing this discontinuity were picked up by the outermost "jugs" in the arrays of the other two traverses.

Geologic Interpretation: The geometry of the discontinuity between layers B and C could be reasonably explained as channel cut and fill structure, related to the meander history of the Pilgrim River. A subsurface profile presented by Harding-Lawson (Stefano and Associates, 1974), based on resistivity data, shows a normal fault which displaces bedrock under the springs, with the north side down-thrown about 500 ft. Although the buried fault scarp shown in the Harding-Lawson section coincides with the subsurface slope break in layer C as defined by our seismic data, we cannot reconcile the difference between our 208 ft. discontinuity (5540/9060 ft/sec) and the 600 ft. depth of alluvial fill above the down-thrown fault block as shown in their structure section.

The 9060 ft/sec velocity calculated from our data is too low for gneisses, granitic rocks, and schists such as those exposed on the surrounding hills. This velocity is appropriate, however, for Tertiary sandstone and conglomerates or highly indurated till. Tertiary (Miocene-Pliocene) coal-bearing sediments occur in a Tertiary Basin a few miles to the northeast in the valley of the Noxapaga River (Sainsbury, 1974). Pilgrim Springs Valley is also an apparent tectonic depression, and there is a good probability that Tertiary rocks are present in the subsurface, under Pleistocene glacio-fluvial sediments.

Another interpretation of the 9060 ft/sec seismic discontinuity and accompanying negative geomagnetic anomaly is offered by a discovery reported by Ackerman (1974) in seismic refraction studies of geothermal anomalies near Raft River, Idaho. A 8500 ft/sec velocity zone was encountered at a depth of 600 ft., where alluvial fan gravels had been hydrothermally cemented into conglomerate by upwelling thermal waters. These same studies also outlined two zones of faulting within the gravels and underlying volcanics, which may have acted as channel ways in the spring conduit system.

Magnetic Profiling

Magnetic profiling was done with a Sharps MF1-100 fluxgate magnetometer, which measures the vertical component of the magnetic field. Readings were taken at 100-ft. intervals along the same line as the seismic profile, with the exception of the area near the old mission buildings where steel siding and roofing caused serious peturbations in the magnetic field. In this case, the north end of the traverse was offset 200 ft. to the east to avoid this effect. The results of the survey are plotted in the diagram shown as Figure 8, along with the subsurface structure as interpreted from the seismic data.

The range in measured magnetic intensity along the traverse was less than 100 gammas, which indicates that the shallow subsurface materials in the section are of similar magnetic susceptibility. Based on seismic data and surficial exposures, the negative deflection in the magnetic profile near the springs may be due to the thickening of the alluvial sand and silt unit, at the expense of underlying glacio-fluvial gravels. The positive slope in magnetic intensity north of the church suggests that the discontinuity between the two units may rise again to the north, and that the magnetic low may be a former river channel cut in gravels which is filled with sand and silt. However, the leaching of magnetic minerals in the sands and silts by thermal spring waters could also lower the magnetic susceptibility, and it is possible that the anomaly may in part reflect such alteration, as discussed below.

Spring Water and Subsurface Temperature Measurements

Instrumentation: Water and soil temperatures were measured with a thermistor probe and meter calibrated against ambient air temperature. Measurements are believed to be accurate to ± 2°C.

Water Temperatures: Water temperatures in the man-made pools and ditches south of the mission church ranged from 17°C to 45°C. Temperatures measured with the probe buried 6" in bottom sediment ranged from 27°C to 80°C, with the highest temperature obtained from bottom sediment at the bottom of the steel cylinder on the north margin of Pool #2 (figure 9).

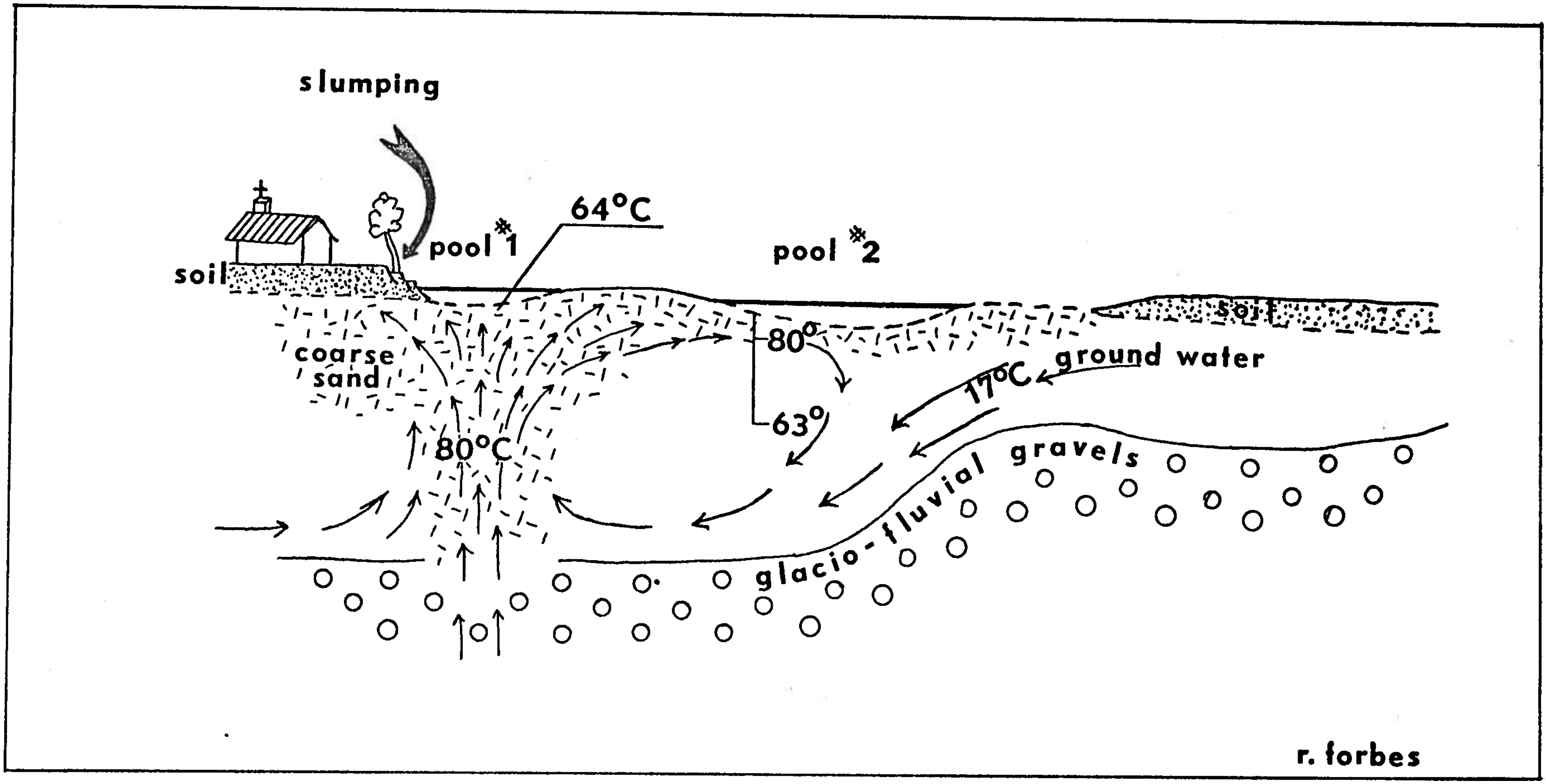

Figure 9. Cartoon illustrating convection system formed by ground water and thermal spring waters at Pilgrim Springs, as visualized by authors.

Temperatures measured in areas of maximum upwelling in Pool #1, with the probe inserted 6" into the bottom sediment averaged 64°C. These temperatures were also measured in other areas to the west end of the airstrip.

Reversed Gradients, Mixing and Possible Convection: A thermal probe which penetrated 7'10" into the bottom sediment of Pool #1 recorded a maximum bottom hole temperature of 80°C (a gradient of approximately 2°C/ft). An unexpected reversal in the temperature gradient was encountered in Pool #2 (25 ft. south). The probe measured a maximum temperature of 80°C 6" into the bottom sediment, but with increasing depth beyond four ft., the temperatures declined to a minimum of 63°C at 7'10".

Ground water temperatures averaging 17°C were measured in shotholes, where the water filled the holes up to 2' below the surface within minutes after detonation. Soil temperatures averaging 19°C were measured 6" below the surface in surrounding areas up to 1000 ft. away from the springs. The mixing of cold ground water and hot, saline spring water may generate a convective circulation system similar to that as shown in Figure 9, below.

Microseismic Background Study

During the nights of September 19-20 and 20-21, a portable high-gain Kinemetrics PS-1A seismograph was operated in the church at Pilgrim Hot Springs. The sensor, a SS-1 Ranger seismometer, was placed on the concrete steps near the southwest corner of the church. During the first night, the system had a ground-to-record magnification of 40,000 at 20Hz which was increased to 80,000 at 20Hz during the second night. The system is capable of running at much higher gain, but in this case, magnification was limited by our activity some 250 ft. from the sensor, which generated large signals which were potentially harmful to the recording pen.

Although it is somewhat risky to draw broad conclusions on two nights of data, the Pilgrim Hot Springs area appears to be very quiet seismically (figure 11). The complete absence of microseismic activity on the record reduces the probability of a subsurface geothermal steam field below Pilgrim Springs, as most producing geothermal steam fields are characterized by a high local microseismic background.

CONCLUSIONS AND RECOMMENDATIONS

Discussion

Geothermal Implications of Spring-Ground Water Mixing: The discovery of 80°C subsurface spring water temperatures, mixing and convection requires a reassessment of the Pilgrim Springs geothermal system.

If 80°C spring water and 17°C ground water are mixing in the shallow subsurface to produce water in upwelling areas of 63°C, mixing is probably occurring at a ratio of approximately 3:1.

Unfortunately, we do not know the chemistry of the uncontaminated ground water at this date. However, we can safely assume that the SiO_2 Na, Cl, Ca and K content of the undiluted 80°C spring water is higher than that of the surface spring water which was previously sampled and analyzed by Waring (1917) and Miller and Barnes (1973). Therefore, application of the SiO_2, Na/K and Na/K/Ca geothermometers to re-analyzed unmixed spring water samples may bring higher estimated reservoir temperatures than those previously calculated.

The prospect of higher reservoir temperatures and possible reservoir and cap rocks in the subsurface, increases the attractiveness of Pilgrim Springs as an exploration target.

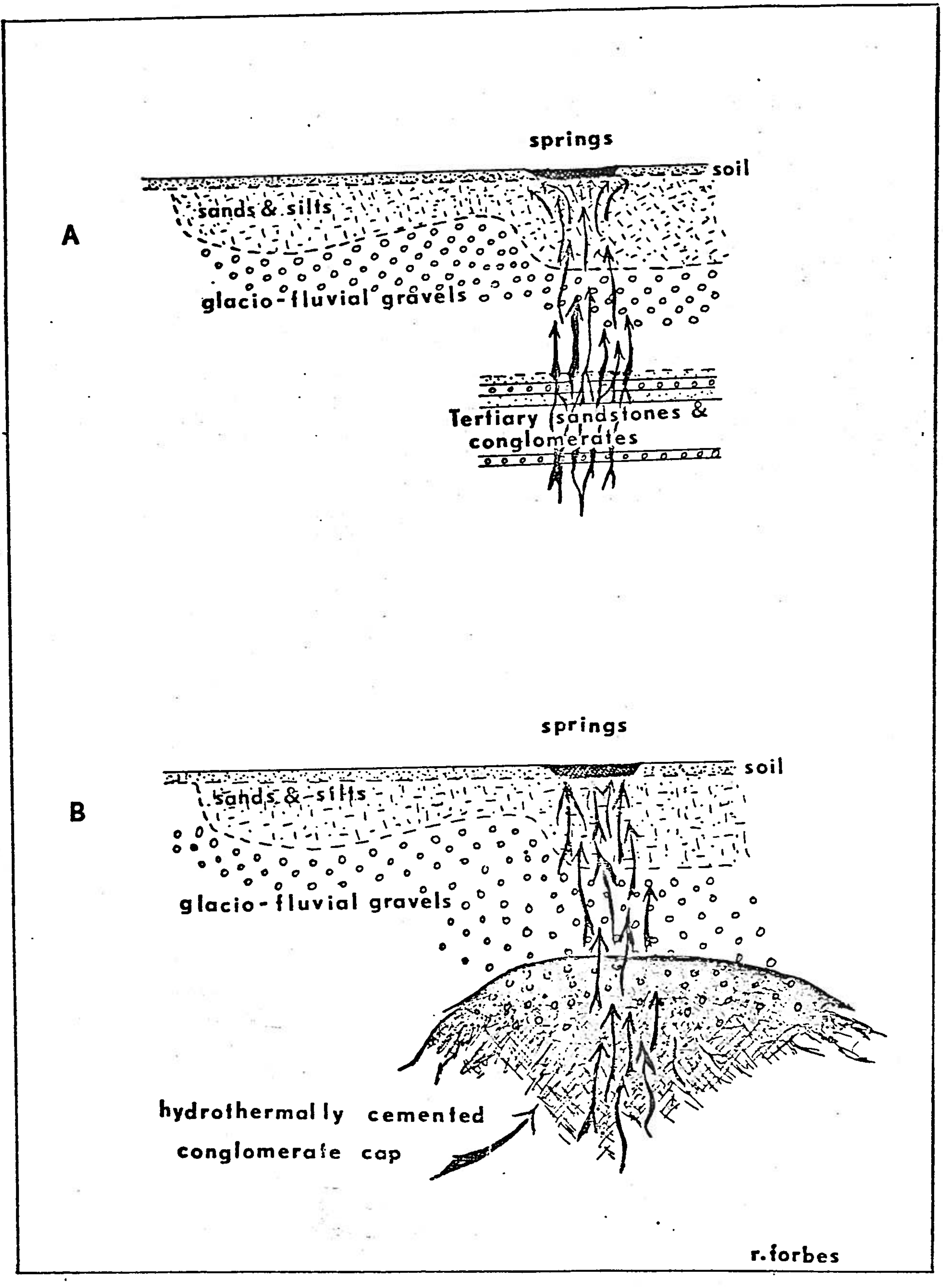

Figure 10. Cartoons illustrating two interpretations of seismic data: (A) presence of Tertiary sandstones and conglomerates at depth, and (B) conglomerate formed from hydrothermally cemented gravels.

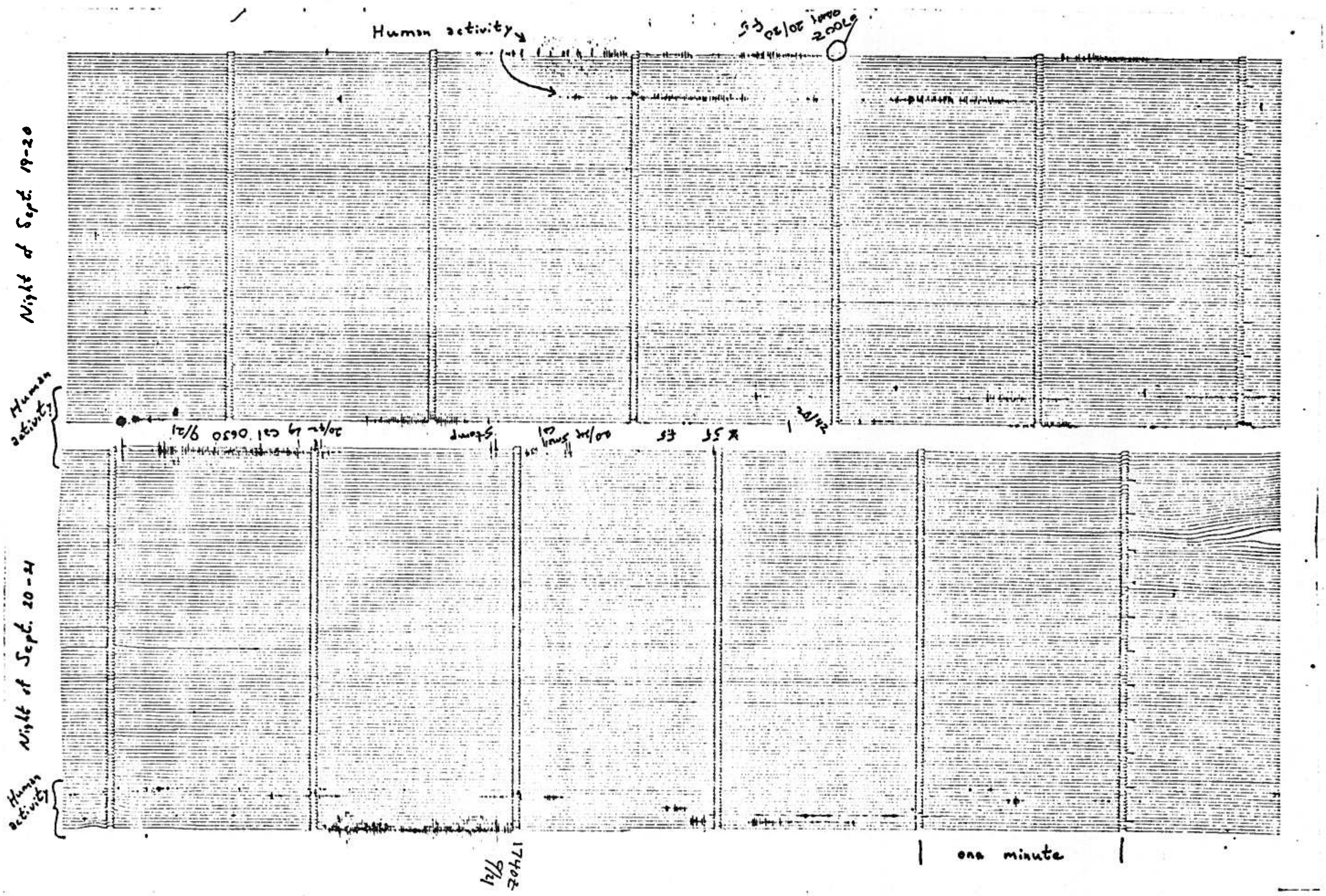

Figure 11. Seismic records taken on the nights of September 19-20 and 20-21, 1974.

Conclusions

(1) Shallow subsurface water temperatures in zones of maximum upwelling reach 80°C a few inches below the bottom sediment.

(2) Pilgrim Springs waters are diluted by mixing and convection with local ground water, and water temperatures and salinities will increase in the subsurface.

(3) A 9060/5540 ft/sec discontinuity is located approximately 208 ft. below the springs, which is believed to be Tertiary sediments or hydrothermally cemented glacio-fluvial gravels. The sedimentary section, if present, may be up to 400 ft. thick.

(4) Tertiary sediments such as those which occur to the northeast, contain permeable rock units which could make good geothermal reservoirs; and a hydrothermally cemented conglomerate cap such as that shown in Figure 10. would offer an interesting target, if it does indeed exist.

(5) The negative magnetic anomaly shown in Figure 8 is most satisfactorily explained by a zone of hydrothermal leaching along the conduit system, which has a lower magnetic susceptibility.

(6) Subsurface spring waters will be more saline at depth, and with increasing temperature will constitute a serious corrosion problem in respect to drilling and applications engineering.

(7) Although the observation period was dangerously short, the absence of microseismic activity during the two recording periods minimizes the probability of vapor phase reservoirs.

Recommendations

1. An extended seismic refraction profile should be completed which includes deeper penetration and north-south step-outs. Objectives include the

definition of Tertiary rocks versus hydrothermally cemented gravels, and the Nome Group basement discontinuity.

2. Based on a refined seismic profile, a shallow drilling program should be initiated which will accomplish the following objectives:
   - (a) A drill hole which penetrates the 208 ft. discontinuity under Pilgrim Springs. The upper part of the hole will be in water-saturated sand, and effective drilling techniques will require driving casing ahead of the bit, and up-hole circulation to remove the unconsolidated and water-saturated sediment.
   - (b) The drilling program should include several halts in drilling activity to allow the development of a reasonably good thermocline in the water column in the cased hole, to allow meaningful gradient measurements.
   - (c) The casing should contain a corrosion resistant plastic liner.
   - (d) If shallow (100 ft.) subsurface temperatures approach 100°C, drilling should be suspended until blow-out prevention equipment is installed at the well head.
   - (e) Draw-down and pumping tests should be conducted after each cycle of down-hole temperature measurements. This is the only method which will supply meaningful flow rate and capacity data in terms of large-scale geothermal applications.
3. An agricultural experimental program should be activated at Pilgrim Springs which would evaluate the feasibility of the following:
   - (a) Shallow subsurface heating of agricultural plots by thermal spring water circulated through networks of plastic pipe.
   - (b) Heating of hydroponic and greenhouse facility by thermal waters from Pilgrim Springs.

(c) Heating of local residences by thermal spring waters.

(d) Desalinization of spring waters to provide potable water.

ACKNOWLEDGMENTS

The geophysical investigations and feasibility studies were supported by AEC Contract AT(45-1)-2229, and the State of Alaska.

Mr. and Mrs. C.J. Phillips of Nome, provided logistics and moral support in our Pilgrim studies, and we express our thanks to them for their hospitality and many favors.

Our co-author and flying geophysicist, Jerry Hook, deserves special acknowledgment for his highly professional bush flying skill .... a prerequisite for operating from and surviving the Pilgrim Springs airstrip.

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