DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

GEOPHYSICAL INVESTIGATIONS
MAP GP-969

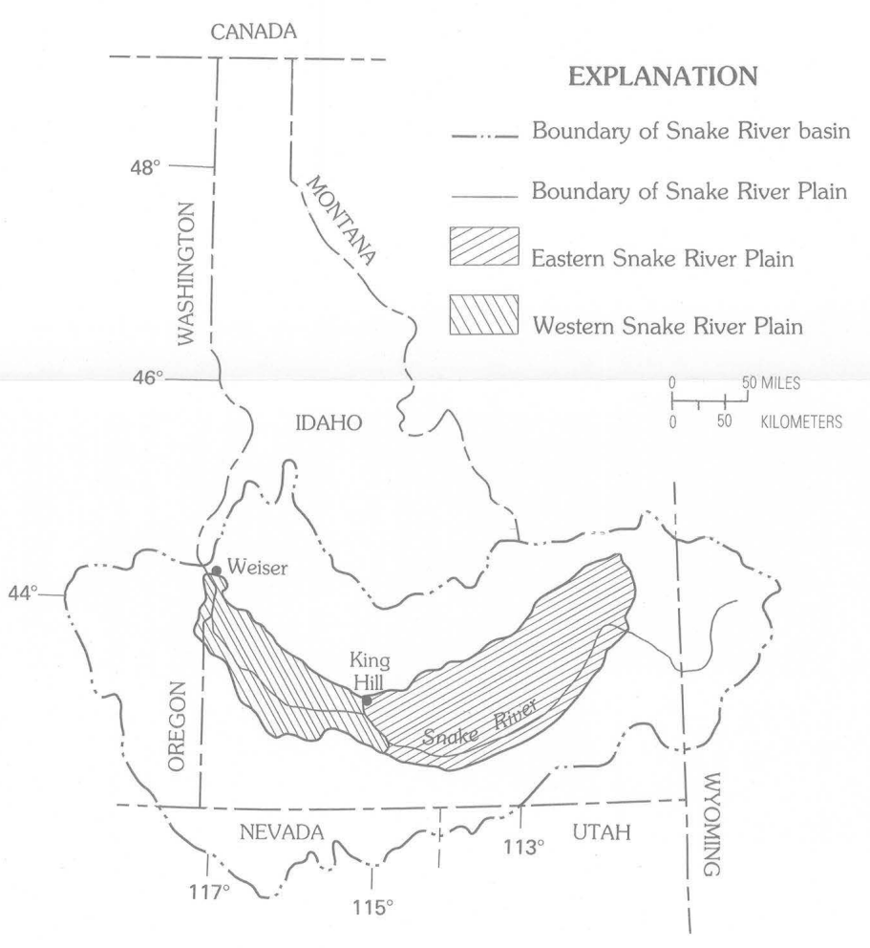
INTRODUCTION

This report is one in a series resulting from the U.S. Geological Survey's Snake River Plain RASA (Regional Aquifer System Analysis) study that began in October 1979.

As stated by Lindholm (1981), one purpose of the study was to refine knowledge of the regional ground-water flow system. To do so, a better definition of the regional geohydrologic framework was required. Because drill-hole information was inadequate in most places, data from geophysical studies were compiled to define the subsurface geology.

As part of the Snake River Plain RASA study, a literature search was made and a list of geophysical studies on and near the Snake River Plain was compiled. The line or approximate area of each survey is shown on the map and is cross-referenced to a table that categorizes each study by type.

The purposes of this report are to present a compilation of selected geophysical references resulting from previous studies done on and near the Snake River Plain and to show the areas of investigation on a map.



THE SNAKE RIVER PLAIN IS AN ARCUATE AREA OF 15,600 SQUARE MILES THAT EXTENDS ACROSS SOUTHERN IDAHO AND INTO EASTERN OREGON.

The plain ranges from about 30 to 70 mi in width and from 2,100 to 6,000 ft in altitude. It has a relatively flat surface that slopes generally southwest and is surrounded by mountains as high as 12,000 ft above sea level. In some reaches, the Snake River is entrenched as much as 700 ft below the plain. The Snake River is one of North America's steepest large rivers (Malde, 1968, p. 6).

Agriculture and related activities dominate the economy of the plain. More than 3 million acres were irrigated in 1980, of which nearly 1 million acres were supplied by ground water (Lindholm, 1981). Ground water is also the source for most municipal, industrial, and domestic needs.

The areal extent of the Snake River Plain, as defined for this study, is based on geology as well as on topography. Generally, the plain's boundary is the contact between Quaternary sedimentary and volcanic rocks and surrounding Tertiary and older rocks. Where rocks of equivalent age to those exposed on the plain extend beyond the plain's boundary (for example, where the boundary crosses the mouth of a tributary valley), a topographic contour was chosen to arbitrarily define the boundary.

The Snake River Plain is best studied and discussed in two parts, herein referred to as the eastern plain and the western plain. The boundary between the two parts is where predominantly basaltic surface rocks of the eastern plain adjoin the predominantly sedimentary surface rocks of the western plain.

GEOPHYSICAL TECHNIQUES

The science of geophysics includes the measurement of Earth properties to determine subsurface conditions using "a few relatively simple but fundamental laws of physics" (Dobrin, 1952, p. 2). Surface geophysics includes seismic, gravity, electrical resistivity, and magnetic techniques that are used to obtain information on stratigraphy, structure, and lithology. Borehole geophysics includes electric, radioactive, and physical techniques that provide a variety of information about the shallow subsurface.

Much of the Snake River Plain is covered by Quaternary lava flows that mask older geologic features. Consequently, several surface geophysical techniques have been used by various investigators to determine the plain's structure and evolution. These investigators include Braile and others (1982) and Sparlin and others (1982), who used seismic profiling to define regional structural features; Eaton and others (1978), who used gravity methods; Mabey and others (1978), who used magnetic methods; and Evans (1982) and Greensfelder and Kovach (1982), who used passive seismic imaging methods.

CONVERSION TABLE

For readers who prefer to use metric units, conversion factors for units used in this report are listed below:

Multiply	*By*	*To obtain*
acre	4,047	square meter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

NGVD of 1929 (National Geodetic Vertical Datum of 1929): The term "National Geodetic Vertical Datum of 1929" replaces the formerly used term "mean sea level" to describe the datum for altitude measurements. The geodetic datum is derived from a general adjustment of the first-order leveling networks in both the United States and Canada. For convenience in this report, the datum also is referred to as "sea level."

SURFACE GEOPHYSICS

SURFACE GEOPHYSICS HAVE HELPED DETERMINE THAT THE SNAKE RIVER PLAIN IS A GRABEN.

Over the years, a variety of geophysical techniques have been used to determine the geological structure of the Snake River Plain. These techniques can be categorized as either passive or active. Passive techniques use natural physical phenomena, whereas active techniques require input to the ground from energetic sources activated by the operator. Passive techniques are generally less expensive to use but often do not provide the detailed information that the more costly active methods provide.

GEOPHYSICAL STUDIES CATEGORIZED BY TYPE, AND CROSS-REFERENCED TO REFERENCES CITED

Gravity
6 9 10 12 17 21 25 26 27 34
35 36 39 40 41 42 43 44 46
47 48 49 55 56 59 62 67 85 87

Magnetic
9 34 40 42 43 44 45 47 49 62
75 76 77 78 79 80 83 85 87 88

Telluric
3,6,29,30,31,32,34,37,46,72,73,85,87

Seismicity
5,23,24,53,60,61,65,
67,69,74,81

Seismic Reflection
86,87

Seismic Refraction
1,2,7,9,13,17,28,36,57,
58,62,64,68,71,84,85

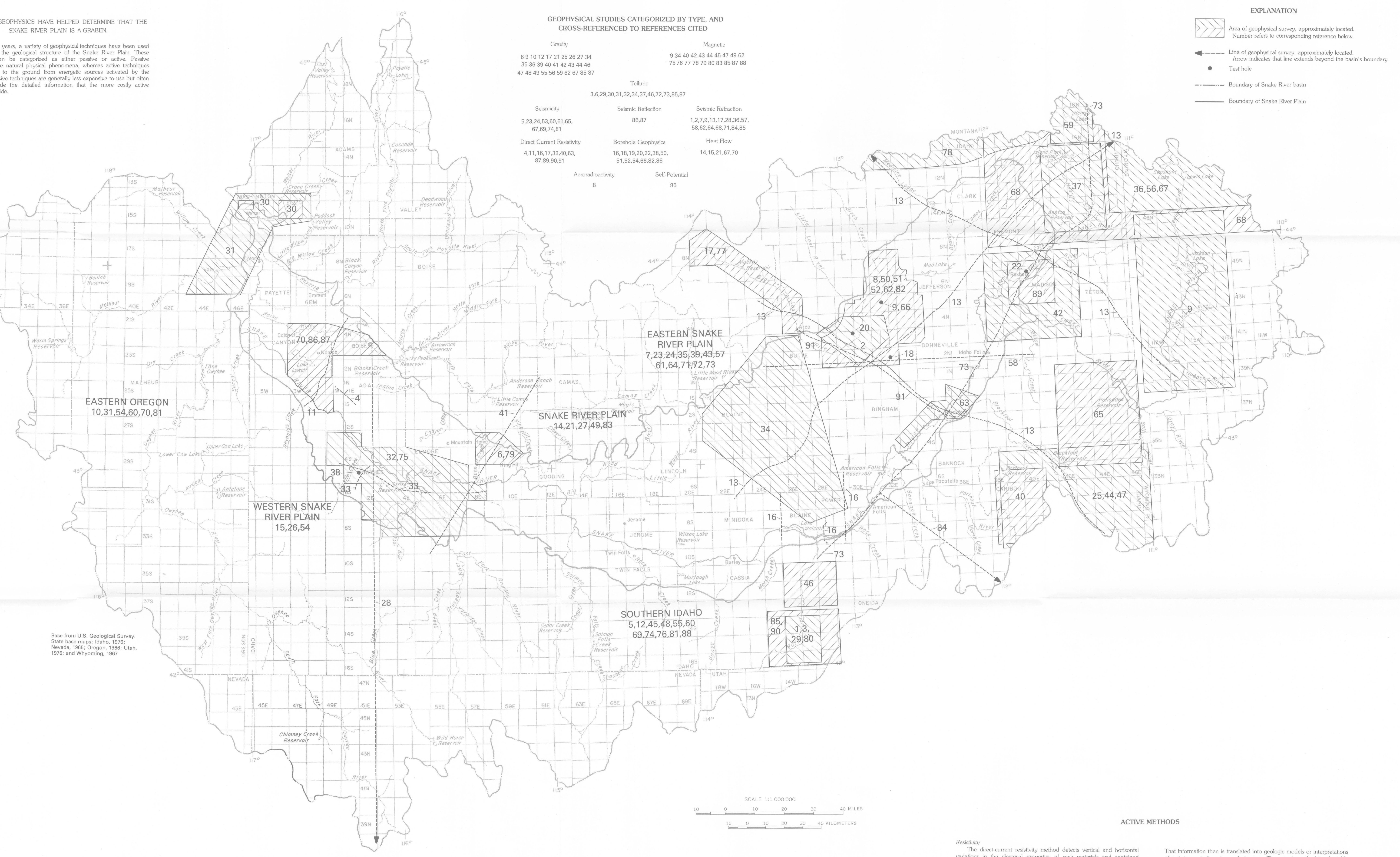
Direct Current Resistivity
4,11,16,17,33,40,63,
87,89,90,91

Borehole Geophysics
16,18,19,20,22,38,50,
51,52,54,66,82,86

Heat Flow
14,15,21,67,70

Aeroradioactivity
8

Self-Potential
85



Base from U.S. Geological Survey.
State base maps: Idaho, 1976;
Nevada, 1965; Oregon, 1966; Utah,
1976; and Wyoming, 1967

PASSIVE METHODS

Aeroradioactivity

Aeroradioactivity surveys are used to determine variations in gamma radiation from the land surface over large areas. The scintillation equipment, installed in aircraft flown at low levels (nominally 500 ft), records only pulses from gamma radiation with energies greater than 50,000 electron volts. The gamma-ray flux has three principal sources: (1) Cosmic radiation, (2) radionuclides in the air, and (3) radionuclides in the surface layer of the ground.

The first two sources can be adjusted by calibration procedures and choosing time of survey in relation to climatic situations. Thus, the residual radiation can be assumed to come from ground sources. The ground sources of gamma radiation can result from naturally occurring radionuclides and fallout radionuclides. The distribution of fallout radionuclides from nuclear fission products, if present, is assumed to be small and constant. Therefore, the ground component from naturally occurring radioactive materials can be isolated.

The aeroradioactivity survey flown for the Idaho National Engineering Laboratory covered most of the eastern plain. Differences in surficial geologic formations correlated well with different levels of gamma radiation.

Gravity

Gravity surveys determine lateral variations in the Earth's gravitational field owing to the subsurface distribution of rocks of varied densities. Preliminary gravity data must be corrected for effects of topography, latitude, and tidal influences that mask lithologic and structural anomalies. Additional corrections to gravity data may be necessary to remove regional geologic effects.

In hydrogeologic studies, gravity surveys are used most often to determine valley or basin bedrock geometry (Eaton, 1974a, p. 100). Interpretation of gravity data is highly dependent on the interpreter's general geologic knowledge of the area. Although interpretations of gravity data are not unique, if coupled with known geologic information, they yield useful information about regional subsurface conditions.

Magnetic

Magnetic surveys measure the intensity of the Earth's magnetic field. Variations in intensities over the area of investigation reveal distortions of the magnetic field produced by magnetic materials in the Earth's crust. Magnetic data can be interpreted to yield information on the general rock type, depth of burial, and extent, structure, age, and magnetic properties of rock units. Magnetic surveys are usually made by aircraft trailing a magnetometer sensitive to variations in the intensity of total magnetism of Earth materials. Airborne surveys are quick, relatively inexpensive, and easy to interpret compared with local ground surveys. Magnetic data are valuable as restrictive parameters in the interpretation of other geophysical data.

In hydrologic studies, magnetic surveys commonly are used to study basalt aquifers and to determine the configuration of basement rock underlying water-bearing sediments (Mabey, 1974, p. 110). As is true for gravity methods, the interpretation of magnetic data is highly dependent on the interpreter's general geologic knowledge of the area. Interpretations of magnetic data are not unique, but when supplemented with geologic or other geophysical data, can yield valuable subsurface information.

Magnetotelluric.--"Telluric currents (Cagniard, 1956; Berdichevskii, 1960; Kunetz, 1957) are natural electric currents that flow in the Earth's crust in the form of large sheets, and that constantly change in intensity and in direction" (Zohdy, 1974, p. 5). Their origin is believed to be in the ionosphere, where charged particles from the Sun become trapped by the Earth's magnetic field. "The magnetotelluric method consists of measuring the geoelectric field strength at the ground surface in one horizontal direction and the geomagnetic field intensity in the horizontal direction at right angles to the first" (Grant and West, 1965, p. 461). From these measurements, an apparent resistivity for a particular signal frequency is calculated and apparent resistivities at multiple frequencies are usually inverted for depth-resistivity models. The magnetotelluric method has been used in the western plain to delineate zones of thermal water (Hoover and Tippens, 1975).

Seismicity

Data on seismicity, or the frequency and distribution of earthquakes, are used to locate geologic and tectonic features. There are many causes for earth movements, such as landslides, effects of filling and draining reservoirs, and reactions to tensional and compressional forces within the Earth.

Established seismic networks monitor local or worldwide seismic activity by recording the intensity and arrival times of earthquake waves, which are used in turn to calculate hyopcenters, epicenters, magnitudes, and other features of the events. These data commonly are used as a relatively inexpensive reconnaissance tool for determining patterns of earth movements in or near areas of interest.

Smith and Sbar (1974) and Vincent and Applegate (1978) found the Snake River Plain to be relatively inactive seismically. However, there has been some activity outside the plain's margins. The epicenter of the October 28, 1983, Idaho earthquake, with a magnitude of 7.3 on the Richter scale, was about 40 mi north of the plain in the Big Lost River valley. The epicenter of the August 17, 1959, Hebgen Lake earthquake, with a magnitude of 7.1, was centered near the northern margin of the eastern plain in Wyoming.

The use of passive seismic data is generally the only means by which the deep crustal system of the Earth can be studied (for example, see Evans, 1982).

Self-Potential

Self-potential, or spontaneous polarization, methods involve measurement of electrical potentials developed locally in the Earth by electrochemical activity, electrofiltration activity, or both (Zohdy, 1974, p. 8). Relatively simple equipment can be used to measure the potentials, which are generally no larger than a few tens of millivolts. However, extraneous sources of potential often obscure the natural potentials.

Interpretations are usually qualitative. The technique has been used in Idaho chiefly for geothermal exploration (Williams and others, 1975, p. 24).

ACTIVE METHODS

Resistivity

The direct-current resistivity method detects vertical and horizontal variations in the electrical properties of rock materials and contained fluids. Electrical depth soundings are made by introducing a low-frequency current into the ground at increasing distances between current electrodes and observing the voltage drop between an inner pair of potential electrodes. Although several different electrode configurations may be used, the most common is the Schlumberger array (Zohdy, 1974, p. 11).

Depth soundings depend, in part, on the distance between current electrodes; horizontal variations are derived from comparisons of a series of these soundings. Observed vertical and horizontal electrical variations are interpreted, generally by curve-matching techniques, to determine stratigraphy, structure, lithology, and type of contained fluid.

Resistivity surveys have been used successfully on the Snake River Plain to define local basalt-sediment contacts. Apparent resistivities for basalts range from 100 to greater than 1,000 ohm-meters; apparent resistivities for saturated, unconsolidated sedimentary rocks range from 70 to 300 ohm-meters. In some areas, clay layers have apparent resistivities of less than 50 ohm-meters.

Resistivity surveys are faster and less expensive than many geophysical methods. As with many other geophysical methods, interpretations are not unique, but when coupled with drill-hole data, may yield subsurface information unobtainable by any other geophysical method.

About 450 mi of resistivity profiling was completed from 1980 to 1982 as part of the Snake River Plain regional aquifer study. The surveys were made by R. J. Bisdorf (U.S. Geological Survey, written commun., 1983). Results are presented in a report by Whitehead (1984).

Seismic

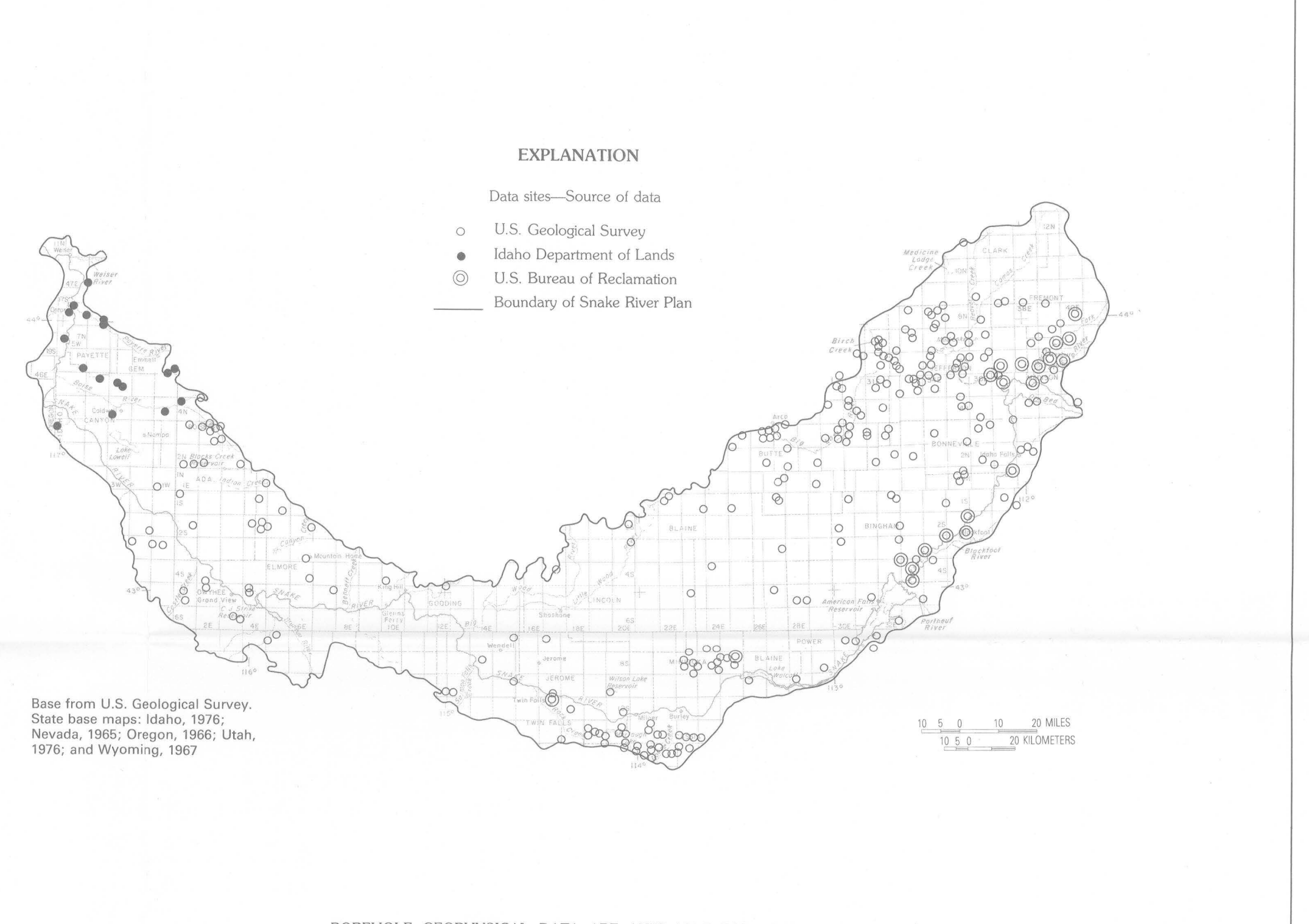
"Applied seismology has, as its basis, the timing of artificially generated pulses of elastic energy propagated through the ground and picked up by electromechanical transducers operating as detectors" (Eaton, 1974b, p. 67). Of interest in seismic studies is the elapsed time of transmission of an energy pulse and the geometry of the travel path. That information then is translated into geologic models or interpretations of rock type, stratigraphy, and structure. The seismic method is adaptable to local or regional studies, a variety of geologic conditions, and varying depths of investigation. Two general types of active seismic methods are reflection and refraction.

Seismic Reflection.--In seismic reflection studies, elastic waves propagate away from energy sources, such as explosions or vibrators, near the Earth's surface. Upon striking an interface between rocks having contrasting elastic properties, part of the elastic energy is reflected back to the land surface, where it is detected by sensitive instruments near the origin. The traveltimes and amplitudes of these reflected waves are used to compute seismic velocities and depth to the reflecting interfaces. The positions and geometry of these reflecting interfaces are used as an aid in determining geologic structure

Numerous publications relate details of the seismic reflection method and interpretation techniques; for example, Dobrin (1976), Eaton (1974b), and Grant and West (1965).

Seismic Refraction.--In seismic refraction studies, part of an elastic energy pulse induced in the Earth is refracted (deflected) as it passes between rock strata with different elastic properties. Traveltime analyses of refracted energy are used to calculate depth to and velocity below the rock interface where the elastic waves were deflected back toward the surface. In the refraction method, in contrast to the reflection method, seismic velocities are determined directly. A limitation of this method is that, for accurate thickness estimates, materials in each succeeding layer must have a seismic velocity greater than that in the layer above. The refraction method has been used successfully in hydrologic studies to define valleys in bedrock that are filled with low-velocity, unconsolidated aquifer materials.

BOREHOLE GEOPHYSICS



Base from U.S. Geological Survey.
State base maps: Idaho, 1976;
Nevada, 1965; Oregon, 1966; Utah,
1976; and Wyoming, 1967

BOREHOLE GEOPHYSICAL DATA ARE AVAILABLE FOR ABOUT 300 DRILL HOLES ON AND NEAR THE SNAKE RIVER PLAIN.

Geophysical well logging, or borehole geophysics, is the technique of lowering sensing devices into a drill hole and recording some physical parameter that may be interpreted in terms of the characteristics of the rocks, the fluids contained in the rocks, and the construction of the well. A variety of sending, sensing, and recording devices have been developed, primarily by the oil industry, to enable logging in both open and cased holes.

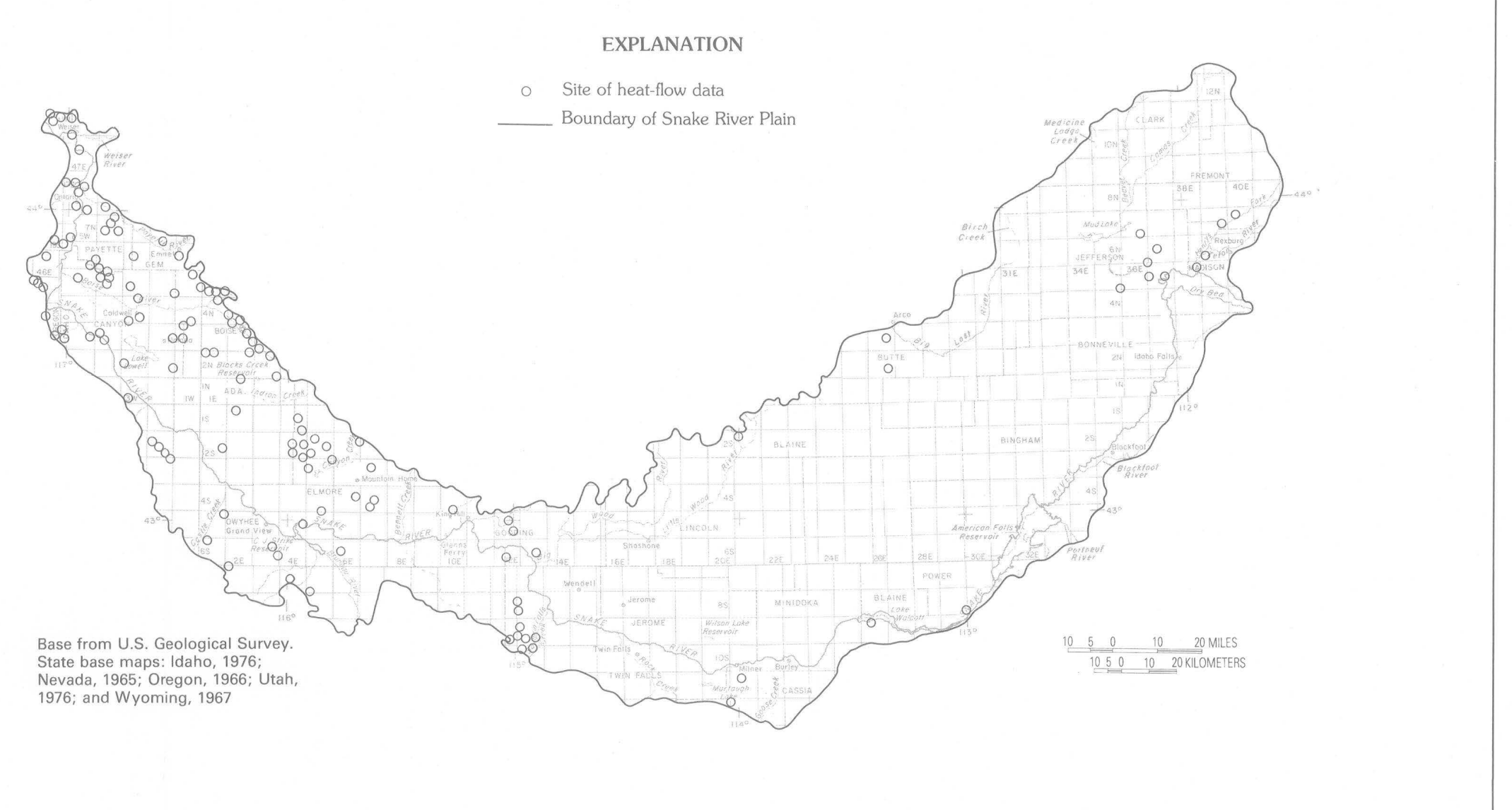
"Geophysical logs can be interpreted to determine lithology, geometry, resistivity, formation-resistivity factor, bulk density, porosity, permeability, moisture content and specific yield of water-bearing rocks, and to define the source, movement, and chemical and physical characteristics of water" (Keys and MacCary, 1971, p. 2).

In ground-water studies, geophysical well logs most commonly are used qualitatively for stratigraphic correlation and determination of lithology and borehole conditions. Because log response is affected by logging speed, borehole diameter, moisture content, drilling mud, and temperature, quantitative analysis is difficult and often not possible. In either case, geologic knowledge about the study area and experience in well-log interpretation are highly desirable. To maximize information return, a suite of geophysical logs is most desirable.

The chief uses of geophysical logs on the Snake River Plain are to aid in well construction and to make stratigraphic correlations. Logs available at the Boise, Idaho, office of the U.S. Geological Survey include caliper, conductivity, gamma-gamma, natural gamma, neutron, resistivity, self-potential, and water temperature.

Only about 30 percent of the 300 wells or test holes have more than three kinds of geophysical logs. In addition, depth of hole and quality of logs are highly variable. Natural gamma logs used to identify sediment zones are available for 90 percent of the holes. Suites of logs for several deep oil and gas and geothermal test holes are on file with the Idaho Department of Lands, Coeur d'Alene, Idaho.

BOREHOLE HEAT-FLOW MEASUREMENTS



Base from U.S. Geological Survey.
State base maps: Idaho, 1976;
Nevada, 1965; Oregon, 1966; Utah,
1976; and Wyoming, 1967

VALUES OF HEAT FLOW IN SHALLOW WELLS, WHEN COMBINED WITH GEOLOGICAL AND GEOPHYSICAL DATA, AID IN DEFINING GEOTHERMAL RESOURCES.

Heat is produced in the Earth from the decay of radioactive minerals and gravitational collapse. To maintain temperature equilibrium between the Earth's interior and surface, heat flows to the surface and is radiated to space. A heat-flow study measures the heat flowing from the Earth's surface. To obtain values of heat flow, geothermal gradients and thermal conductivity of rock units must be known

The geothermal gradient is calculated from the relation of temperature change with depth. Thermal conductivity measurements can be made in the laboratory on samples of rock materials representing those in the field.

A major problem in heat-flow determinations is the lack of information on porosity of rocks in the borehole, which can affect estimates of thermal conductivity. Another problem is that geothermal gradients may be disturbed by topographic features, water circulation, air temperature changes in unsaturated zones, and geological and structural changes

The Snake Plain aquifer, a large mass of cool freshwater masks the local geothermal gradient. In addition, an unusual disturbance caused by deep (as much as 300 ft) air circulation in unsaturated vesicular basalts has been recorded. However, heat-flow determinations were useful in defining the geothermal resources along the margins of the eastern plain and in much of the western plain.

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REFERENCE LIST OF SELECTED UNPUBLISHED GEOPHYSICAL DATA AND SOURCES

In addition to studies referenced, the following unpublished data are available for inspection at places indicated.

Type of survey	*Investigators*	*Agency and repository*
Borehole geophysics	Gary King	U.S. Bureau of Reclamation Boise, Idaho
Borehole geophysics	U.S. Geological Survey	U.S. Geological Survey Water Resources Division Boise, Idaho
Borehole geophysics	Various exploration companies	Idaho Department of Lands Coeur d'Alene, Idaho
Direct-current resistivity	A. A. R. Zohdy and R. J. Bisdorf	U.S. Geological Survey Geologic Division Denver, Colorado

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COMPILATION OF SELECTED GEOPHYSICAL REFERENCES FOR THE SNAKE RIVER PLAIN, IDAHO AND EASTERN OREGON

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