McNitt (1963)

CASA DIABLO

Casa Diablo Hot Springs are located in Mono County, about 40 miles northwest of Bishop on Highway 395. These springs are one of several hot spring groups on the west side of Long Valley, near the headwaters of the Owens River. Long Valley occupies the east side of a large topographic basin which is oval in shape and oriented with its long axis east-west. This basin is known as the Mammoth Embayment because of the east-west offset which it produces in the steep, northeast front of the Sierra Nevada. Mono basin, a similar topographic depression, is located about 10 miles north of the Long Valley area.

Geology

The Sierra Nevada on the west and south of Long Valley, and the Benton Range and the Black Mountains on the east of the basin, are composed of Late Paleozoic metasedimentary rock which is intruded by Cretaceous rocks ranging in composition from gabbro to granite (Rinehart and Ross, 1956, p. 5-7). Cenozoic volcanic rocks, as well as alluvial and glacial deposits, fill the Long Valley basin and cover much of the pre-Tertiary rocks to the north.

The gravity data shown in figure 11 indicate that Long Valley is a structural depression as well as a physiographic basin, and is bounded on all sides by steep faults. The structural depression is also elliptical in shape, 23 miles long and 12 miles wide. The Cenozoic deposits in the depression increase gradually from a thickness of less than 5,000 feet on the west to 18,000±5,000 feet on the east (Pakiser, 1961, p. 253). Pakiser has interpreted Long Valley to be "a volcano-tectonic depression caused by subsidence along faults, following extrusion of magma from a chamber at depth".

Gilbert (1938, p. 1860) believes that the Long Valley depression was the major locus for vents which erupted the Pleistocene Bishop Tuff, a pyroclastic deposit of the nuée ardente type. The visible extent of the Bishop Tuff is approximately 350 square miles, but because of its probable continuation beneath the alluvium of Owens, Long and Adobe Valleys, the total areal extent of the tuff should be about 400 to 450 square miles. The thickness of the tuff exposed in stream gorges ranges between 400 and 500 feet; consequently, the total volume of the Bishop Tuff approximates 35 cubic miles (Gilbert, 1938, p. 1833).

Approximately 200 feet of Pleistocene lacustrine deposits (Cleveland, 1961) overlying rhyolite flows in

Photo 7.
East end of Long Valley structural depression.
Photo by Mary Hill.

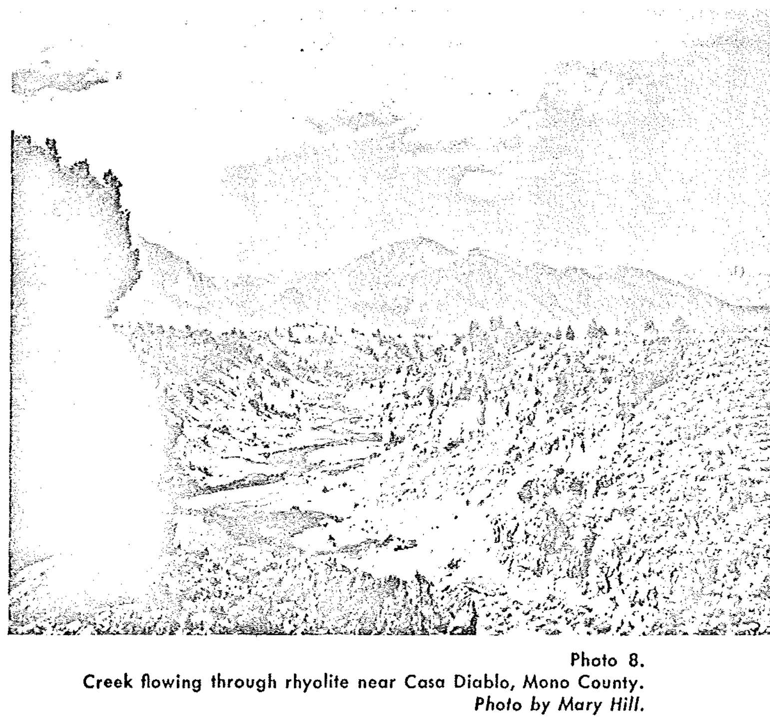


Photo 8.
Creek flowing through rhyolite near Casa Diablo, Mono County.
Photo by Mary Hill.

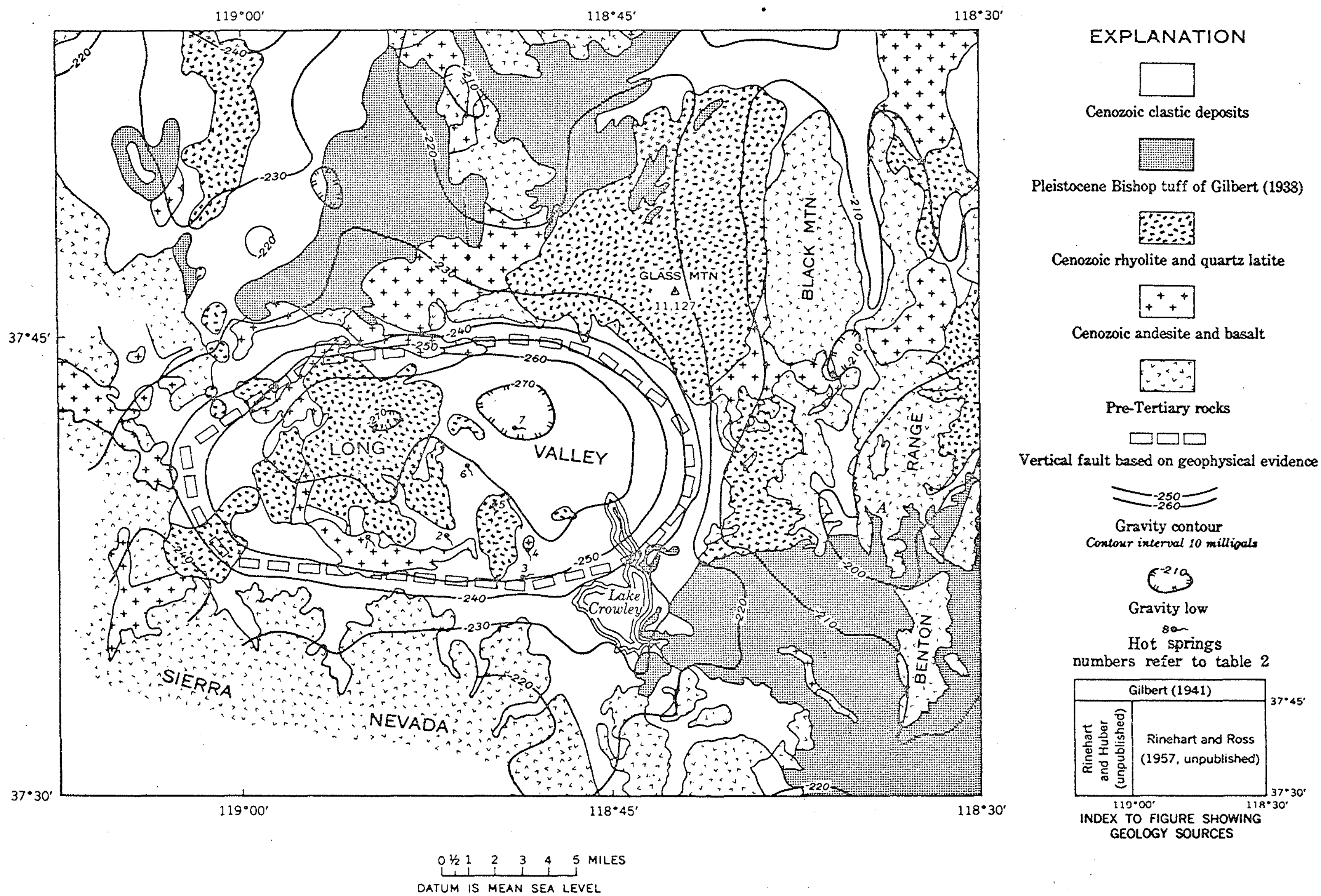


Figure 11. Geologic and gravity anomaly map of Long Valley. (Gravity data after Pakiser, 1961.)

Long Valley is evidence that the depression has existed at least from mid-Pleistocene. Volcanic activity in this region has continued to a very recent time, as indicated by the presence of a basalt flow in the Mammoth Creek area which overlies lacustrine sediments thought to be deposited during the Tahoe glaciation (Cleveland, in press).

An aeromagnetic survey of the region disclosed a sharp magnetic high, having a relief of from 2500 to 5000 gammas, located over the center of Long Valley (Pakiser, 1961, p. 252). This magnetic anomaly roughly corresponds to a local positive gravity anomaly which has a relief of about 10 milligals, as compared with a 60 milligal negative anomaly over the major part of the Long Valley depression. The calculated depth to the upper surface of the magnetic body is about 3000 feet below the valley floor, which places the top of the body in the upper part of the Cenozoic section as determined by gravity methods. This mass of dense and magnetic material may represent the buried volcanic or intrusive rock which is the heat source for the various thermal springs in Long Valley.

The principal drilling in this area for geothermal power has been done at Casa Diablo Hot Springs. The springs are located near two structural features: a) a fault trending north-northwest, and b) a west-trending contact between a Quaternary basalt flow and a late Tertiary rhyolite (Rinehart and Ross, in press). The rhyolite is the principal flow covering the west half of the Long Valley depression. Because of poor outcrops in the Casa Diablo Hot Springs area, the nature of the basalt-rhyolite contact is not known with certainty.

Photo 9.
Extent of thermal activity prior to drilling of steam wells at Casa Diablo Hot Springs. *Photo by Mary Hill.*

Rinehart and Ross (written communication, 1962) are of the opinion that the thermal activity at Casa Diablo Hot Springs, as well as in most of the Long Valley area, appears to be localized along steeply dipping to vertical faults that trend north to northwest. The writer believes that arcuate faults, trending to the northwest from Casa Diablo Hot Springs are suggested by the configuration of the contact between the Tertiary rhyolite and younger Pleistocene units. Moreover, inspection of aerial photographs strongly suggests that collapse structures enclosed by arcuate faults are common in the Long Valley depression. If this is correct, then there is a striking similiarity between the geologic structure of the Casa Diablo thermal area and the graben structure at The Geysers in Sonoma County.

Thermal activity

The surface temperature and approximate discharge of seven spring groups in Long Valley are given in table 2 (Stearns, Stearns, and Waring 1935, p. 126-127). The number given to each spring group corresponds to the number in figure 11.

In addition to these thermal areas, there are many localities, mainly northeast of Casa Diablo, where the rhyolite has been altered to clay and opal by hydrothermal solutions. Although there is evidence for very recent thermal activity at a few of these clay deposits, it is believed that most of them formed in the mid-Pleistocene and are not closely related to present thermal activity (Cleveland, in press).

Table 2. Temperature and discharge of Long Valley thermal springs (after Stearns, Stearns and Waring, 1935, p. 126-127).

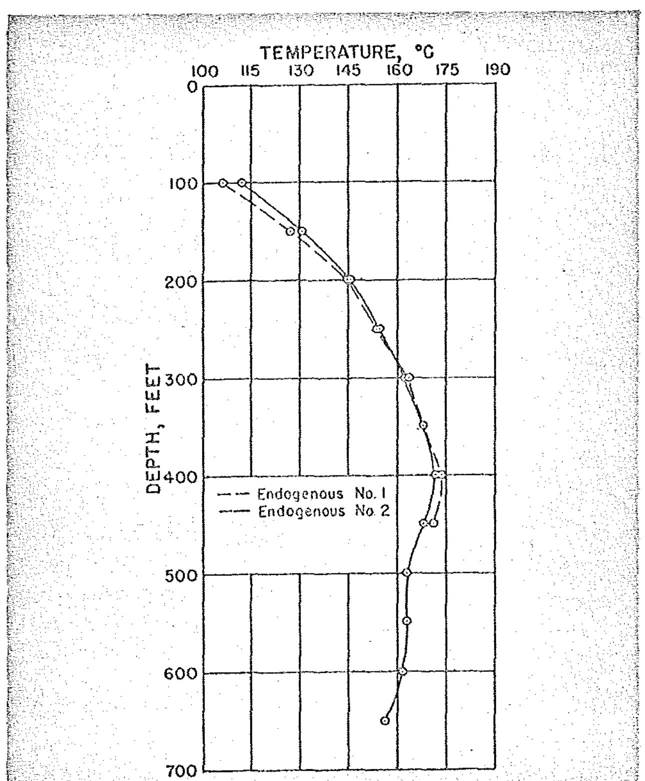
Map no.	Location	Name	Temp. °C	Total discharge, gal/min	No. of springs
1	NW¼, sec. 32, T.3S., R.28E.	Casa Diablo Hot Springs	46-90	35	20
2	NW¼, sec. 35, T.3S., R.28E.	Casa Diablo Hot Pool	82	Intermittent	--
3	NW¼, sec. 6, T.4S., R.29E.	Whitmore Hot Springs	36	306	2
4	NE¼, sec. 31 T.3S., R.29E.	--	23-38	450	4
5	NE¼, sec. 30, T.3S., R.29E.	"The Geysers"	49-94	500	5
6	NW¼, sec. 13, T.3S., R.28E.	--	77	5	1
7	NE¼, sec. 7, T.3S., R.29E.	--	--	--	--

Photo 10.
Geologist taking temperature of Casa Diablo Hot Pool. *Photo by Mary Hill.*

History of development

In 1959, two wells were drilled at Casa Diablo Hot Springs by the Magma Power Company. The first well, Mammoth No. 1, was drilled about 1200 feet northeast of Highway 395 and the second just west of the highway near an active fumarole. Mammoth No. 1 was drilled to 1,063 feet, but the second well was abandoned at a shallow depth because extensive steam seeping around the well area indicated very pervious ground. In 1960 Magma Power Co. entered into a partnership agreement with Endogenous Power Co. (now known as Natural Steam Corporation). This new company drilled the third, fourth and fifth wells on the west side of the highway, approximately 100 yards apart in a northwest-southeast line. From south to north these wells are named Endogenous No. 1 through 3, and were drilled to 630, 810 and 570 feet, respectively. In 1961 Endogenous No. 4 was drilled adjacent to the other Endogenous wells, but east of the highway. Also in 1961, Endogenous Power Co. drilled Chance No. 1 at Casa Diablo Hot Pool, a thermal spring 3 miles east of Casa Diablo. In 1962, Endogenous Nos. 5, 6, and 7 were drilled at Casa Diablo on the east side of Highway 395 to 405, 756 and 670 feet, respectively.

Figure 12. Thermal gradient of Endogenous Nos. 1 and 2, Casa Diablo thermal area.



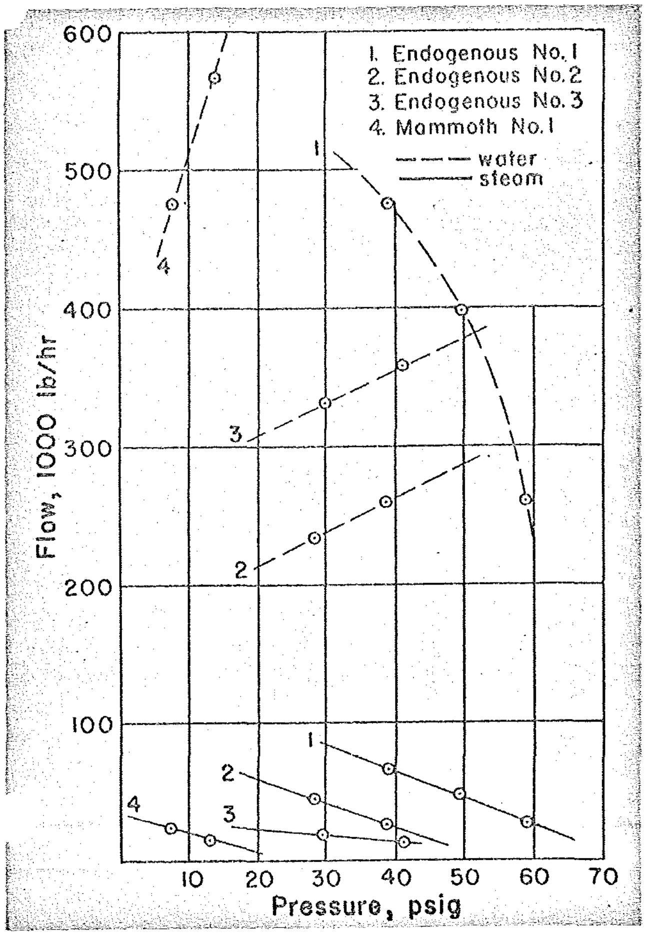


Figure 13. Mass flow-wellhead pressure curves for Casa Diablo steam wells.

Production

The four wells tested to date are Endogenous No. 1 through No. 3 and Mammoth No. 1. The Endogenous wells were completed with two strings of casing, leaving an open hole below. The outer casing is 13⅜ inches in outside diameter and was set to depths ranging from 140 to 220 feet. The inside casing is 9⅝ inches in outside diameter and was installed to depths ranging between 350 to 400 feet. Both sets of casings are hung from the surface and cemented from bottom to top. Mammoth No. 1 has one string of casing 165 feet long and 9⅝ inches in outside diameter.

Temperatures in the wells were taken with a maximum recording thermometer after the wells had been static for several weeks. Under these conditions, the maximum temperatures recorded in Endogenous No. 1 through 3 were 178° C, 174° C and 172° C, respectively, and 148° C in Mammoth No. 1. Figure 12 shows the thermal gradients measured in Endogenous Nos. 1 and 2 after the wells had been static for a period of six months. The temperatures shown in figure 12 were measured with a mechanical temperature logging device in the latter part of 1962. This device was developed in New Zealand and is considered more reliable than electrical instruments for recording well temperatures under these extreme conditions.

The four wells produce a mixture of saturated steam and hot water. Well performance was tested by W. M. Middleton in October 1960. The following table summarizes the well characteristics under producing conditions.

Well no.	*Temperature °C*	*Pressure psig*	*Steam lb/hr*	*Water lb/hr*
Endogenous No. 1	148	39	69,300	473,000
Endogenous No. 2	181	38.5	45,000	233,500
Endogenous No. 3	157	30	19,000	330,000
Mammoth No. 1	132	7.5	25,000	471,000

The chemical constituents in water and condensate from the Casa Diablo wells are given in table 3.

The steam produced from Endogenous No. 4 contains 0.36 percent by volume and 0.87 percent by weight of non-condensable gases. This gas is composed of 98.25 percent by volume or 98.64 percent by weight of CO_2 and 1.75 percent by volume or 1.36 percent by weight of H_2S. An infrared spectrum of the samples indicated that there were no other gases present.

Reservoir characteristics

The variation of steam and water flow with wellhead pressure for the four wells is shown in figure 13. As would be expected, steam flow increases with decreasing pressure in all the wells. In Endogenous No. 1, water flow increases with decreasing pressure, but in the other three wells, water flow decreases with decreasing pressure. The anomalous relationship of

Table 3. Chemical constituents of fluids from Casa Diablo wells in ppm.

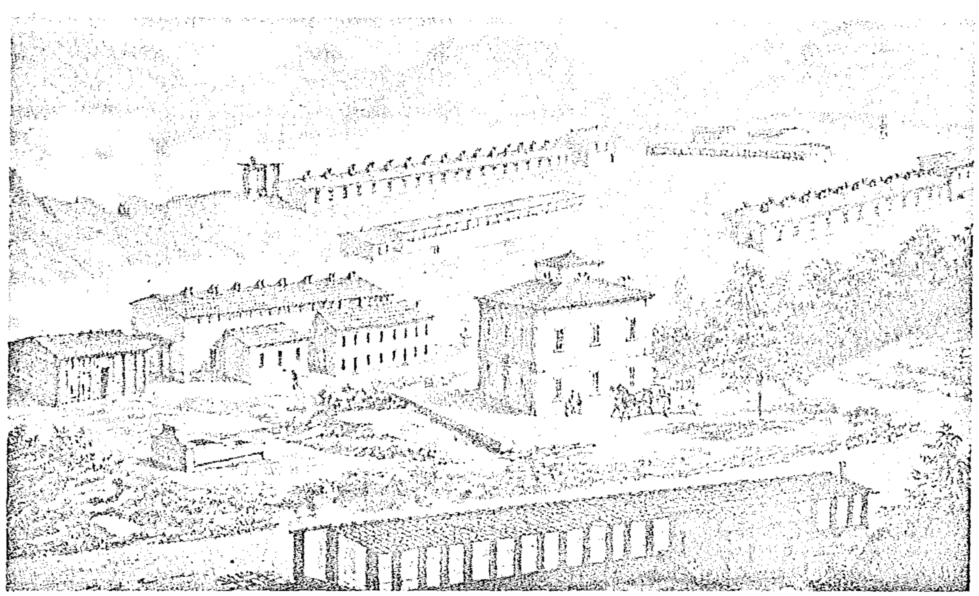
	Endogenous No. 1[2]	Endogenous No. 1[1]	Endogenous No. 2[2]	Mammoth No. 1[1]	Endogenous No. 4[3]	Endogenous No. 4[4]
SiO_2	250	278	256	292	200	0.8
Ca		2		30	4	
Mg		tr.		tr.		
Na	380	236	375	247	308	5
K	47	62	45	71	32	
Li		4		3	0.3	
Fe		5		4		
Al		2		1		
B		60		49	11	0.3
Cl	276	266	276	301	227	5
SO_4	61	108	62	124	96	2
H_2S					14	11
F					20	
NH_3					0.1	0.5
CO_2					180	205
As					0.2	
pH	8.86	7.5	8.61	8.0	6.5	4.9

Analyst: Abbot A. Hanks, Inc., San Francisco.
[1] Sample taken from wellhead immediately after flowing. Some water flashed to steam.
[2] Sample taken from wellhead after cooling. No flashing to steam.
[3] Water sample taken during flow test.
[4] Condensate of steam sample taken during flow test.

decreasing water flow with decreasing wellhead pressure is probably the effect of relative permeability. When both a vapor and liquid phase are being produced, a reservoir is considerably more permeable to the vapor than to the liquid. At low wellhead pressures, vapor expansion in a reservoir could be so great as to block the passages to liquid flow. The effect of relative permeability becomes more pronounced as the absolute permeability of the rock decreases.

The relative permeability effect should not be noticeable where water is flashing to steam within the well bore, provided that the bore has not been restricted by mineral deposition. If on the other hand, some water flashes within the reservoir rock, the relative permeability effect should become more pronounced. Where flashing occurs within the reservoir rock, the relative permeability effect offers a method for comparing reservoir permeability from one bore to another, irrespective of the area of the hole open to production: the greater the tendency of a water production curve to flatten or even to slope in a positive direction (figure 13) with decreasing wellhead pressure, the less permeable the reservoir in the vicinity of the well displaying this type of water production curve.

In regard to the four Casa Diablo wells, the water production curve of Endogenous No. 1 reflects the greatest reservoir permeability, Mammoth No. 1 the least permeability, and Endogenous No. 1 and 2 intermediate permeability. The comparatively large total flow of Mammoth No. 1 is most probably due to the fact that its "open hole area" is approximately three times greater than that of any of the other wells. The comparatively low permeability reflected by the production curves of Endogenous No. 1 and 2 and Mammoth No. 1 may be due to either or both of two factors: (a) the well flow is restricted by the deposition of calcite and silica in the region where hot water is flashing to steam, or (b) these three wells did not intersect the main steam bearing fissure, but are producing from relatively small subsidiary fractures. In order to explain the differences of steam production as well as the slope of the water production curve between Endogenous No. 1 and Mammoth No. 1, the latter interpretation is preferred, because both bores were cleaned of calcite deposits before the tests were made. On the other hand, Endogenous No. 1 and 2 seemed to sustain equal mass flows directly after completion of the wells, so that calcite deposition in Endogenous No. 2 is the more probable explanation of its relatively low rate of flow.



SASSO, ITALY, 1850.