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**AN EXPERIMENTAL INVESTIGATION OF THE
PERMEABILITY OF KAYENTA AND ST. PETER
SANDSTONES TO HYPERSALINE BRINE IN THE
TEMPERATURE INTERVAL 70 TO 90°C
AT 10.3-MPa CONFINING PRESSURE**

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SYMBOLS

L	Length of core sample (cm).
D	Diameter of core sample (cm).
R	Radius of core sample (cm).
A	Area of core sample (cm ²).
V	Volume of core sample (cm ³).
PV	Pore volume of core sample (cm ³).
k	Permeability (millidarcies, mD), where $\text{mD} \times 9.87 \times 10^{-14} = \text{m}^2$.
Q*	Volume of liquid passing through the sample in unit time (cm ³ /s).
P ₂ *	Pressure upstream from the sample (atm), where $\text{atm} \times 1.013 \times 10^5 = \text{Pa}$.
P ₁ *	Pressure downstream from the sample (atm), where $\text{atm} \times 1.013 \times 10^5 = \text{Pa}$.
ΔP*	P ₂ * - P ₁ * (atm), where $\text{atm} \times 1.013 \times 10^5 = \text{Pa}$.
η	Dynamic viscosity (cp), where $\text{cp} \times 10^{-3} = \text{Pa} \cdot \text{s}$.
t	Time (h).
P ₂	Gage pressure upstream from the sample (psi), where $\text{psi} \times 6.89 \times 10^3 = \text{Pa}$.
P ₁	Gage pressure downstream from the sample (psi), where $\text{psi} \times 6.89 \times 10^3 = \text{Pa}$.
P _c	Confining pressure (psi), where $\text{psi} \times 6.89 \times 10^3 = \text{Pa}$.
T _c	Temperature (°C) estimated for core.
TTF	Total time of flow through core(h).
pH _e	pH of brine entering core.
pH _f	pH of brine after it has passed through core.
SiO _{2e}	Silica concentration (ppm) of brine entering core.
SiO _{2f}	Silica concentration (ppm) of brine after it has passed through core.
PVF	Total number of pore volumes of brine that has flowed through core.

AN EXPERIMENTAL INVESTIGATION OF THE PERMEABILITY OF KAYENTA AND ST. PETER SANDSTONES TO HYPERSALINE BRINE IN THE TEMPERATURE INTERVAL 70 TO 90°C AT 10.3-MPa CONFINING PRESSURE

ABSTRACT

Permeabilities of 10.2 cm in length, 2.5 cm in diameter Kayenta (porosity, 20.7, $\pm$ 1.66%) and St. Peter (porosity, 13.6, $\pm$ 0.13%) sandstones to Magmamax No. 1 brine containing suspended solids were determined from 70 to 90°C at 10.3-MPa confining pressure. We performed measurements without filters, with one 10- μ m filter, and with two 10- μ m filters inserted upstream of the core sample. In all cases, there was a dramatic decrease in permeability within the first hour of flow or few hundred pore volumes of flow through the core. Experiments conducted without filters or with one filter yield permeabilities that represent both the rock and the 2- to 3-mm amorphous silica-iron layer on the top face of the core. The experimental results show that if the Salton Sea Geothermal Field (SSGF) were composed of porous, sedimentary formations similar to Kayenta sandstone, long-term injection of unmodified Magmamax brine would not be feasible. In the case of acidified brine, most of the permeability decline may result from the mobilization of calcite.

INTRODUCTION

The goal of the Lawrence Livermore Laboratory (LLL) geothermal program is to convert the thermal energy of high-salinity brines found in the Salton Sea Geothermal Field (SSGF) to electricity. The LLL total flow concept envisions passing the entire wellhead product through stationary nozzles, forming high velocity jets that turn an axial-flow impulse turbine to generate electricity.¹ After passing through the energy conversion steps in the power plant and losing its enthalpy, the cool, "spent" brine must ultimately be pumped back into the geothermal reservoir.

The ability to inject "spent" geothermal brine

may be a critical and perhaps limiting factor in the development of fluid-dominated geothermal resources. In order to understand and evaluate changes in formation permeability and porosity at depth as a result of the injection of brine effluents, we conducted experiments at temperatures from 70 to 90°C at 10.3-MPa confining pressure in conjunction with the ongoing brine chemistry and materials evaluation effort at the LLL Field Test Station located in the SSGF, Imperial Valley, California. This paper reports the results of the experimental investigation performed during July and August, 1977.

SAMPLES, APPARATUS, AND EXPERIMENTAL METHOD

The sedimentary rocks investigated in the study were Kayenta and St. Peter sandstones. Table 1 provides geological locations, classification, geological age, mineralogy, and pore space information for the sandstones. Table 2 gives dimensions, sample volumes, and pore volumes of the right-circular cylinders used in the experiments.

Cores were cut from each sandstone at LLL and dried at approximately 80°C for 48 to 72 h in the field at a pressure of approximately 10 kPa. The samples were then cooled approximately 8 h, saturated with 1M NaCl solution, and stored under this solution in a desiccator. Prior to commencing an experiment, each specimen was taken from the

Table 1. Description of samples used in experiments.

Rock	Location	Mineralogy and pore space ^a	Classification ^a	Age
Kayenta sandstone	Kayenta formation, Mesa County, Colorado	<p>60-75% quartz; grains are subrounded to rounded with a continuum of sizes from approximately 0.1 mm to 0.5 mm; contacts are mostly curved and sutured; some quartz overgrowths exist.</p> <p>5% chert; fairly microcrystalline; subrounded to rounded; size is approximately 0.5 mm.</p> <p><1% epidote.</p> <p>5% microcline; grid twinned; grains range between 0.25 mm and 0.5 mm.</p> <p><1% plagioclase; both untwinned; equant 0.4-mm grains and albite twinned equant 0.25-mm grains.</p> <p><1% muscovite.</p> <p>5-10% lithic rock fragments; subrounded 0.5-mm fragments possibly of volcanic origin.</p> <p>5-10% calcite cement.</p> <p><2% clay (possibly illite).</p> <p><2% possible carbonaceous matter.</p> <p>2-5% hematite; appears in pore space between grains and along grain boundaries.</p> <p>Pore space; half is closed; size is approximately 0.2 mm; half is interconnected; size is approximately 0.5 mm.</p>	Subfeldspathic lithic quartz arenite	Triassic
St. Peter sandstone	Illinois	<p>95-99% quartz; well-rounded to rounded grains; mean size of approximately 0.5 mm.</p> <p><1% epidote.</p> <p><<1% mafics (possibly hornblende).</p> <p><<5% calcite; possibly cement with traces of clay dusting grain boundaries.</p> <p>Odom, <i>et al.</i> (1977),¹¹ report that the St. Peter sandstone also contains traces of clay, illite, kaolinite, smectite, chlorite, k-feldspar, pyrite, dolomite, jarosite, alunite, and gypsum.</p> <p>Pore space; 60-70% is closed; size is approximately 0.15-0.25 mm; 30-40% is interconnected and lath-like in size range of 0.5 to 0.8 mm.</p>	Orthoquartz arenite	Ordovician

^aData obtained from Chan (1977).¹²

1M NaCl solution, jacketed with tygon, and placed in the Field Permeability Test System (FPTS). The FPTS was mounted on a 1.83-m × 1.22-m × 0.019-m plywood sheet. All required valves, gages, and

piping were exposed in order to facilitate quick and easy changing or modification of components if the need arose. A schematic diagram that illustrates the various components of the FPTS is shown in Fig. 1.

Table 2. Dimensions of samples used in experiments.

Sandstone	No.	Orientation	L, cm	D, cm	R, cm	A, cm ²	V, cm ³	PV, cm ³
Kayenta	K-1	Parallel to bedding	10.291	2.513	1.256	4.956	51.00	10.55
Kayenta	K-2	Parallel to bedding	10.205	2.516	1.258	4.972	50.74	10.50
Kayenta	K-3	Parallel to bedding	10.200	2.523	1.261	4.996	50.96	10.54
Kayenta	K-4	Parallel to bedding	10.325	2.517	1.258	4.972	51.34	10.62
Kayenta	K-5	Parallel to bedding	10.218	2.520	1.260	4.988	50.97	10.55
Kayenta	K-6	Parallel to bedding	10.300	2.463	1.232	4.765	49.08	10.15
Kayenta	K-7	Parallel to bedding	10.251	2.467	1.234	4.780	49.00	10.14
Kayenta	K-8	Parallel to bedding	10.290	2.473	1.237	4.803	49.42	10.22
Kayenta	K-9	Parallel to bedding	10.473	2.515	1.258	4.968	52.03	10.77
Kayenta	K-10	Parallel to bedding	10.213	2.470	1.235	4.792	48.94	10.13
Kayenta	K-A	Perpendicular to bedding	9.610	2.478	1.239	4.823	46.35	9.59
St. Peter	S-1	Perpendicular to bedding	10.270	2.524	1.262	5.003	51.38	10.63
St. Peter	S-2	Perpendicular to bedding	9.680	2.514	1.257	4.964	48.05	9.94

More detailed views of the apparatus are shown in Figs. 2, 3, and 4. A comprehensive list of components and manufacturers is provided in Appendices A and B.

We shall now describe in detail the FPTs by tracing the path of an increment of brine as it comes from the wellhead (approximately 25 m from the FPTs) and passes through the separator into the apparatus. In order to continuously feed brine to the specimen for the duration of the experiment, we used a positive displacement pump. Figure 2 illustrates the CAT pump, which is capable of

delivering differential pressures as great as 4.82 MPa through 0.953-cm o.d., 0.75-cm i.d., 316 stainless steel tubing. A 10- μ m, cartridge-type filter placed directly upstream of the pump is the first filter that incoming brine passes through (see Fig. 2). After exiting the pump, the pressurized brine is again filtered by means of a porous, 10- μ m, sintered, stainless steel disc. After passing through this second filter, brine pressure is recorded on the upstream pressure gage; it then enters the tygon-jacketed specimen in the pressure vessel (see Figs. 3 and 5). Confining pressure on the sample is

Field Permeability Test System

Figure 1. Schematic diagram illustrating the layout and components of the Field Permeability Test System.

Figure 2. Pump assembly for the Field Permeability Test System. Legend: (1) Insulated 316 stainless steel pipe containing brine coming from the Magmamax No. 1 wellhead; (2) Cartridge-type, 10- μ m filter assembly for backflushing; (3) Insulated 316 stainless steel pipe delivering filtered, hot, pressurized brine to the Field Permeability Test System; (4) Pressure adjustment valve; (5) CAT pump; (6) Insulated 316 stainless steel pipe containing brine coming from the Magmamax No. 1 wellhead; (7) Insulated 316 stainless steel pipe delivering filtered, hot, pressurized brine to the Field Permeability Test System; (8) Cartridge-type, 10- μ m filter assembly installed upstream to the CAT pump; (9) Safety valve; (10) Pressure gage; (11) CAT pump support pier.

*Note that all electrical components (e.g., Variac controls, clock timer, and Sym-ply-trol units) are encased in plastic bags to prevent electrical shock caused by salt deposits resulting from periodic brine rainfalls.

Figure 4. Enlargement of the lower-central portion of Fig. 3. Legend: (1) Pressure gage upstream to the test sample; (2) 1.83-m $\times$ 1.22-m $\times$ 0.019-m plywood sheet; (3) Pressure gage downstream to the test sample; (4) Oil-filled gage isolator (see legend to Fig. 3 for comment); (5) 316 stainless steel pipe leading to burette (see Fig. 3); (6) Ball valve; (7) Insulated 316 stainless steel pipe carrying hot, pressurized, filtered brine to test sample; (8) Needle valve; (9) Thermocouple connected at one end to entry brine pipe and at the other end to the Sym-ply-trol readout; (10) Insulated 316 stainless steel pipes; (11) 316 stainless steel pipe carrying brine out of the test specimen; (12) Backflushing pipe assembly (see Fig. 5 and Appendix B); (13) Pressure vessel lid (see Fig. 5 and Appendix B); (14) Pressure vessel (see Fig. 5); (15) Sym-ply-trol temperature recording unit; (16) Bourdon-tube pressure gage that records confining oil pressure; (17) Variac control unit to adjust temperature of the pressure vessel; (18) Variac control unit to adjust temperature of the incoming brine pipe assembly; (19) Insulation that covers heat strip placed to heat pressure vessel.

Figure 3. The Field Permeability Test System.* Legend: (1) Pressure relief valve; (2) Insulated 316 stainless steel pipe delivering twice-filtered, hot brine pressurized by the CAT pump (see Fig. 2); (3) 1.83-m $\times$ 1.22-m $\times$ 0.019-m plywood sheet; (4) Bourdon-tube pump pressure gage; (5) Pressure gage upstream from the test sample; (6) Pressure gage downstream from the test sample; (7) Burette; (8) Oil-filled gage isolator (used to prevent hot, corrosive brine from reacting with gage components); (9) Ball valve; (10) Sym-ply-trol temperature recording assembly; (11) Needle valve; (12) Variac power control unit; (13) Insulated pressure vessel; (14) Gage reading the confining oil pressure inside pressure vessel; (15) Timing unit; (16) 20-litre brine reservoir; (17) Bypass line to Baker tank.

Figure 5. Schematic diagram of the pressure vessel (AAA77-106435-00) used in the Field Permeability Test System.

transmitted by oil under pressure, which is generated by a hydraulic hand pump located beneath the pressure vessel (see Figs. 1 and 5).

The temperature of the core sample is controlled by the temperature of the confining oil in the vessel (see Fig. 5). Heat strips that are wound around the outside of the pressure vessel and regulated by the nearby Variac control units raise or lower the oil temperature as required. Temperatures of the in-

coming brine, outlet brine, and confining oil are monitored by iron-constantan thermocouples attached directly to the inlet stainless steel tubing and read continuously by Sym-ply-trol units (see Fig. 4).

After the brine has flowed through the test specimen, pressure downstream is measured by a second Bourdon tube pressure gage (see Figs. 1, 3, and 4). Various differential pressures can be obtained across the sample by adjusting the needle and ball valves up- and down-stream from the core; and by restricting flow by means of a bypass line leading to the nearby Baker tank (see Figs. 1 and 3). Rate of brine flow through the test sample is determined by noting the time it takes for 50 cm³ of fluid to flow through a nearby burette (see Figs. 1 and 3). A 20-ℓ container resides beneath the burette, and volume can be tabulated by emptying its contents into a smaller beaker (see Figs. 1 and 3).

Once the jacketed core sample was placed in the FPTs, it was pressurized to 10.3 MPa. Temperature was then raised, and geothermal brine was allowed to flow through the sample. When the specimen attained thermal equilibrium, flow rate was measured at a series of differential pressures in order to establish that data were being collected in a laminar flow regime. Permeability can then be evaluated by

$$k = \frac{\eta Q^* L}{A(P_2^* - P_1^*)}$$

as previously discussed by Wycoff, *et al.* (1934)² and Muskat (1937).³ The pressures P_2^* and P_1^* were directly measured in the field via Bourdon tube pressure gages; Q^* was determined by noting the time of brine flow into a burette using a stopwatch; and viscosity of Magmamax No. 1 brines was obtained from Piwinskii, *et al.* (1977).⁴

EXPERIMENTAL RESULTS

Results of the experiments on the Kayenta and St. Peter sandstones are portrayed in Figs. 6 through 13. Tabular information of $P_2^* - P_1^*$, Q^* , PVF, TTF, pHe, pHf, SiO_{2e}, and SiO_{2f} are provided in Appendices C and D. Data show that permeability of all rocks decreases dramatically with the first hour of flow or within a few hundred pore volumes of flow through the sandstones. We conducted the experiments in three basic modes:

1. No filters operational upstream of the core.
2. One 10-μm cartridge filter operational upstream of the core.
3. One 10-μm cartridge filter and one 10-μm depth-type filter operational upstream of the core.

When we conducted experiments with one filter or no filters in operation, the permeability calculated is a composite of the rock and a 2- to 3-mm amorphous silica and iron layer on the top face of the core (see Fig. 14). The thickness of the sludge layer is not fixed but is a function of time of sample exposure to the brine. All samples run in modes 1 and 2 show this type of sludge buildup. As a result, it is very difficult to assess the intrinsic permeability of the sandstone or the permeability of the sludge layer on the core face.

We conducted only two experiments in mode 3 for any period of time using Kayenta sandstone K-A (see Fig. 11) and St. Peter sandstone S-1 (see

Figure 6a. Liquid permeability data for Kayenta sandstone K-4, parallel to the bedding.

Figure 6b. Permeability of Kayenta sandstone K-4, parallel to the bedding, as a function of time. The pH of inlet and outlet brine is read on the upper right ordinate.

Figure 6c. Permeability of Kayenta sandstone K-4, parallel to the bedding, as a function of the number of pore volumes of brine passed through the sample. The pH of inlet and outlet brine is read on the upper right ordinate.

Figure 7a. Liquid permeability data for Kayenta sandstone K-6, parallel to the bedding.

Figure 7b. Permeability of Kayenta sandstone K-6, parallel to the bedding, as a function of time. K-6-top is portrayed on the bottom of the diagram, while K-6-inverted is recorded on the top of the figure. The pH of the inlet and outlet brine is read on the right ordinate.

Figure 7c. Permeability of Kayenta sandstone K-6, parallel to the bedding, as a function of the number of pore volumes of brine passed through the sample. K-6-top data is portrayed on the bottom of the diagram; K-6-inverted is recorded in the middle of the figure. The pH of the inlet and outlet brine is read on the right ordinate.

Figure 8a. Liquid permeability data for Kayenta sandstone K-7, parallel to the bedding.

Figure 8b. Permeability of Kayenta sandstone K-7, parallel to the bedding, as a function of time. The pH of inlet and outlet brine is read on the right ordinate.

Figure 8c. Permeability of Kayenta sandstone K-7, parallel to the bedding, as a function of the number of pore volumes of brine passed through the sample. The pH of the inlet and outlet brine is read on the right ordinate.

Figure 9a. Liquid permeability data for Kayenta sandstone K-8, parallel to the bedding.

Figure 9b. Permeability of Kayenta sandstone K-8, parallel to the bedding, as a function of time. The pH of the inlet and outlet brine is read on the right ordinate.

Figure 9c. Permeability of Kayenta sandstone K-8, parallel to the bedding, as a function of the number of pore volumes of brine passed through the sample. The pH of the inlet and outlet brine is read on the right ordinate.

Figure 10a. Permeability of Kayenta sandstone K-10, parallel to the bedding, as a function of time. The pH of the inlet and outlet brine is read on the right ordinate.

Figure 10b. Permeability of Kayenta sandstone K-10, as a function of the number of pore volumes of brine passed through the sample. The pH of the inlet and outlet brine is read on the right ordinate.

Figure 11a. Liquid permeability data for Kayenta sandstone K-A, perpendicular to the bedding.

Figure 11b. Permeability of Kayenta sandstone K-A, perpendicular to the bedding, as a function of time. The pH of the inlet and outlet brine is read on the right ordinate.

Figure 11c. Permeability of Kayenta sandstone K-A, perpendicular to the bedding, as a function of the number of pore volumes of brine passed through the specimen. The pH of the inlet and outlet brine is read on the right ordinate.

Figure 12a. Liquid permeability data for St. Peter sandstone S-1, perpendicular to the bedding.

Figure 12b. Permeability of St. Peter sandstone S-1, perpendicular to the bedding, as a function of time. The pH of the inlet and outlet brine is read on the right ordinate.

Figure 12c. Permeability of the St. Peter sandstone S-1, perpendicular to the bedding, as a function of the number of pore volumes of brine passed through the sample. The pH of the inlet and outlet brine is read on the right ordinate.

Figure 13a. Liquid permeability data for St. Peter sandstone S-2, perpendicular to the bedding.

Figure 13b. Permeability of the St. Peter sandstone S-2, perpendicular to the bedding, as a function of time. The pH of the inlet and outlet brine is read on the right ordinate.

Figure 13c. Permeability of the St. Peter sandstone S-2, perpendicular to the bedding, as a function of the number of pore volumes of brine passed through the specimen. The pH of the inlet and outlet brine is read on the right ordinate.

Figure 14. Jacketed sample of Kayenta sandstone K-6-top, after exposure to Magmax No. 1 brine. Note that the top face of the core is covered with a 2- to 3-mm deposit of orange-brown substance. Also seen are specks of a black rubbing material and grease, due to the failure of the Moyno pump. Orange-brown deposits covering the top face of the core are always present when no filters or only one filter was inserted upstream of the core. (See text for additional information.)

Figure 15. Cartridge-type filters used upstream to the CAT pump. Code indicates the experiment in which the filter was employed. See text and Appendices A and B for additional information.

Fig. 12); both specimens were cut perpendicular to the bedding. When both filters were operational upstream to the core, an extremely small sludge buildup occurred on the top face of S-1, while the top of sample K-A showed the smallest accumulation of material of any sample ever run in Salton Sea field tests. (See Fig. 15 for some of the material filtered out of the inlet Magmamax No. 1 brine by the CAT pump cartridge filters.) As a result, the permeabilities measured for these two rocks must have reflected changing internal conditions within the core itself, not a combination of the core plus

the sludge layer on the core face.

Data illustrated in Fig. 11 show that the permeability of Kayenta sample K-A decreased from approximately 700 to 200 mD in the first hour of brine flow or the first 1400 pore volumes of brine flow through the core. Data portrayed in Fig. 12 indicate that the permeability of St. Peter sample S-1 decreased from approximately 25 to 8 mD in the first hour of brine flow or the first 93 pore volumes of brine flow through the core. The dramatic permeability loss must then represent a severe alteration of the original pore structure of the rock.

DISCUSSION

Data presented above indicate a similar result, independent of rock type, pH of the incoming brine, temperature of the brine, and number of filters operational upstream of the core. We found permeability to decrease dramatically with the first one to two hours of brine flow or the first several hundred pore volumes of brine flow through the core. Formation damage due to the flow of various solutions through porous media has been known for a long time.^{5,6} However, it was subsequently found that permeability loss in sedimentary rocks containing appreciable clays or clay minerals could be minimized by the use of saline solutions instead of water.^{7,8} In light of these studies, our results of permeability loss in sedimentary rocks, when filtered

brines of ionic strength 2.5 to 3.5⁴ are the flowing media, are somewhat surprising.

Results similar to ours have been reported⁹ that attribute severe permeability losses at ambient temperature in friable, recent sediments to two mechanisms. The "first . . . involves mica alteration by exchange of interlayer potassium with sodium or calcium ions. Potassium removed causes the edges of mica particles to expand and fray. Particles break off, migrate downstream, and plug pore throats, which decreases permeability . . . The second damage mechanism involves slow dissolution of natural carbonate cement by neutral salt solution . . . Carbonate cement removal frees mineral particles to move and plug flow channels."⁹

We believe we have sufficient information to comment on the viability of one of Reed's⁹ suggested mechanisms at elevated temperatures. Data in Table 1 indicate that Kayenta sandstone possesses around 5–10% calcite cement, less than 1% muscovite, and less than 2% clay, while the "cleaner" St. Peter sandstone contains only small amounts of calcite as the cementing medium. Data plotted in accompanying graphs show that when acidified Magmamax No. 1 brine enters Kayenta sandstone, the pH of the brine exiting from the core increases markedly to over 5.0 and even to 6.0 as in the case of Kayenta specimen K-4. This suggests that the calcite cement is being dissolved by the hot permeating acid brine yielding a carbonated exit brine of higher pH.

Data presented in Figs. 6, 7, 10, 11, and 12 reveal that the SiO₂ content of brines exiting the cores is much lower than that of the entering solution. However, only the information on the Kayenta and St. Peter specimens provided in Figs. 11 and 12 is of value because these experiments were performed with two filters operating upstream of the cores. Looking at the results illustrated in these figures, we see that for the Kayenta sample, SiO₂ concentration of the inlet brine was 477 ppm, while SiO₂ concentration of the outlet brine after 5.3 h of flow was 353 ppm. For the St. Peter specimen, the SiO₂ concentration of the inlet brine was 458 ppm, while SiO₂ concentration of the outlet brine after approximately 0.78 h of flow was 115 ppm. This suggests

that silica precipitation occurred in each of the sandstones, presumably closing down the size of pore throats and causing the loss of permeability.

Information regarding the pH increase of brine exiting the sandstone and the SiO₂ decrease suffered by the brine as it passed through the core suggests that the porosity and pore structure of the sandstones are being altered due to the passage of hot, low pH brine through the rock. The exact nature of this change will be better known when Scanning Electron Microscope (SEM) studies of the rocks now underway are completed. However, some evidence exists that suggests small calcite particles resulting from the dissolution of calcite cement are plugging pore throats.

Grens¹⁰ measured the particle size distribution in the Magmamax No. 1 as it exited Kayenta sample K-4 by means of a laser light scattering particle analyzer. He found a tremendous increase in particles in the 2- to 5- μ m size range in brine that had flowed through Kayenta sandstone after 0.83 h. Figure 6 indicates that incoming brine pH was approximately 3.3 while outlet brine pH was approximately 5.7 at 0.83 h of flow. This suggests to us that small calcite particles were being generated in large quantities because of the dissolution of calcite cement. Coupled with the precipitation of amorphous silica, this must result in the reduction of the size of pore throats and pore channels in the rock. The effect on the permeability is clearly seen in Fig. 6.

SUMMARY AND CONCLUSIONS

Unmodified Magmamax brine contained about 140 ppm suspended silica solids. In acidified brine, however, silica suspended solids concentrations were ≤ 15 ppm. Depending on pH, acidified brine effluents have long-term (20–200 h) stability with respect to silica precipitation. In unmodified brine, suspended solids levels reach 300–400 ppm within 2 h at 90°C. Rapid permeability decline occurred when *untreated and unfiltered* brine permeated sample K-4 and when *acidified and filtered* brine passed through samples K-10 and K-A (see Fig. 1). In the former case, permeability decline was due to the accumulation of a thick filter cake on the top face of the core sample, which was composed of amorphous silica and iron. In the latter situation,

loss of permeability was caused by the precipitation of amorphous silica and generation of large quantities of calcite particles from the dissolution of the matrix cement.

The experimental results thus show that if the SSGF were composed of porous sedimentary formations similar to Kayenta sandstone, long-term injection of unmodified Magmamax brine is not feasible. In the case of acidified brine, most of the permeability decline may result from the mobilization of calcite. Additional experiments will be conducted in the future at lower flow rates to test the possibility of long-term injection of filtered, acidified geothermal brine.

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APPENDIX A: COMPONENTS OF FPTs

Part	Description	Manufacturer
Ball valve—Hoke	6.35-mm, 316 stainless steel	CON-VAL, Inc. 142 Pendleton Way Oakland, CA
Needle valve—Dragon	6.35-mm, 316 stainless steel	Dragon Valves, Inc. Norwalk, CA These valves are also sold as an LLL-Stores item.
Pump—CAT	CAT model 280 positive displacement pump, maximum delivery rate of 10.4 l/min	CAT Pumps International Rostocker Strasse 9 6200 Wiesbaden-Bierstadt West Germany
Pump—Moyno	Progressive cavity pump with a variable delivery rate from 0.4 to 19.2 l/min, model 9B3-CDQX	Robbins and Myers, Co. Springfield, OH
Pump pressure gage Confining pressure gage	Bourdon-tube variety, range is 6.89 kPa–50.0 MPa	LLL-Stores item
Pressure tubing	9.53-mm o.d. × 7.49-mm, 316 stainless steel	Available from LLL-ME Division, Bldg. 343
Pressure gage upstream and downstream	Bourdon-tube variety, range is 6.89 kPa–50.0 MPa	Weksler Instruments Co. P.O. Box 3040 Freeport, L.L., NY
Gage isolator	TA isolator diaphragm, type RA	AMETEK Co. Sellersville, PA
Isolator installation and gage calibration	—	Bostrom Instrument Co. 440 Eleventh Ave. San Diego, CA
Pressure vessel	Flanged, 1-l capacity, 30 MPa maximum pressure, 250°C maximum temperature	High Pressure Equipment Co. c/o B. W. Brundage Co. 4390 Piedmont Ave. Oakland, CA
Confining pressure pump	Piston-type hydraulic hand pump with maximum working pressure of 59.6 MPa	Enerpac Division of Applied Power, Inc. Butler, WI
Temperature recorders	Sym-ply-trol, iron-constantan thermocouple recording assembly	LLL-Stores item
Burette	Standard 50-cm ³ capacity	LLL-Stores item

APPENDIX B: DETAILS OF THE PRESSURE VESSEL LID AND CORE HOLDER ASSEMBLY

Figures 16 and 17 denote the pressure vessel lid and core holder assembly details.

Pressure Vessel Lid

Figure 16. Details of the pressure vessel lid (AAA77-103530-00).

Core Holder Assembly

Figure 17. Details of the core holder assembly (AAA-103529-00).

**APPENDIX C: KAYENTA SANDSTONE EXPERIMENTAL
RESULTS TABULATIONS**

Specimen	P _c	Date	T _c	P ₂ [*] - P ₁ [*]	Q [*]	Q [*] /A	P ₂ [*] - P ₁ [*] /L	η	PVF	k	Time	TTF	pH _e	pH _f	SiO _{2e}	SiO _{2f}
K-4	1500	9/14/77	85	20.41	0.825	0.166	1.98	-	-	-	1633	0.30	-	-	-	-
K-4	1500	9/14/77	86	14.29	0.608	0.122	1.38	0.54	-	48	1638	0.38	-	-	-	-
K-4	1500	9/14/77	86	8.30	0.281	0.057	0.80	-	-	-	1642	0.45	-	-	-	-
K-4	1500	9/14/77	-	-	-	-	-	-	-	-	1645	-	3.3	-	-	-
K-4	-	9/14/77	85	20.41	0.731	0.147	1.98	0.54	194.2	40	1647	0.53	-	-	-	-
K-4	-	9/14/77	89	13.61	0.107	0.022	1.32	0.515	-	9	1705	0.83	-	5.7	-	-
K-4	-	9/14/77	91.5	13.61	0.093	0.019	1.32	0.50	-	-	1717	1.03	-	-	-	-
K-4	-	9/14/77	89.5	15.31	0.082	0.016	1.48	0.51	-	6	1744	1.48	-	-	-	-
K-4	-	9/14/77	-	13.61	0.058	0.012	1.32	-	-	-	-	-	-	-	-	-
K-4	-	9/14/77	-	13.61	0.054	0.011	1.32	-	-	-	1755	1.66	-	-	-	-
K-4	-	9/14/77	81.5	13.61	0.066	0.013	1.32	0.57	-	6	1800	1.75	4.6	-	-	-
K-4	-	9/14/77	85	13.61	0.082	0.016	1.32	0.54	-	7	1811	1.93	-	-	-	-
K-4	-	9/14/77	-	-	-	-	-	-	274.4	-	1826	2.18	-	-	-	-
K-4	-	9/14/77	-	-	-	-	-	-	-	-	1830	2.25	3.8	-	-	-
K-4	-	9/14/77	83	13.61	0.041	0.008	1.32	0.56	282.1	3	1850	2.58	-	-	-	-
K-4	-	9/14/77	-	-	-	-	-	-	-	-	1900	2.75	4.8	-	-	-
K-4	-	9/14/77	-	-	-	-	-	-	284.2	-	1910	2.92	-	-	-	-
K-4	-	9/14/77	80	13.61	0.043	0.009	1.32	0.58	-	4	1935	3.16	-	-	-	-
K-4	-	9/14/77	77	13.61	0.044	0.009	1.32	0.61	-	4	1950	3.42	-	-	-	-
K-4	-	9/14/77	80	13.61	0.033	0.007	1.32	0.58	-	3	2000	3.58	5.3	-	-	-
K-4	-	9/14/77	89.5	13.61	0.032	0.006	1.32	0.51	-	2	2010	3.75	-	-	-	-
K-4	-	9/14/77	86.5	13.61	0.034	0.007	1.32	0.535	-	3	2030	4.08	5.2	-	-	-
K-4	-	9/14/77	75	13.61	0.021	0.004	1.32	0.62	-	2	2059	4.57	-	-	-	-
K-4	-	9/14/77	78	13.61	0.015	0.003	1.32	0.60	319.1	1	2127	5.20	5.1	-	-	-
K-4	-	9/14/77	-	-	-	-	-	-	-	-	2300	6.75	5.0	-	-	-
K-4	-	9/14/77	-	-	-	-	-	-	-	-	2400	7.75	5.4	-	-	-
K-4	-	9/15/77	-	-	-	-	-	-	-	-	0100	8.75	4.9	-	-	-
K-4	-	9/15/77	-	-	-	-	-	-	-	-	0300	10.75	4.8	-	-	-
K-4	-	9/15/77	-	-	-	-	-	-	-	-	0500	12.75	4.8	-	-	-
K-4	-	9/15/77	-	-	-	-	-	-	-	-	0600	13.75	4.6	-	-	-
K-4	1000	9/15/77	-	-	-	-	-	-	428.3	-	0745	15.50	-	-	-	-
K-4	1500	9/15/77	-	-	-	-	-	-	-	-	0800	15.75	4.35	-	-	-
K-4	1500	9/15/77	84	-	-	-	-	-	433.2	-	0800	15.75	4.35	6.2	-	181
K-4	1500	9/15/77	74.5	17.22	0.028	0.006	1.67	0.62	435.6	2	0842	16.45	4.4	-	-	-
K-6-Top	1500	9/16/77	85	13.61	0.539	0.113	1.32	0.55	714.3	47	0820	0.16	5.8	-	-	-
K-6-Top	1500	9/16/77	85.5	13.61	0.253	0.053	1.32	0.545	-	22	0840	0.52	-	-	-	-
K-6-Top	-	9/16/77	85	13.61	0.239	0.050	1.32	0.55	806.0	21	0845	0.58	-	-	-	-
K-6-Top	1500	9/16/77	83.5	13.61	0.128	0.027	1.32	0.56	-	11	0915	1.06	-	-	-	-
K-6-Top	-	9/16/77	83.0	20.41	0.190	0.040	1.98	0.57	836.7	-	0926	1.27	-	-	-	-
K-6-Top	-	9/16/77	85	27.22	0.242	0.051	2.64	0.55	841.8	-	0937	1.45	-	-	-	-
K-6-Top	-	9/16/77	85	13.61	0.112	0.024	1.32	0.55	-	10	0940	1.50	-	5.8	-	-
K-6-Top	-	9/16/77	-	-	-	-	-	-	-	-	1000	1.75	5.9	-	-	-
K-6-Top	1500	9/16/77	83.8	13.61	0.106	0.022	1.32	0.56	877.6	9	1020	2.16	-	-	-	-
K-6-Inv	1500	9/17/77	-	-	-	-	-	-	-	-	1100	0.00	3.15	-	451	-
K-6-Inv	1500	9/17/77	65.0	-	-	-	-	-	175.5	-	1125	0.16	-	4.85	-	-
K-6-Inv	1500	9/17/77	83.5	3.40	0.207	0.043	0.33	0.54	-	-	1347	0.35	-	-	-	-
K-6-Inv	-	9/17/77	82.5	6.80	0.591	0.124	0.66	0.55	236.7	103	1356	0.50	-	-	-	-
K-6-Inv	-	9/17/77	-	-	-	-	-	-	-	-	1400	0.57	4.50	-	-	-
K-6-Inv	-	9/17/77	-	-	-	-	-	-	-	-	1418	0.70	-	5.28	-	396
K-6-Inv	-	9/17/77	-	-	-	-	-	-	-	-	1425	0.82	3.35	-	-	-
K-6-Inv	-	9/17/77	83.5	6.80	0.260	0.055	0.66	0.54	580.6	45	1442	1.26	3.35	-	-	-
K-6-Inv	-	9/17/77	80.5	-	-	-	-	-	-	-	1502	1.60	3.45	5.25	-	-
K-6-Inv	1500	9/17/77	84	6.80	0.168	0.035	0.66	0.54	726.5	29	1544	2.30	-	-	-	-
K-6-Inv	-	9/17/77	-	-	-	-	-	-	-	-	1600	2.58	3.55	-	-	-
K-6-Inv	1500	9/17/77	77.5	6.80	0.165	0.035	0.66	0.59	838.8	31	1750	4.40	2.65	5.15	-	-
K-7	1500	9/19/77	-	-	-	-	-	-	76.5	-	1518	0.10	5.2	-	453	-
K-7	1500	9/19/77	78	6.80	3.70	0.774	0.66	-	-	-	-	-	-	-	-	-
K-7	1500	9/19/77	76	13.61	9.80	2.05	1.33	0.61	-	940	1530	0.30	-	-	-	-
K-7	1500	9/19/77	76	20.41	13.89	2.91	1.99	-	-	-	1531	0.32	-	-	-	-
K-7	-	9/19/77	75	13.61	10.42	2.18	1.33	0.615	515.3	1008	1532	0.33	-	-	-	-
K-7	-	9/19/77	-	-	-	-	-	-	-	-	1538	0.43	-	5.15	-	-
K-7	-	9/19/77	78	13.61	9.26	1.94	1.33	-	-	-	1547	0.58	-	-	-	-
K-7	1500	9/19/77	75	13.61	5.63	1.18	1.33	0.615	-	546	1558	0.77	5.3	-	-	-
K-7	-	9/19/77	75	13.61	0.832	0.174	1.33	0.615	1515.3	80	1603	0.85	-	-	-	-
K-7	1500	9/19/77	75	13.61	2.06	0.431	1.33	0.615	-	199	1618	1.10	5.3	-	-	-
K-7	-	9/19/77	76	13.61	1.60	0.335	1.33	0.61	-	154	1628	1.27	-	-	-	-
K-7	-	9/19/77	77.5	13.61	1.24	0.259	1.33	0.595	-	116	1638	1.43	-	-	-	-
K-7	-	9/19/77	77.5	13.61	1.08	0.226	1.33	0.595	-	101	1648	1.60	-	-	-	-
K-7	-	9/19/77	-	-	-	-	-	-	-	-	1658	1.78	5.15	-	-	-
K-7	1500	9/19/77	77.5	13.61	1.39	0.291	1.33	0.595	-	130	1700	1.80	-	5.35	-	-
K-7	1500	9/19/77	81	13.61	0.765	0.160	1.33	0.57	-	69	1715	2.05	-	-	-	-
K-7	-	9/19/77	-	-	-	-	-	-	-	-	1800	2.80	5.10	-	-	-
K-7	-	9/19/77	-	-	-	-	-	-	-	-	1900	3.80	5.10	-	-	-
K-7	-	9/19/77	67	13.61	1.30	0.272	1.33	-	-	-	2005	4.81	4.75	-	-	-
K-7	1500	9/19/77	83	13.61	0.020	0.004	1.33	0.56	2688.7	2	2105	5.88	4.85	5.20	-	-
K-7	-	9/20/77	-	-	-	-	-	-	3627.6	-	0415	13.05	-	-	-	-
K-10	-	9/20/77	-	-	-	-	-	-	-	-	0900	0.00	5.90	-	426	-
K-10	1500	9/20/77	77	13.61	1.24	0.259	1.33	0.62	255.1	121	0956	0.33	-	-	-	-
K-10	-	9/20/77	-	-	-	-	-	-	-	-	1000	0.39	-	5.55	-	267
K-10	1400	9/20/77	73	13.61	1.02	0.213	1.33	0.645	290.8	103	1005	0.48	-	-	-	-
K-10	1500	9/20/77	86	13.61	0.969	0.202	1.33	0.55	-	84	1007	0.52	-	-	-	-
K-10	1500	9/20/77	74	13.61	0.631	0.132	1.33	0.63	420.9	63	1040	1.07	-	-	-	-
K-10	-	9/20/77	73	13.61	0.595	0.124	1.33	0.645	471.9	60	1056	1.33	-	-	-	-

Specimen	P _c	Date	T _c	P ₂ - P ₁	Q*	Q*/A	P ₂ - P ₁ /L	η	PVF	k	Time	TTF	pH _e	pH _f	SiO _{2e}	SiO _{2f}
K-10	-	9/20/77	-	-	-	-	-	-	-	-	1100	140	5.8	-	-	-
K-10	-	9/20/77	71	13.61	0.541	0.113	1.33	0.67	523.0	57	1110	1.57	-	5.70	-	-
K-10	1550	9/20/77	71	13.61	0.365	0.076	1.33	0.67	574.0	38	1127	1.85	-	-	-	-
K-10	1600	9/20/77	72	13.61	0.197	0.041	1.33	0.66	625.0	20	1156	2.33	-	-	-	-
K-10	1600	9/20/77	71	13.61	0.134	0.028	1.33	0.67	655.6	14	1230	2.90	-	-	-	-
K-10	1600	9/20/77	74	13.61	0.142	0.030	1.33	0.63	696.4	14	1309	3.55	5.7	5.70	-	172
K-8	-	9/21/77	-	-	-	-	-	-	-	-	1525	0.00	2.0	-	458	-
K-8	1500	9/21/77	78	3.40	0.184	0.038	0.33	-	28.8	-	1540	0.25	-	-	-	-
K-8	-	9/21/77	83	6.80	1.07	0.223	0.66	-	35.4	-	1541	0.27	-	-	-	-
K-8	-	9/21/77	76	13.61	5.21	1.08	1.32	0.60	-	490	1542	0.28	-	-	-	-
K-8	-	9/21/77	82	13.61	6.94	1.44	1.32	0.56	141.4	611	1543	0.30	-	-	-	-
K-8	-	9/21/77	-	-	-	-	-	-	-	-	1545	0.33	2.8	4.50	-	-
K-8	1600	9/21/77	81	13.61	5.56	1.16	1.32	0.56	267.7	492	1549	0.40	-	-	-	-
K-8	-	9/21/77	80	6.80	2.54	0.529	0.66	0.57	353.5	457	1556	0.47	-	-	-	-
K-8	1600	9/21/77	75	13.61	3.97	0.827	1.32	0.60	-	376	1609	0.73	-	-	-	-
K-8	-	9/21/77	-	-	-	-	-	-	-	-	1610	0.75	4.25	-	-	-
K-8	-	9/21/77	-	-	-	-	-	-	1009.6	-	1625	1.00	-	-	-	-
K-A	-	9/22/77	-	-	-	-	-	-	-	-	0910	0.00	4.05	-	477	-
K-A	1500	9/22/77	72	3.40	1.44	0.299	0.35	-	69.9	-	0916	0.10	-	-	-	-
K-A	-	9/22/77	73	6.80	3.27	0.678	0.71	-	-	-	0918	0.13	-	-	-	-
K-A	-	9/22/77	73	13.61	7.58	1.57	1.42	0.63	-	697	0920	0.16	-	-	-	-
K-A	-	9/22/77	73	20.41	11.11	2.30	2.12	-	-	-	0921	0.18	-	-	-	-
K-A	-	9/22/77	73	13.61	4.63	0.960	1.42	0.63	376.3	426	0922	0.20	-	-	-	-
K-A	-	9/22/77	-	-	-	-	-	-	-	-	0924	0.23	-	4.50	-	-
K-A	1500	9/22/77	68	13.61	4.39	0.910	1.42	0.57	-	365	0924	0.23	-	-	-	-
K-A	-	9/22/77	71	13.61	4.39	0.910	1.42	0.65	-	365	0932	0.37	-	-	-	-
K-A	-	9/22/77	70	13.61	4.63	0.960	1.42	0.66	-	446	0933	0.38	-	-	-	-
K-A	-	9/22/77	70	13.61	4.50	0.933	1.42	0.66	-	434	0934	0.40	-	-	-	-
K-A	-	9/22/77	71	13.61	4.27	0.885	1.42	0.65	-	405	0937	0.45	-	-	-	-
K-A	-	9/22/77	71	13.61	4.27	0.885	1.42	0.65	-	405	0939	0.48	-	-	-	-
K-A	1500	9/22/77	70	13.61	4.17	0.865	1.42	0.66	849.5	402	0943	0.55	-	-	-	-
K-A	-	9/22/77	-	-	-	-	-	-	-	-	0948	0.63	4.55	-	-	-
K-A	-	9/22/77	73	13.61	2.69	0.558	1.42	0.63	-	248	0949	0.65	-	-	-	-
K-A	-	9/22/77	72	13.61	2.45	0.508	1.42	0.64	-	229	0951	0.68	-	-	-	-
K-A	-	9/22/77	72	13.61	2.31	0.479	1.42	0.64	-	216	0952	0.70	-	-	-	-
K-A	-	9/22/77	72	13.61	2.35	0.487	1.42	0.64	-	219	0953	0.72	-	4.60	-	-
K-A	1500	9/22/77	73	13.61	2.06	0.427	1.42	0.63	-	189	1000	0.83	-	-	-	-
K-A	-	9/22/77	73	13.61	2.03	0.421	1.42	0.63	-	187	1003	0.88	-	-	-	-
K-A	-	9/22/77	73	13.61	1.98	0.411	1.42	0.63	-	182	1004	0.90	-	-	-	400
K-A	-	9/22/77	74	13.61	2.14	0.444	1.42	0.62	-	194	1008	0.97	-	-	-	-
K-A	-	9/22/77	74	13.61	2.14	0.444	1.42	0.62	-	194	1010	1.00	-	-	-	-
K-A	-	9/22/77	74	13.61	2.19	0.454	1.42	0.62	-	198	1011	1.02	-	-	-	-
K-A	-	9/22/77	74	13.61	2.19	0.454	1.42	0.62	-	198	1015	1.08	-	-	-	-
K-A	-	9/22/77	74	13.61	2.38	0.493	1.42	0.62	1354.8	213	1017	1.12	-	-	-	-
K-A	1500	9/22/77	71	3.40	0.231	0.048	0.35	0.65	1360.2	89	1047	1.25	-	4.60	-	-
K-A	-	9/22/77	-	-	-	-	-	-	-	-	1052	1.33	3.40	-	-	-
K-A	-	9/22/77	78	3.40	0.181	0.038	0.35	0.59	1376.3	64	1058	1.43	-	4.60	-	-
K-A	1600	9/22/77	72	3.40	0.171	0.035	0.35	0.64	1387.1	64	1109	1.62	2.70	4.80	-	-
K-A	1600	9/22/77	75	3.40	0.180	0.037	0.35	0.61	1397.8	64	1117	1.75	-	-	-	-
K-A	-	9/22/77	71	3.40	0.179	0.037	0.35	0.65	1403.2	69	1123	1.85	-	-	-	-
K-A	-	9/22/77	71	3.40	0.172	0.036	0.35	0.65	1408.6	67	1127	1.92	-	-	-	-
K-A	1600	9/22/77	70	3.40	0.162	0.034	0.35	0.66	1414.0	64	1133	2.02	-	-	-	-
K-A	-	9/22/77	72	3.40	0.148	0.031	0.35	0.64	1419.4	57	1139	2.12	-	-	-	-
K-A	-	9/22/77	73	3.40	0.127	0.026	0.35	0.63	1424.7	41	1146	2.23	-	-	-	-
K-A	-	9/22/77	72	3.40	0.112	0.023	0.35	0.64	1430.1	42	1154	2.37	-	-	-	-
K-A	1500	9/22/77	70	3.40	0.094	0.019	0.35	0.66	1435.5	36	1209	2.62	3.10	-	-	-
K-A	-	9/22/77	70	3.40	0.080	0.017	0.35	0.66	1440.9	32	1213	2.68	-	5.00	-	-
K-A	-	9/22/77	70	3.40	0.069	0.014	0.35	0.66	1446.2	26	1226	2.90	-	-	-	-
K-A	-	9/22/77	69	3.40	0.047	0.010	0.35	0.66	1451.6	19	1245	3.22	-	-	-	-
K-A	-	9/22/77	73	3.40	0.017	0.004	0.35	0.63	1457.0	7	1325	3.88	-	-	-	-
K-A	-	9/22/77	-	-	-	-	-	-	-	-	1400	4.46	4.00	-	-	-
K-A	-	9/22/77	71	6.80	0.013	0.003	0.71	0.65	1462.4	3	1415	4.72	-	-	-	-
K-A	1300	9/22/77	72	27.22	0.423	0.088	2.83	0.64	1467.7	20	1417	4.75	-	-	-	-
K-A	1300	9/22/77	76	20.41	0.329	0.068	2.12	0.60	1473.1	19	1421	4.82	4.30	5.20	-	-
K-A	1500	9/22/77	71	13.61	0.196	0.041	1.42	0.65	1478.5	19	1425	4.88	-	-	-	-
K-A	1500	9/22/77	71	6.80	0.094	0.019	0.71	0.65	1483.9	17	1435	5.05	-	-	-	-
K-A	-	9/22/77	71	6.80	0.080	0.017	0.71	0.65	1489.2	16	1443	5.22	-	-	-	-
K-A	-	9/22/77	72	27.22	0.460	0.095	2.83	0.64	-	21	1452	5.33	-	-	-	-
K-A	-	9/22/77	72	27.22	0.479	0.099	2.83	0.64	-	22	1456	5.40	-	-	-	353
K-A	-	9/22/77	72	27.22	0.483	0.100	2.83	0.64	-	23	1500	5.47	4.20	4.90	-	-

**APPENDIX D: ST. PETER SANDSTONE EXPERIMENTAL
RESULTS TABULATIONS**

Specimen	P _c	Date	T _c	P ₂ [*] - P ₁ [*]	Q [*]	Q [*] /A	P ₂ [*] - P ₁ [*] /L	η	PVF	k	Time	TTF	pH _e	pH _f	SiO _{2e}	SiO _{2f}
S-1	1500	9/21/77	-	-	-	-	-	-	-	-	0915	0.00	5.00	-	458	-
S-1	-	9/21/77	80	13.61	0.289	0.058	1.33	0.58	-	25	0923	0.13	4.95	-	-	-
S-1	-	9/21/77	80	20.41	0.412	0.082	1.99	0.58	28.6	24	0929	0.23	-	-	-	-
S-1	-	9/21/77	80	27.22	0.527	0.105	2.65	0.58	-	23	0931	0.27	-	-	-	-
S-1	-	9/21/77	80	6.80	0.152	0.030	0.66	0.58	-	26	0937	0.37	-	-	-	-
S-1	-	9/21/77	82	13.61	0.246	0.049	1.33	0.565	57.1	21	0941	0.43	-	-	-	-
S-1	-	9/21/77	-	-	-	-	-	-	-	-	0942	0.45	-	5.60	-	-
S-1	1500	9/21/77	83	13.61	0.114	0.023	1.33	0.56	78.7	10	0956	0.68	5.20	-	-	-
S-1	-	9/21/77	-	-	-	-	-	-	-	-	1002	0.78	-	-	-	115
S-1	1500	9/21/77	80	13.61	0.083	0.017	1.33	0.58	100.1	7	1027	1.20	-	-	-	-
S-1	1600	9/21/77	80	13.61	0.064	0.013	1.33	0.58	121.6	6	1058	1.72	4.80	-	-	-
S-1	-	9/21/77	-	-	-	-	-	-	-	-	1059	1.73	-	5.80	-	-
S-1	1600	9/21/77	85.5	13.61	0.053	0.011	1.33	0.535	143.1	4	1136	2.35	5.15	5.75	-	-
S-1	-	9/21/77	-	-	-	-	-	-	-	-	1145	2.50	5.15	-	-	-
S-1	1600	9/21/77	80	13.61	0.047	0.009	1.33	0.58	157.4	4	1204	2.82	-	-	-	-
S-2	1500	9/21/77	-	-	-	-	-	-	-	-	1650	0.00	-	-	-	-
S-2	-	9/21/77	-	-	-	-	-	-	-	-	1655	0.08	4.75	-	-	-
S-2	-	9/21/77	-	-	-	-	-	-	-	-	1700	0.16	4.55	-	-	-
S-2	-	9/21/77	74	6.80	0.276	0.056	0.70	0.62	28.6	50	1701	0.28	-	-	-	-
S-1	-	9/21/77	76	13.61	0.559	0.113	1.41	0.60	35.8	48	1703	0.22	-	-	-	-
S-2	-	9/21/77	72	20.41	0.801	0.161	2.11	0.64	50.1	49	1704	0.23	-	-	-	-
S-2	-	9/21/77	72	13.61	0.543	0.109	1.41	0.64	64.4	49	1707	0.28	-	5.10	-	-
S-2	-	9/21/77	71	13.61	0.466	0.094	1.41	0.65	100.1	43	1719	0.48	-	-	-	-
S-2	-	9/21/77	73	13.61	0.331	0.067	1.41	0.63	136	30	1733	0.72	-	-	-	-
S-2	-	9/21/77	74	13.61	0.251	0.051	1.41	0.62	191	22	1748	0.97	4.20	5.65	-	-
S-2	-	9/21/77	74	13.61	0.225	0.045	1.41	0.62	-	20	1800	1.16	3.80	-	-	-
S-2	-	9/21/77	-	-	-	-	-	-	-	-	1900	2.16	4.25	-	-	-
S-2	-	9/21/77	74	20.41	0.152	0.031	2.11	0.62	-	9	1950	3.00	-	-	-	-
S-2	-	9/21/77	75	13.61	0.099	0.020	1.41	0.61	377	9	2003	3.22	4.00	-	-	-
S-2	-	9/21/77	73	13.61	0.088	0.018	1.41	0.63	-	8	2022	3.53	-	-	-	-
S-2	-	9/21/77	70	13.61	0.071	0.014	1.41	0.66	-	7	2100	4.16	3.60	5.60	-	-
S-2	-	9/21/77	70	13.61	0.058	0.012	1.41	0.66	431	6	2127	4.62	-	-	-	-
S-2	1300	9/22/77	60	13.61	0	0	1.41	-	-	0	0700	14.16	-	-	-	-