PROCEEDINGS, Tenth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 22-21. 1985
SGP-TR-84

DISCUSSIONS ON A TYPE OF RESERVOIR CELL BOUNDARY IN THE GEYSERS STEAM FIELD

Jeffrey J. Hebein

Diamond Shamrock Thermal Power Company
601 California St.
San Francisco, CA 94108

Abstract

The boundaries of reservoir fluid convection cells are discreet and intricate zones, commonly sealed or reduced in permeabilities, which are often quite readily identifiable in many hydrothermal systems. Cell boundaries in the Geysers Steam Field are more vague; however, they are gradually being revealed by cumulative and extensive wellbore data. A profound example of a type of boundary has been revealed by drilling in one area of the steam field. A proposed model utilizes a sericitic alteration scheme to establish cell self-sealing. Mineralogical, permeability, and temperature properties all coincide so as to allow formation of a boundary model. This reinforces previously held views that the reservoir cell rock and hydrothermal system are greatly out of equilibruim. Such similar phenomena are suggested from drilling experiences in other ports of the steam field. Considerably, more work is required to better define and comprehend the nature and location of reservoir cell boundaries within the Geysers Steam Field.

Introduction

Reservoir cell boundaries within the Geysers Steam Field are seldom mentioned in literature and may be a bit mysterious in nature when viewed by field operators during drilling and reservoir assessments. Undoubtedly, more than one type of boundary probably exists in different parts of the field. Differing lithologic, structural, and mineralogical properties of field reservoir cells must dictate just how and where a boundary will occur. Hebein (1983) presented conceptions of a reservoir cell and its associated boundaries for one area of the steam field. This model may well be applicable to other portions of the field and should be utilized as part of proper comprehension of reservoir conditions. The following discussions will relate the model to specific finding throughout the steam field.

Boundaries In Hydrothermal Reservoirs

Any hydrothermal cell must terminate for some reason or other. Several accepted ideas now circulate in geothermal thought. A liquid dominated cell may rise and lose temperature while mixing outward into cold groundwater (i.e., Wairakei). A mineralogical seal (figure 1) may develop above and/or around the cell, isolating it from its surroundings (i.e., Roosevelt). Various structural (fracturing) influences may dictate how fluid flow travels and terminates. Combinations of deep structural facets, hydrologic facets, and mineralogical seal facets could terminate a reservoir cell (i.e., South Brawley; Hebein, 1984b). Certain varying lithologic types can influence the propagation of permeable fracture systems (figure 2). The active and eroded fossil hydrothermal records are full of various examples.

Highly vaporous cells in the Geysers Field must terminate for various intricate reasons also; the transition between the surrounding hydrostotic and the inner vaporstatic reservoir gradients is sometimes rapid. Varying tectonic stresses control the propagation of nonhomogenous reservoir fractures within the Geysers cells. Argillite rich units are usually open fracture deficient, implying that such units could act as appropriate permeability barriers where condensate alteration sealing then becomes prolific.

One certainty is that the Geysers reservoir cells must be tightly and effectively sealed at great depths. A seal of sericitic alteration was proposed by Hebein (1983; 1984a) for a Geysers cell.

Sealing by the acidic alteration of racks by steam condensate is often seen in near surface fumarolic type systems (figure 3). White et al. (1971) offer various acceptable examples of such systems. The Geysers Field cells should not, however, be confused as being this type of shallow low temperature system (Hebein, 1983), even though comparisons are drawn.

The Model

Figure 4 illustrates and defines a type of reservoir cell boundary encountered in the Geysers Field. The well, drilled somewhere within the steam field, offers a conclusive example of how a particular cell had become terminated though condensate alteration and subsequent self sealing. It is highly plausible that the boundary will extent into an isolated neighboring cell; it too perhaps, sealed in the same manner at apprecaible depths (Hebein, 1984a). This well was anomalous to the normal trends of alteration and permeability encountered in the surrounding wells. Initial interpretations were difficult. However, when coupled to a temperature profile, the situation was conclusively ascertained.

The actual sealing process is basic. It can be defined as follows:

1. Detrital and hydrothermal feldspars + hot steam condensate yield — illite (± interlayers) + quartz ± realgar (and/or other epithermal sulfides).
2. Illite + hot steam condensate yield —swelling chlorite.
3. Pyrite + hot steam condensate yield — limonite.
4. Zeolite (Wairakite?) precipitates.

The sericitic alteration is commonly associated with sheared slickensides and terminated (joint) surfaces, indicating condensate acted on wall rocks along active tension and shear fractures /faults.

Reservoir Disequilibruim

The reservoir represented by this boundary model is appreciably out of equilibrium with respect to current and former temperatures, current and former fluid phases, and mineralogical hydrothermal alteration assemblages. Vaporstatic reservoir temperatures are too high in the uppermost portions (unaltered tectonic breccia) and too low in the lowermost portion (toumaline-garnet breccia) of the cell in respect to the various hydrothermal alteration assemblages present. Current highly vaporous conditions (some residual liquid saturation) are out of phase with the highly liquid phases that once deposited vein alteration minerals. The earlier Na/Ca silicate (epidote, albite, actinolite) metasomatism has been overprinted by K–silicate (adularia) metasomatism. Hydrogen ion (sericite) metasomatism has overprinted both of the former assemblages above the steam cell and in the laterally sealed cell boundary. This stongly suggests that a former liquid system (single phase at depth) boiled down to great depths and formed a highly vaporous phase (with an overlying condensation zone) at the perimeter of the cell.

Large accumulations of hot steam condensate most probably acted *on* rocks along the current boundry, forming an impermeable **seal.** With time, the seal may have moved inward as unaltered rock became sericitized and rendered sealed along fracture trends. This particular reservoir cell has experienced a long history of changing hydrothermal events.

Concluding Discussion

The aforemenioned type of reservoir cell boundary need not ultimately define the final reservoir boundary. Renewed tectonic strain fracturing could break the seal and allow fluids to propagate outward or upward into relatively fresh rock and cause new alteration. Produceable permeable fractures might then exist in otherwise hot dry rock. In such a new environment, steam attaining great superheat could be then drawn laterally from the main reservoir; here then, liquid reserves would probable be very negligible. Such remote cases probably exist in certain parts of the steam field.

It is highly conceivable that the condensate type of boundary exists in other parts of the steam field. Public and privileged field data reveals that water entries (some massive) encountered while drilling at the fringes of steam reservoir cells probably represent large accumulations of steam condensate. Further extents of lateral drilling then penetrate hot dry rock. It is plausible that boundary sealing mechanisms are also at play in these regimes.

In fact, more than one type of cell boundary must exist in the Geysers Field. Considerably, more detailed evidence and proper geologic thought are required in order to derive other acceptable explanations for various modes of reservoir cell boundaries. Detailed reservoir temperature/pressure responses and lithologic/ structural manifestations should be correlated **so as** to ascertain the exact location and intrinsic nature of all cell boundaries.

Acknowledgement

The views and conclusions expressed herein are those of the author and may not necessarily represent the views and conclusion of Thermal Power Co., it's affiliated companies, it's venture partners, or any other entity.

References

Berger, B.R. and Eimon, P.I., 1983, Conceptural models of epithermal precious metal deposits: in, Cameron Volume on Uncoventional Mineral Deposits, A.I.M.E., New York, pp 191-205

Giles, D.L. and Nelson, C.E., 1982, Principal features of epithermal lode–gold deposits of the Circum-Pacific Rim: in, Transactions Third Circum–Pacific Energy and Mineral Resources Conference, A.A.P.G., Tulsa, pp 273–278

Hebein, J.J., 1983, Exploration, drilling, and development operations in the Bottlerock area of the Geysers Steam Field, with new geologic insights and models defining reservoir parameters: Proceedings Ninth Workshop Geothermal Reservoir Engineering, Stanford University, #SGP-TR-74, pp 135-144

Hebein, J.J., 1984a, Reflectons On The Nature Of The Geysers Geothermal Field: Geothermal Hot Line; California Division of Oil and Gas #TR02, vol. 14, #1, pp 29-31

Hebein, J.J., 1984b, The South Brawley (Mesquite Basin) Geothermal Resource, Imperial Valley, California: Geothermal Resources Council

Bulletin, Submitted for publication

Henley, R.W. and Thornley, P., *1981,* Low grade metamorphism and the geothermal environment of massive sulphide ore formation, Buchans, Newfoundland: Geological Association of Canada, Speical Poper *22,* pp *205-228*

McLaughlin, R.J.; Moore, D.E.; Sorg, D.H.; McKee, E.H., (1983), Multiple episodes of hydrothermal circulation, thermal metamorphism, and magma injection beneath the Geysers Steam Field, California: Geological Society of America, Abstracts with Programs; 15; No. *5,* p4*17*

Schoen, Robert, White, D.E., and Hemley, J.J., 1974, Argillization by descending acid at Steamboat Springs, Nevada: Clays and Clay Minerals, vol. *22,* pp *1-22*

White, D.E., Muffler, L.J.P., and Truesdell, A.H., *197* I, Vapor-dominated hydrothermal systems compared with hot-water systems: Economic Geology, vol. *66,* pp *75-97*

White, D.E., Fournier, R.O., Muffler, L.J.P., Truesdell, A.H., *1975,* Physical Results of Research Drilling in Thermal Areas of Yellowstone National Park, Wyoming: United States Geological Survey Professionol Poper *892,* 70 pp

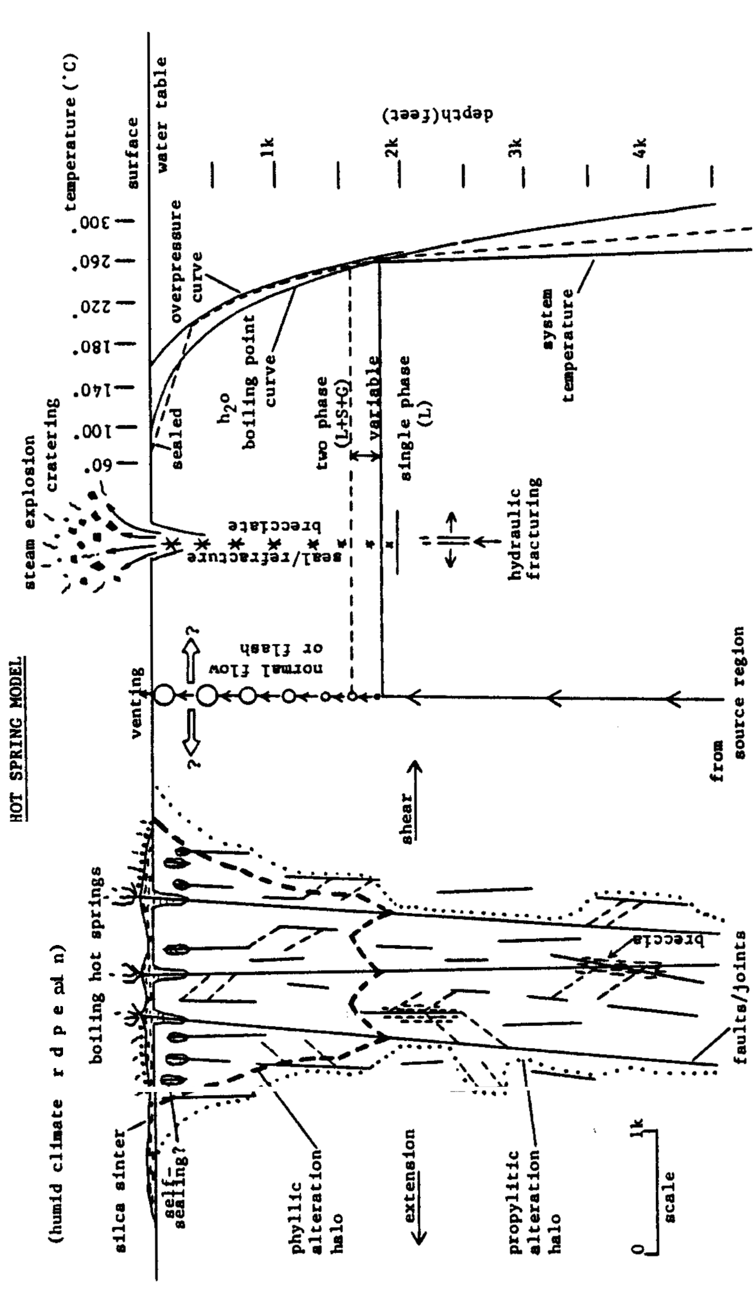


Figure 1. A conceptual illustration of an active, near-surface, self-sealing two-phase geothermal reservoir. Sealing may also take place at much deeper levels, not only near the surface. Fluid phase relationships will vary with NaCl and CO_2 concentrations. The plumbing conduits could form within a brecciated volcanic pipe. This type of model is witnessed in worldwide active and eroded fossil hydrothermal systems. Active examples: Yellowstone, WY. and Waiotapu, N.Z.; Fossil Examples: Bodie, CA and Marysvale, UT. Modified in part after White, et al. (1975); Henley and Thornley (1981); Giles and Nelson (1982)

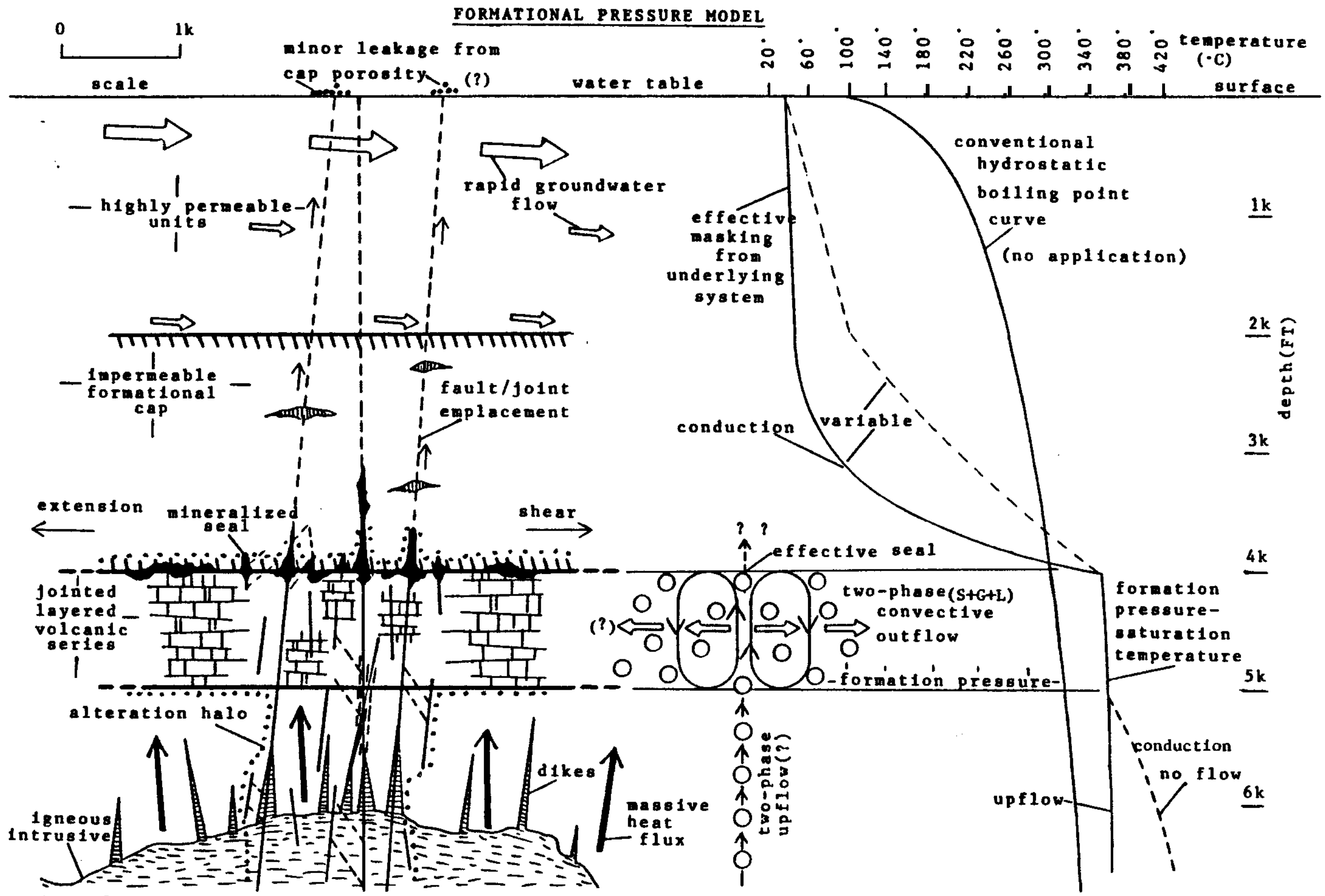


Figure 2. A conceptual illustration of a type of a deeper, effectively capped, formational pressure reservoir. Fluid chemistry, pressure retention, and degree of outside heat flux will determine the saturation temperatures of fluids. The conventional boiling point curve is not applicable in the lower sections. Cold overlying sections can completely mask the conductive and convective effects below. The faults emplaced through and below the reservoir may not neccesarily be permeable or part of that system. The ultimate temperatures in either permeable reservoir type are probably less than 400°C. Active examples: Puna, Hawaii and Olkaria, Ken.(?). Fossil examples: Creede, Co.(?) and some skarn/replacement deposits (Renison Bell, Tasm.).

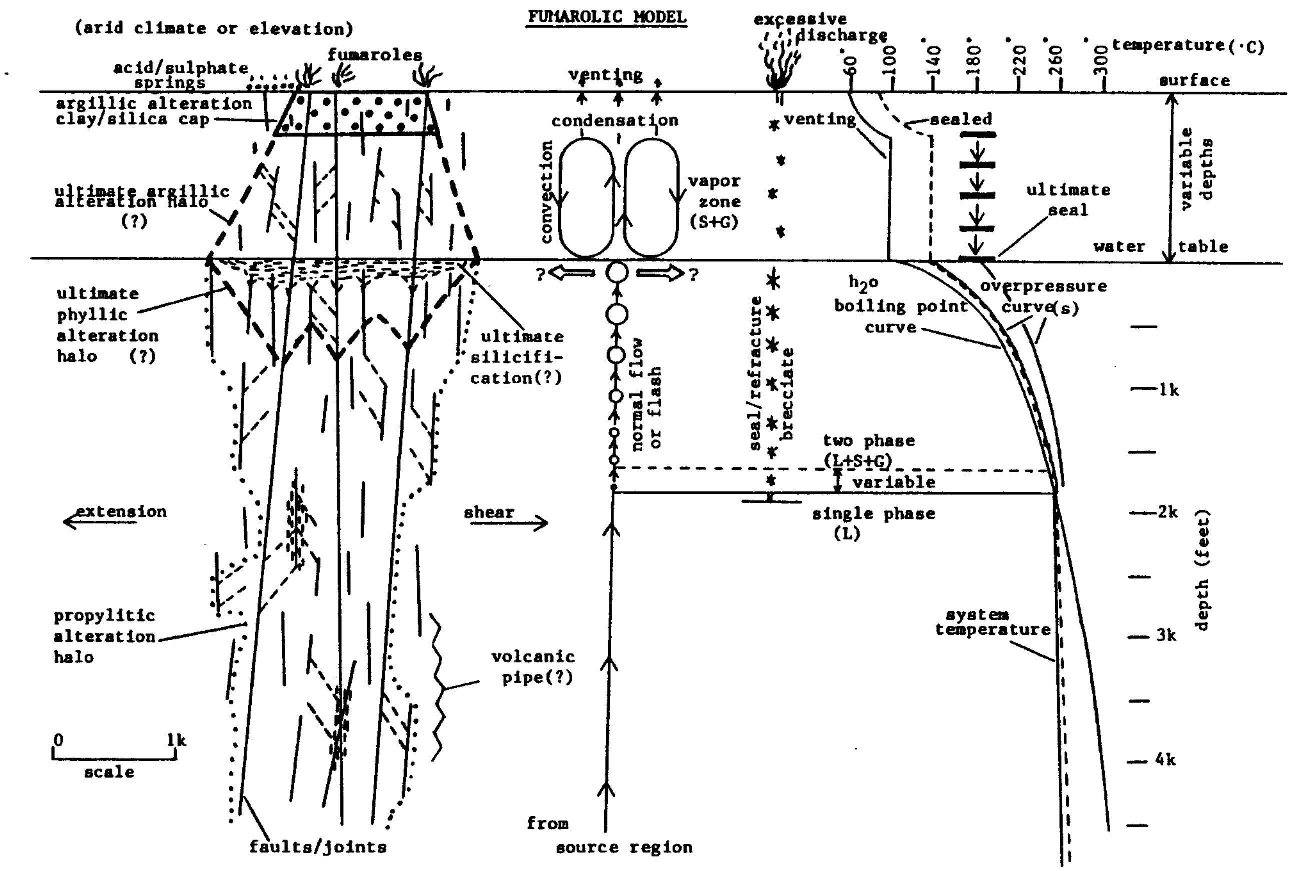


Figure 3. A conceptual illustration of an active, near-surface, self-sealed, vapor-dominated multi-phase geothermal reservoir. Some of these mechanisms could be applied to former and current conditions in the Geysers Steam Field and in other systems. Such a system could also be pipe-like and have varying fluid phase relations. Active examples: Steamboat Springs, Nev. and Coso, Ca. Fossil examples: Sulfur, Nev. and Pachuca-Real Del Monte, Mx. Modified in part after Schoen, et al. (1974); Berger and Eimon (1983)

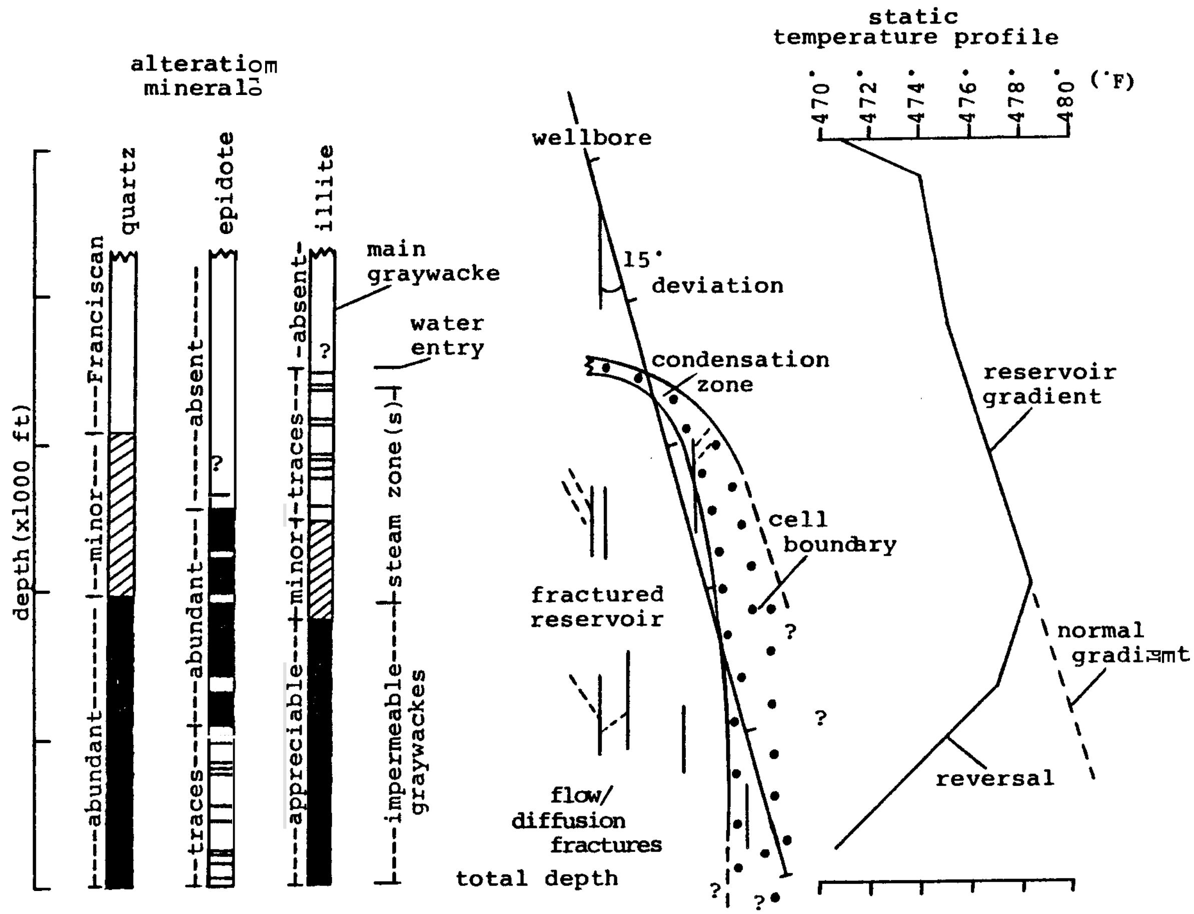


Figure 4. A conceptual illustration of a type of reservoir cell boundary encountered within the Geysers Steam Field. The wellbore ("Well X") penetrates overlying condensation zone, the reservoir proper, and the deep altered and sealed flanks of the reservoir cell. The flank boundary may have been a zone of low fracture density and/or high argillite content. The alteration mineral assemblages are highly descriptive of the overprinting of older alterations by the most recent sericitic alteration assemblage. Other wells in this area assume a normal vaporstatic temperature gradient. Here, the temperature reversal is quite revealing. Modified in part after Hebein (1983), Hebein (1984a), and other privileged steam field well data.

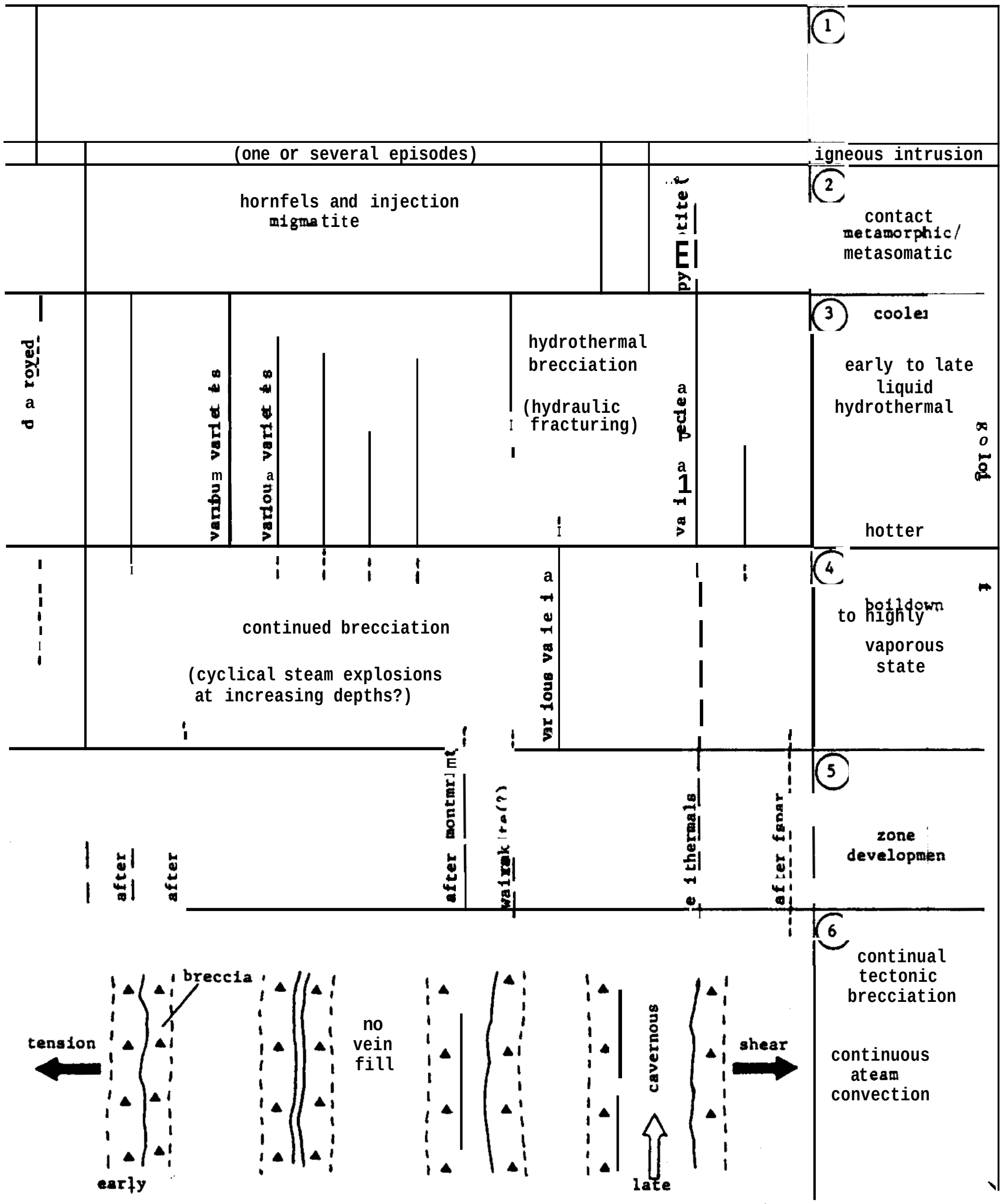
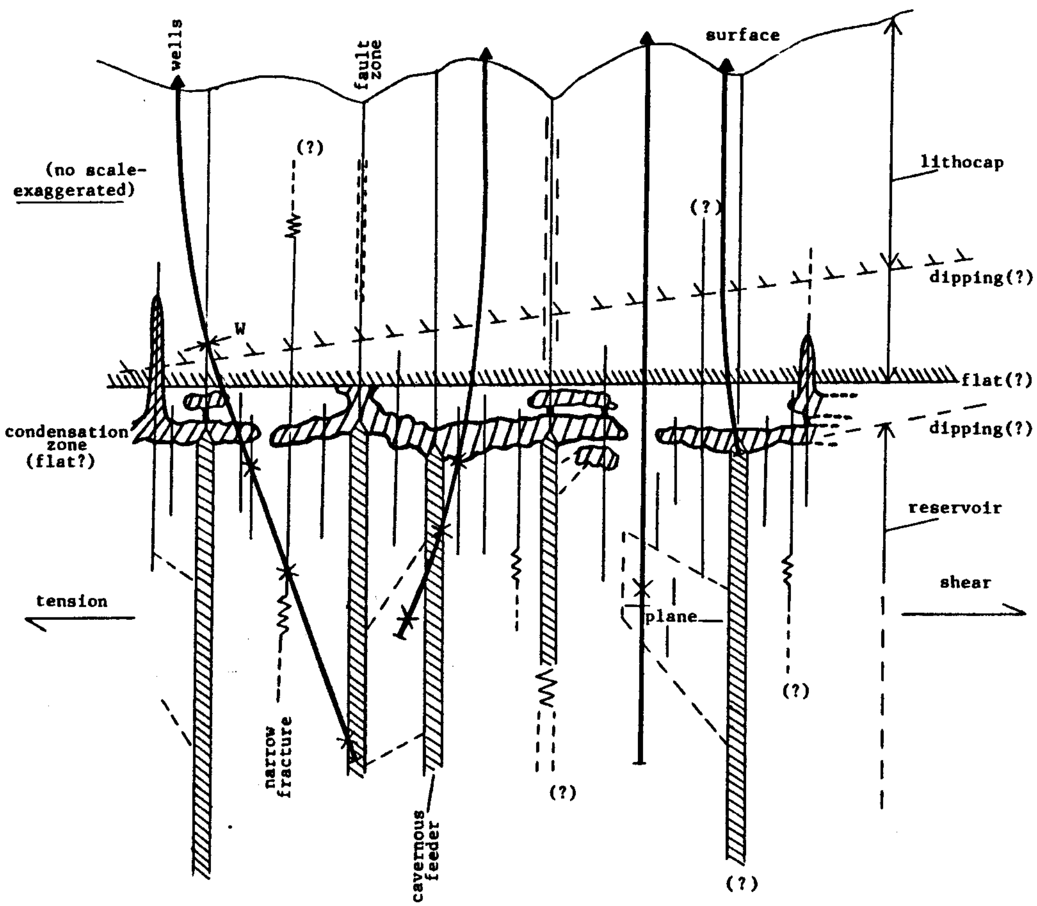


Figure 5. A flovchart illustrating a generalized scheme of probable hydrothermal events through late quaternary time in several areas of the Geysers Steam Field. As higher heat flux builds at depth, new alterations form. Here, geologic time is more appropriate than specific locations of event (stage) alteration. Stage transitions are gradual rather than abrupt. Based in part on scenarios by Hebein(1983), Hebein(1984a), and McLaughlin, et al. (1983).



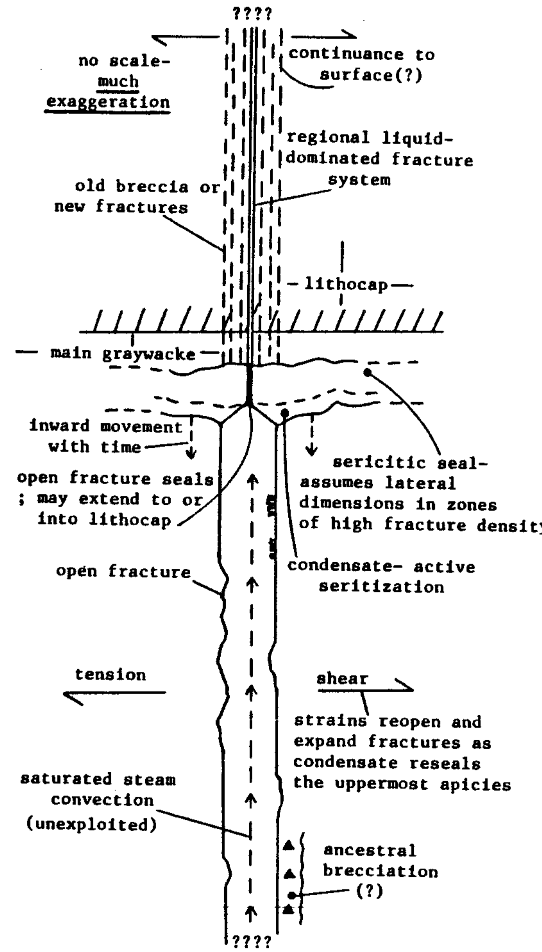


Figure 6. A conceptual illustration of a probable geological setting responsible for the occurence of a reservoir condensation zone(s) in certain parts of the Geysers Steam Field. ~~The lithocap and condensation zone could dip regionally and be irregular.~~ Directional drilling gives the impression that first steam occurs along flat structural features; actually, permeable vertical joints and shear faults probably terminate upward into a condensation zone seal. Vertical drilling may yield very poor results. The condensate seal may be very difficult to distinquish along the shallow depth crests of reservoir cells. The scale is undoubtedly exaggerated.