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NEW ACHIEVEMENT IN SEEKING DEEP RESERVOIR AT YANGBAJAIN GEOTHERMAL FIELD, TIBET, CHINA

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ABSTRACT

The downhole temperature of 202℃ at 959 m depth was recorded by a explorative well at Sulfur Mine, the uphill terrain northwestern to the borefield, of Yanbajain Geothermal Field, where the exploitation has been restricted within the shallow reservoir of limited size for more than then years. The explorative drilling also reveals the fracture permeability within the granite at deep level, and a systematicall vertical zonation of hydrothermal alteration represented by advanced argillization + acid sulfate alteration → silicification and brecciation → illite + epidote alteration, suggesting the upflow condition of geothermal fluid. It is believed that the upflow zone of Yangbajain geothermal system is located at, or even northwestern to, Sulfur Mine, and probably a deep hot reservoir was created there.

INTRODUCTION

Yangbajain geothermal field, located at 4300 m elevation, 90km NW of Lhasa, has been exploitated to generate electricity since 1975. So far, eight units, with the total capacity of 25 MW, have been installed, which meet up half of the electricity demand of the Lhasa region.

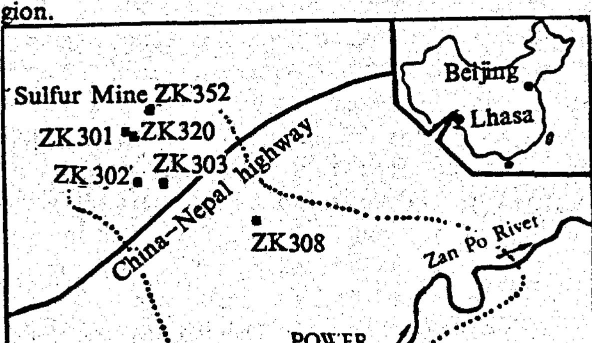

Fig1. Location map of Yanbajain Geothermal Field.

The field is set within a narrow intramountainous graben elongated SW to NE, which seperates Mt. Nyainqentanglha composed of Pre-Cambrian gneiss and Mt. Tang cmposed of Mesozoic and Paleozoic sedimentary series. The graben is filled by 200m–300m thick Quaternary glacial–alluvial sediments on the granitic basement. The Nyainqentanglha Fault, the NW marginal fault of the graben, is the predominant structure in this area with high tectonic activity, accompanied by intensive seismic ~~and hydrothermal activities~~. Yangbajain geothermal → = yielding ...drothermal anomalies along ...ault. Minor faults, NS and NW trending, were developed in Sulfur Mine, the uphill terrain northwestern to the borefield.

Alough characteristic of the deep part of Yanbajain geothermal system hasn't been well defined yet, the shallow reservoir has been intensively studied (Zheng et al, 1985; Cappetti and Wu, 1985). 150–170℃ hot water was produced from this 200m–300m thick shallow reservoir, which consists of Quaternary sediment (gravels, sands, silts and clays) and covers an area of 2×4 km^2. The fluid is believed to be fed by the faults of granitic bedrock in the area north of the China–Nepal highway where wells ZK 302 and ZK 303 are located (zheng et al, 1985) (see Fig.1).

Recently, high temperature (202℃) at deep level (1000m) was validated by the drilling of the explorative Well ZK 352 at Sulfur Mine.This paper is intended to summarize the characteristics of the reservoir rocks penetrated by ZK 352, based on the petrological study of the drill cores, compared with another deep well, ZK 308.

ZK 352 & ZK 308

Among the more than 50 wells have been drilled so far, only two, ZK 308 and ZK 352, are deep wells over 1000m.

ZK 352 is sited at 4406m elevation. The drilling was carried out from Oct. 1987 to July 1988 with mud to the total depth of 1003m. The casing was set at 496m.

There were total losses of circulation between 268m and 498m, significant losses at 251m and 879–881m, and minor losses from 489m to 1000m intermittently. Water table is located at – 120m (4286m elevation)Fig. 2 shows the geology –drilling log of ZK 352. T–1 is the downhole temperature at the end of well completion, T–2 is the 48-hour–recovery temperature, and T–3 is the 72-hour–recovery temperature. As yet the chemical analysis of the fuid in this well hasn't been available. (Wang et al, 1988).

ZK 308 is sited at 4297m elevation. The drilling of the well was started in June 1980 and completed in Oct. 1982 to the total depth of 1726m. The maximum dowanhole temperature of 158℃ was measured at 150m, an inversion to 120℃ between 500–1000m was noted. Below 1000m the temperature again risen with the gradient of 40 ℃ / km (Fig. 3).

The downhole measurements clearly outline the extent of the shallow reservoir, which is situated within granitic bedrock between 4230 – 4000m elevation at northern part, and ascended to Quaternary sediments between 4280 – 4100 m elevation at southern part of the field. At deep level, temperature grident in the northern part (19℃ / 100m) is higher than that in the southern part (4℃ / 100m) of the field.

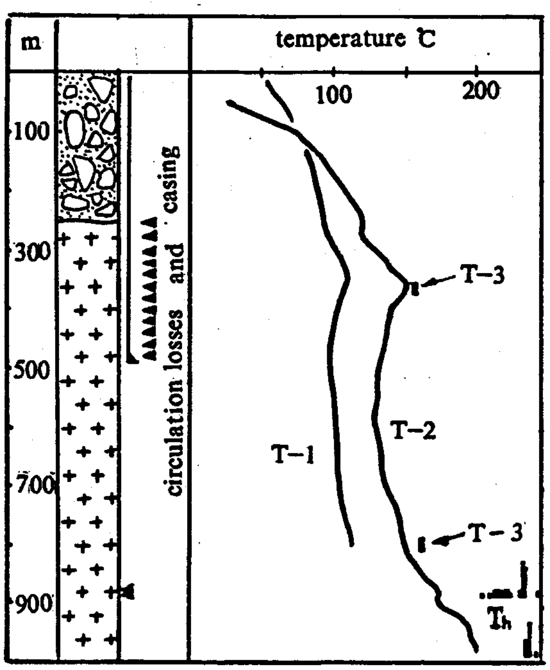

Fig2. Drill log and down hole temperature in ZK 352

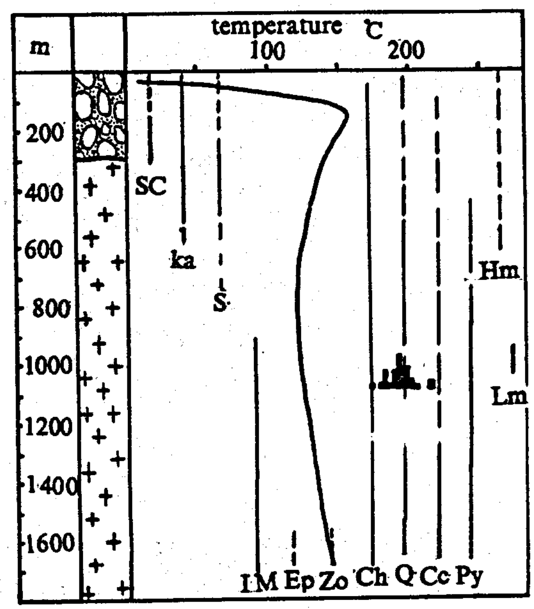

Fig3. Drill log and down hole temperature in ZK 308. ka–kaolinite, Ch–chlorite, S–smectite, I–illite, SC–mixedlayer smectite–chlorite, Ep–Epidote, Zo–Zoisite Lm–Laumontite. Cc–calcite, Py–pyrite, Hm–hemtite, Q–quartz.

HYDROTHERMAL BRECCIATION

The breccias, both tectonic and hydrothermal in origin, were found in cores of ZK 352. The tectonic breccias are texturally characterized by mylonization, cataclasis, granulation, slickensides, rotation of clasts. Hydrothermal breccias, on the other hand, display the texture of hydraulic fractaring: jigsaw puzzle texture, cementation of hydrothermal minerals, open–space and vug–filling, as those described in other active and fossil hydrothermal systems (e.g. Hedenquist and Henley, 1985; Hulen and Nielson, 1988). Both tectonic and hydrothermal braccias were intensively alterated.

The hydrothermal breccias are concentrated in 327 – 402m. At 327m, the breccias consist of angular granitic clasts, up to 10cm (average 0.5 – 2cm) in diameter, cemented by the chalcedonic quartz matrix. Vertical fractures are abundant, which resulted in the upward displacement of fragements. Vugs, up to few cm in diameter, are widespread (Fig.4A). At 366m, the clasts are of well–rounded to subanyular alterated granite, hydrothermal quartz, and rebrecciated breccias consisting of dark colored quartz–rock flour matrix supported angular clasts. The breccias were partially cemented by quartz, and the portion of vugs is higher than that of 327m. It is noted that the clasts are usually made up by a nuclear of fragment and a shell of hydrothermal quartz (Fig. 4B). The breccias at 402m are somewhat alike those of 327m but less in the portion of matrix and vugs. A smaller hydrothermal brecciation zone was also found at 537m. Rather than vertically, the breccia veinlets incline at 50 ° from the vertical, as indicated by the lamina in quartz–rock flour matrix. The breccias show a jigsaw puzzle type texture. The vugs are less common and partilly filled by quartz (Fig. 4C)The texture of breccias suggests that they were modified by hydrothermal fluidization, and experenced a multi–stage brecciation. The porous, kastic network would provide excellent channels for hydrothermal fluid.

Tectonic breccias are found more extensive than the hydrothermal breccias. At 489m, 625m, 725m and 945m, rocks show cataclasis up to mylonitic breccias, containing rounded clasts of quartz, orthoclase and a matrix made up by quartz and illite. At 1003m, the rock was also intensively crushed, illite pseudomorphs of feldspars were extensively veined by micro–veinlets of chlorite. The mylonization may not provide good channels for fluid, but the widespread fractures, noted at 489m, 725m and 800m, could increase the permeability of the reservoir rock significantly.

HYDROTHERMAL ALTERATION

The rocks penetrated by ZK 352 are highly altered. Hydrothermal mineals, dominated by clay, make up 40 – 70 (vol)% of the rock. Fig. 5 Shows the hydrothermal minerals with their approximate aboundance, determined by XRD and thin section study, in ZK 352.

The vertical distribution of hydrothermal minerals in ZK 352 displays a zonal pattern. A shallow kaolinite–dickite zone extents from the surface to the depth of 243m (4406m – 4163 elevation), in which alunite、chalcedony、and opal occur in the intensively altered rocks along fractures, and smectite occurs in the less altered rocks (Zhu and Xu, 1989). Below this zone, the alteration is charaterized by silicification, which extents from 243m to 400m. Within the silicification zone, illit and mixed–layer smectite chlorite are abandant. The presence of 0 –5% expandable layr in illite is suggested by the mica basal reflection shift of – 0.04A ° — –0.15A ° , and location of $(001)_{10}/(002)_{17}$and $(002)_{10}/(003)_{17}$peaks at 8.85 ° –8.70 ° 2θ and 17.50 ° –17.70 ° 2θ respectively, after glycolation (Reynolds and Hower, 1970; Sroden, 1985). Orderly interstratified smectite–chlorite (30–40% expandable layer) occurs at 327m, and gives away to randomly interstraified facies at 402m and then swelling chlorite below 489m. Below the silicification zone, illite and chlorite, swelling or non–swelling, are the predominant facies. Epidote is introduced at about 800m and become more common at the bottom of the well.

Hydrothermal alteration in ZK 308, by the contrast, is much less both in intensity and rank. Hydrothermal minerals are never in excess of 15 (vol)% in all the examinated samples.The distribution of hydrothermal minerals in ZK 308 is showne in Fig 3. The shallow kaolinite–dickite–alunite–opal alteration is absent in ZK 308. Within the shallow sediments, the alteration is characterized by kaolinite and randomly interstratified smectite–chlorite. It is noted that betwen 323 to 482m, mixed–layer illite–smectite (expandeble layers >90~80%) is the dominant faices, along with kaolinite and chlorite. Below this level, The content of expandable

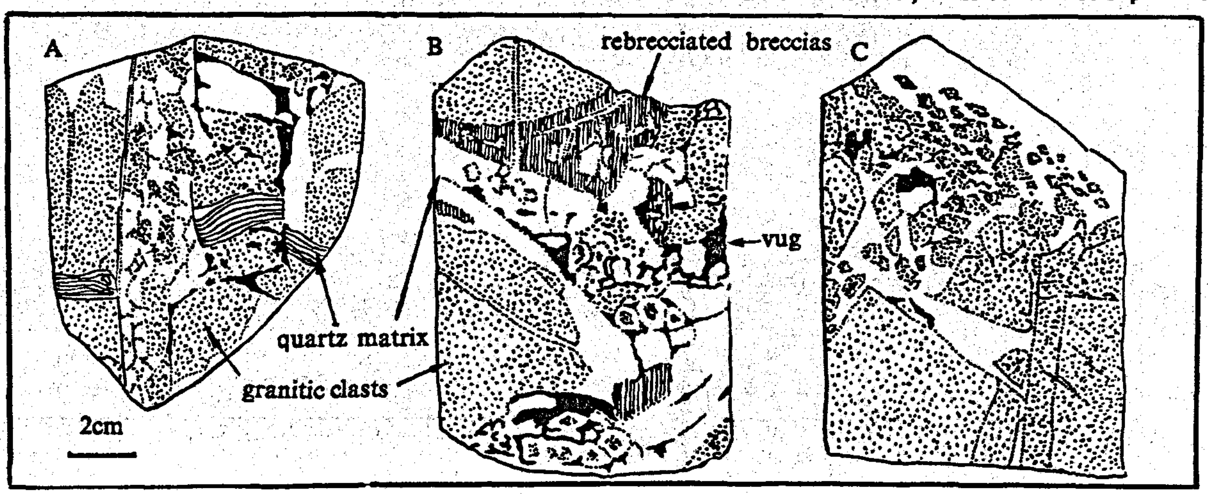

Fig4. Hydrothermal breccias from ZK 352. A –327m, B–366m, C–537m.

layer in mixed–layer illite–smectite decreases with the increasing depth : ~ 27% at 1087m, ~ 12% at 1273m, 14% at 1405m, and about 5% at 1598m respectively. Epidote occurs occasionally below 1500m.

CHEMICAL CHANGES DUE TO ALTERATION

As a consequence of the breakdown of primary minerals and the precipitation of hydrothermal minerals, the bulk rock composition is modified, which differs one alteration zone to another.

Examination of Fig. 6 reveals that the shallowest kaolinite–dickite zone is characterized by the depletion of most of the oxides except Fe_2O_3, and the gain of H_2O, indicating a process of acid–leaching and

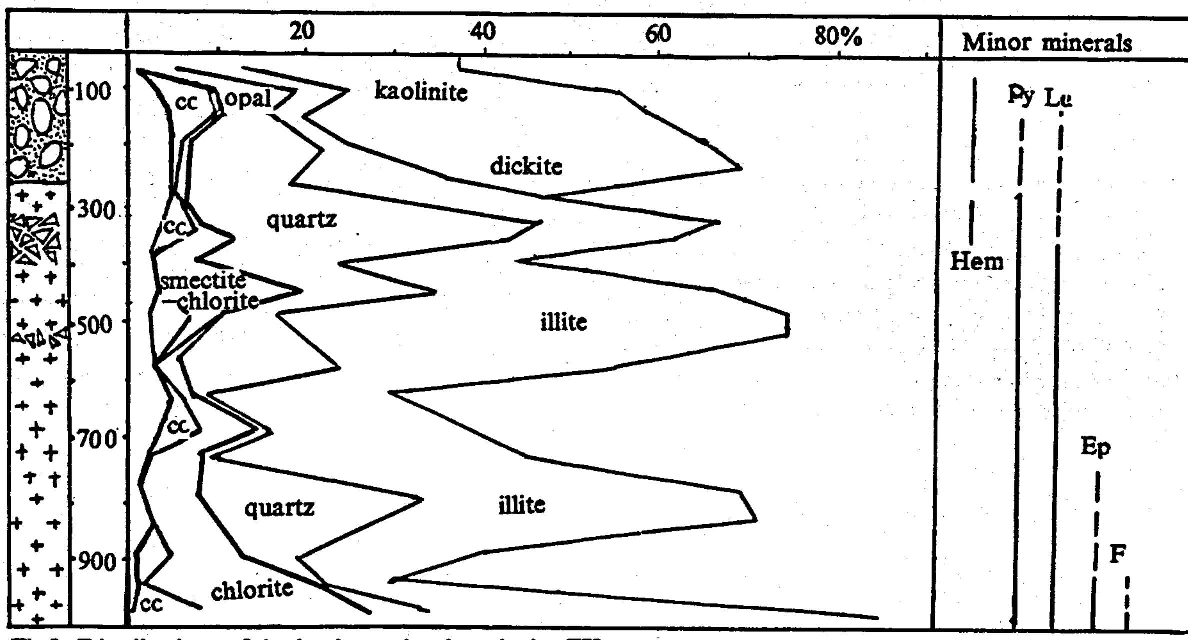

Fig5. Distribution of hydrothermal minerals in ZK 352. D–Dickite, F–flourite. See Fig3 for others.

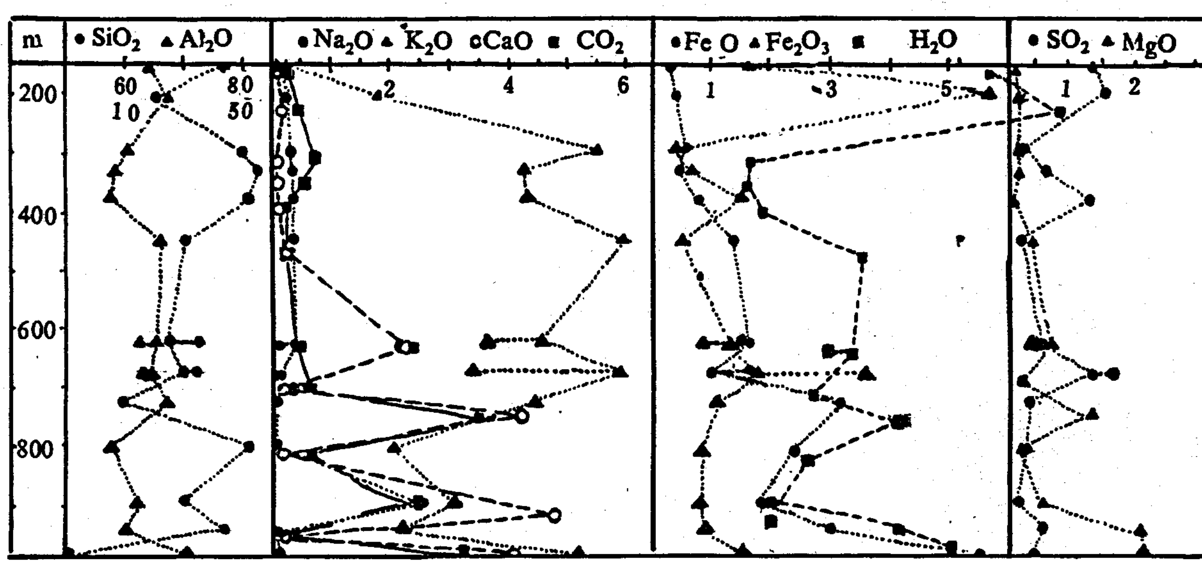

Fig6. Relationship between petrochemistry and depth of ZK 352.

oxidation. The hydrothermal brecciation zone (from 327 – 400m) is characterized by the significant enrichment of silica, slightly gains of H_2O、 $CO_2$and SO_2, and the depletion of CaO、 NaO_2、 Fe_2O_3、 FeO. Below 500m, the range of chemical variations is rather wide, and shows strongly structural dependency, even at same depth (e.g: 625m, 675m). The intensively altered and fractured rock seems to gain more K_2O、 H_2O、 SO_2、 CO_2、 and loss more Na_2O and CaO. It is noted that there is a high K / Na throug out ZK 352 except at 900m. The values of K / (K+Na) are increased from 0.4 – 0.6 of the unalterated granite (Tu et al, 1982) to 0.9 in the samples from ZK 352 by alteration. MgO and FeO irregularly increased with the increasing depth. The low K_2O and high Na_2O at 800m and 900m suggests that this interval is less intensively altered. Alough high temperature was recorded, and permeability was indicated by circulation loss here, it seems that flow channel of hot fluid is not encountered in this level. The deepest sample (1003m) is characterized ty low SiO_2 and high K_2O. The 49 (w) % SiO_2seems contrast to the fact of occurence of 15 (vol)% primary quartz. The depletion of SiO_2 at this level, probably due to the breakdown of feldspars, Suggests a condition different from shallow reservoir.

In contrast to ZK 352, ZK 308 displeys a lower magnitude of compositional changes. The chemical gains and losses of samples from ZK 352 and ZK 308, relative to the average composition of the granite in Yangbajain region (Tu et al, 1982), are compared in Fig. 7. The total mass transfer is calculated assuming no net transfer of Al. It is evident from Fig. 7. ZK 308 displays slightly losses in SiO_2、 CaO、 $Fe_2O$and gains of Na_2O and H_2O, and ZK 352 shows significant gains in SiO_2、 H_2O、 $CO_2$and SO_2, slightly gains of K_2O、 Fe_2O, and depletion of Na_2O and CaO. The completely loss of Na_2O indicates the high intensive alteration when plagioclase replaced by clay minerals

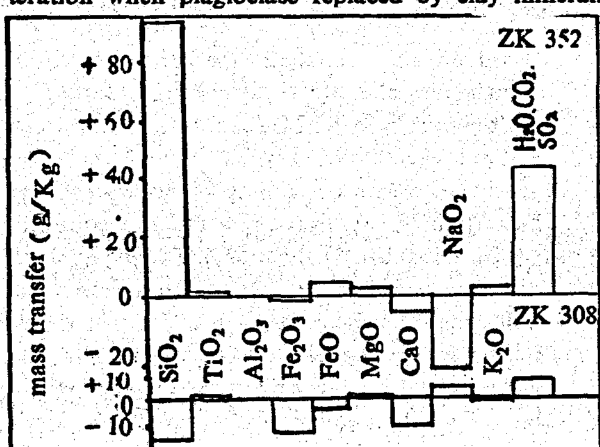

Fig7. Mass transfer of ZK 352 and ZK 308

completely. The slightly enrichmet of K_2O and significant gains of SiO_2、 SO_2suggest the alteration of hot, H_2S rich fluid, i.e, the alteration near the upflow path of a hydrothermal system.

HYDROTHERMAL VEINS AND MICRO–THERMOMETRY OF FLUID INCLUSION

Fluid inclusions are usually trapped in many hydrothermal minerals. quartz, calcite and fluorite, which record various stages of evolution of hydrothermal activities. Alough massive quartz and calcite veins are found in the brecciation–silicification zone in ZK 352 and ZK 301, in which fluid inclusions are seldom large enough for microthermometry study. In the brecciation zone, very finely anhedral chalcedonical quartz, with banding texture and numerous vugs, is widespread. The clear, euhedral quartz crystals are also common in the veg–fillings and veinlets. In 175–250m interval of ZK 301, hydrothermal veins consist of intercalated bladed calcite and chalcedonic quartz. These textures suggest that the quartz may have formed at low temperature (<200℃) from the amorphous silica initially deposited by very supersaturated silica (Bodner et al, 1985; Fournier, 1985). The high supersatuaration of silica can be contributed to the sudden dercease in fluid presure resulting from hydrothermal brecciation. In addition, the bladed morphology of calcite is believed to be formed due to CO_2loss (Browne, 1984)

Homogenization temperature are measured for 43 two–phase, liquid–dominated fluid inclusions in two hydrothermal fluorite (from depth of 900m and 1000m). At 1000m depth, only primary inclusions, characterized by regular shape and randomly distribution, are found, which displanys a narrow range of homogenization temperature from 239℃ to 245℃, with one exception of 248℃ (see Fig. 2). At 900m, both primary and secondery inclusions, along the heeled fracture and cleavage planes, are found, which have honogenization temperature ranges of 238℃–244℃, and 207℃–229℃, respectively.

35 homogenization temperature are measured for fluid inclusions in calcite from 1087m of ZK 308, which ranges from 167℃ to 227℃ with the most population at 185℃ (fig. 3).

Fluid inclusion data reveal the alteration temperature of 240–245℃ in ZK 352 and 180–200℃ in ZK 308, which are in excess of 40 – 45℃ and 60 – 80℃ compared with current downhole temperature.

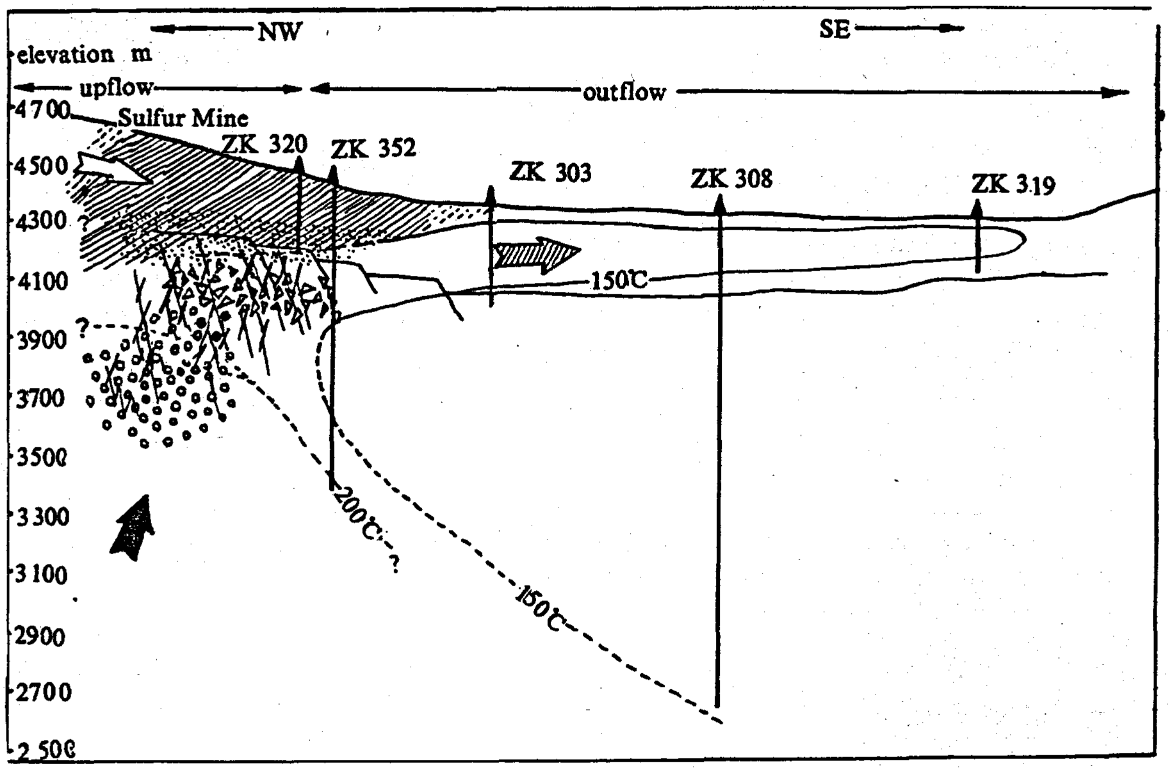

Fig8. Geochemical Model for Yanbajain Geuthernal Field. hot fluid. fracture channels. boiling, two phase condition. silicification–brecciation. acid salfate alteration and advanced argillic alteration reduced permeability. condensate acid sulfate water ground water. diluted water in shallow reservoir.

CONCLUSION & DISCUSSION

The data obtained from ZK 352 and ZK 308, along with other shallow wells, permit to hypothesize a model for Yangbajain geothermal system, as that shown in Fig. 8.

The region penetrated by ZK 308 displays a condition of outflow, indicated by the alteration pattern and downhole femperature. The deep granitic bedrock has never been circulated by the fluid as hot as that in the northern part.

The rocks penetrated by ZK 352 demonstrate a systematical zonal alteration, indicating the upflow condition at Sulfur Mine, by the occurence of a shallow advanced argillization and acid–sulfate alteration above a silicification–brecciation zone. In fact, acid sulfate condensate water was encountered by ZK 320 in 4320m – 4200m alevation (ENEL. 1985) at Sulfur Mine. The intensive and extensive alteration and fractures validate the high permeability at depth, which could provid good channels for upwelliing fluid and probably creat a deep reservoir within the granite.

Alough high temperature was recorded, the ZK 352 temperature profiles suggest a outflow condition rather than a upflow one. The current upflow zone, approached but not encountered by the ZK 352, prbably has shifted northwestern–toward. At the upflow region, self–sealing and brecciation have happened intermittemtly, which resulted in the shift of flow clannels with time. This process has been maintained by the high tectonic and seismic activities in Yangbajain region.

Based on above analysis, the further exploration in Yangbajain should be foused on locating current upflow zone in Sulfur Mine area. Detailed geophysical and geological surveies, which have n't been carried out yet due to rough topography of this aree, should be of benefit to sit exploration wells. The problem more chanllenging than validating the high temperature is producing the fluid in such a steep terrain, alough the fluid would be encountered at a shallower level in the upflow zone. The water table sets at –120m in ZK 352 and will be deeper if the production wells are sited uphill. Downhole pump and directional drilling will be necessary for production.

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