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ABSTRACT

A study was made of the hydrothermal alteration mineralogy found in well T-2, a 1020 m deep well in the Tuzla geothermal area.

The strata is composed of Quaternary and Recent alluvium sediments, underlain by Miocene volcanic rocks; including rhyodacitic ignimbrite, trachyte and trachyandesite lavas, monzonite intrusion, granodiorite intrusive rocks, and a Permian metamorphic basement rocks.

The hydrothermal mineralogical data include minerals which are associated with both low and high temperature geothermal environments. A comprehensive study of cross-cutting vein relationships and mineralogical evolution is suggestive of at least two hydrothermal events.

The first hydrothermal event, involved high temperature conditions, resulting in contact metamorphic calc-silicate mineralization, including garnet, epidote, chlorite, sphene, magnetite, actinolite, diopsite and prehnite. This high temperature (>300°C) mineral assemblage was not found in well T-1, suggesting a contact metamorphic origin in well T-2.

The second hydrothermal event, which relates to the present day hydrothermal system is evidenced by smectite, mixed layer clay, kaolinite, mica, pyrite, haematite, quartz, calcite, barite and gypsum.

A model of the Tuzla geothermal system suggests a strong relationships between the geothermal waters and a N-S striking fault zone.

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1. INTRODUCTION

1.1. PURPOSE OF WORK

The author was awarded a six month UNU fellowship to study Borehole Geology from April to October 1986, at the UNU Geothermal Training Programme, National Energy Authority, Iceland. The training started with 6 weeks introductory lectures and followed by two weeks excursion to low and high temperature geothermal fields in Iceland.

The specialized training programme included a 9 days field excursion to a fossil high-temperature area in the Geitafell Central Volcano, SE-Iceland, a one week visit to the low-temperature geothermal fields in E and N-Iceland to study the Geological and Geophysical exploration method. This was followed by petrographic study of thin sections as well as XRD techniques of clay mineral analyses of cores and cutting samples from well T-2 of the Tuzla geothermal field, Turkey. An introduction training in fluid inclusion studies was also included.

This report includes a general description of the tectonic relationships of the Tuzla geothermal field with respect to the hydrothermal alteration in well T-2.

The Tuzla geothermal field is located in the NW-part of Turkey. Tuzla village lies within the geothermal area.

1.2. GENERAL GEOLOGY OF TURKEY

Turkey is located within the Alpine - Himalayan orogenic belt. Within the Alpine - Himalayan system, the distribution of seismicity is not homogeneous, but concentrated in high strain zones, many of which are major strike-slip faults, such as the North Anatolian Fault (Ketin, 1968), East Anatolian Transform fault (Dewey and Sengör 1979) and graben zones (e.g. Gediz, Menderes, Manyas, Kizilcahamam) (c.f. Fig. 1.).

The broad tectonic framework of the Aegean, Turkey, and the eastern Mediterranean region is dominated, as shown by McKenzie (1972), by the rapid westward motion of the Anatolian Plate relative to the Black Sea (Eurasia) Plate and west to southwestward motion relative to the African Plate (Dewey and Sengör 1979) (c.f. Fig.2).

The Anatolian Plate (Palaeozoic massifs, Fig. 2) may be considered as a "floating" continental plate being pushed eastward from the intracontinental Bitlis Suture Zone, (The southern edge of the Arabian - Eurasia convergent strain zone). This kind of lateral escape of "floating" continental fragments from intracontinental convergent zones is said to be common; in the case of the Anatolian Plate it is clearly being pushed westward where its motion, relative to Africa, is taken up by subduction at the Hellenic Trench (Dewey and Sengör 1979). The Anatolian region consists of a mosaic of fragments of continental crust (Palaeozoic massifs, Fig.2) originally scattered over the Tethyan Sea. This have been collected together as an intervening oceanic crust has been eliminated by a series of subduction episodes over the past 200 m.y. (Crampin & Evans 1986). These differential plate motion is responsible for the east and west Anatolian young volcanic activity (Figs. 1 & 2). Block faulting and North Anatolian transform movement apparently began in Mid- Miocene (ca. 15 m.y. ago).

The complex structure and tectonic movements of the Anatolian Plate, as well as seismo-tectonic events have been the subject of several reports in the last twenty years or so. Irrespective of somewhat opponent models on plate tectonics, the Anatolian plate itself is clearly defined to the north, east, and south as shown in Fig. 2.

The distribution of hot springs in Turkey closely follows the tectonic patterns. For instance, all hot springs above 50°C (Fig.3) in East and West Anatolia clearly relate to young volcanic activity and block faulting (grabens).

Plutons formed as a result of magmatic intrusions that took place at different stages during all periods of Palaeozoic ages cover extensive areas in West Anatolia, Aegean Islands, Greece and Bulgaria. When their regional distributions and petrochemical character was compared, it appeared that the plutons progressively became younger from north to south (Ercan & Turkecan 1984). The same appears to apply to the volcanoes in the East Anatolia where the activity moved southward with time (e.g. Mt. Ararat, Mt. Suphan, Mt. Nemrut Caldera and Solhan volcanoes) (Karamanderesi et al. 1984; Saroglu and Yilmaz 1984).

1.3. GENERAL GEOLOGY OF TUZLA FIELD

The basement of the Tuzla geothermal field consists of metamorphic rocks of Permian age (older than 200 m.y.). The metamorphic rocks include calc-schist, quartzite, marble and dolomites. The metamorphic basement is intruded by a large granodioritic pluton, which has been dated as young as 28 m.y. (Fytikas et al. 1976). The basement rocks are overlain by andesitic lavas, which have been dated by Borsi et al. (1972) as late Tertiary (22-17 m.y) (see Table 1). Therefore a chronological relationship between the pluton and the subaerial volcanics is evidenced, as well as a major unconformity between the Permian and the late Tertiary rocks.

Table 1 : Simplified stratigraphic division of Tuzla geothermal field.

Unit	Thickness	Age	Explanation
	50 m	Recent	Alluvium
		Unconformity	
	100 m	Pliocene	Sediments
		Unconformity	
	150 m	Miocene 17.1 m.y.	Rhyodacitic ignimbrite
	200 m	Miocene 19.1 m.y.	Trachyte
	250 m	Miocene 21.5 m.y.	Trachyandesite
		Unconformity	
		Permian	Metamorphic rock
		Oligocene 28.1 m.y.	Granodiorite

(From : Öngur 1973; Samilgil 1966; Age's from Borsi et al. 1972; Fytikas et al.1976).

The subaerial volcanics are divided into three lithological units (Fig.4). The earliest of these are the trachyandesite lavas, which according to Öngur (1973) originated within the Ayvacik volcanic centre some 20 km east of the Tuzla field. The second lithological unit is composed of trachytic lavas originated in the Assos Babakale centre 10 km southwest of Tuzla field, while rhyodacitic ignimbrites compose the third lithological unit, believed to be extruded from the Behramkale volcanic centre, presently submerged in the Edremit Bay about 15 km SE of the Tuzla field. Subsequently the Tertiary volcanics were partly covered by Pliocene and Pleistocene sedimentary rocks.

The region has experienced several active tectonic episodes since late Miocene to the present, leaving a number of faults and fractures with main directions N-S and ENE-WSW. Furthermore, the Tuzla geothermal field appears to be influenced by the North Anatolian Fault. For instance, Neotectonic model of the Marmara Sea region (Crampin and Evans 1986) assumes that the North Anatolian Fault is located in the northern part of the Tuzla field (Fig.4), and similarly, Dewey and Sengör (1979) show the North Anatolian Fault - line at the northern boundary of the Tuzla field. Other models assume the main North Anatolian Fault line runs along the Marmara sea and the Saros bay north of Turkey. In any case, a parallel line to the North Anatolian Fault crosses the Tuzla geothermal field, on which three extinct surface alteration fields are located (Ahmetler, Centirler and Tuzla, Fig.4). At present, however, N-S fault is active in the region as seen from the three hot spring fields at Kestanbol, Akcakecili and Tuzla (Samilgil, 1984). Therefore, the present day hydrothermal activity appears to be related to regional N-S faulting.

Water outflow from about 100 springs in the Tuzla field is estimated to be close to 50 l/s of about 102°C hot water. Total dissolved solids amount to 59,000 (ppm) and salinity is twice that of seawater (see Table 2). Widespread hydrothermal surface manifestations characterize the field. Chemical geothermometry suggests a 200 - 218°C hot reservoir fluid (Samilgil 1984).

1.4. GEOTHERMAL EXPLORATION OF THE TUZLA FIELD.

Geothermal study of the Tuzla field began some 20 years ago by a geological and volcanological survey (Alpan 1975; Samilgil 1966; Erdogan 1966; Urgun 1971; Öngur 1973). These were followed by a geophysical survey (Demirörer 1971; Ekingen 1972).
Based on this survey about 10 thermal gradient wells were drilled to 50 - 100 m depth in 1974. High temperatures (145°C) were met at about 50 m depth in some of these wells, and due to vigorous boiling within the wells two of them were lost in blow - outs (Karamanderesi and Öngur 1974).

The result of these studies gave reason for the drilling of deep exploration wells. Two deep wells were sunk in the field in 1982 and 1983, T-1 to 814 m depth and T-2 to 1020 m depth. Circulation losses were experienced in both wells, and the highest temperature measured was 173°C (Table 3). Since then, a detailed study of the surface alteration has been published (Gevrek and Sener 1985) showing three surface alteration zones to be present, silica zone, a montmorillonite zone, and illite zone.
In the present study a detailed investigation of the hydrothermal alteration of well T - 2 is undertaken. The result is further studied with respect to other data from the field and a tentative geothermal model presented.

2. HYDROTHERMAL ALTERATION

2.1. ANALYTICAL TECHNIQUES

The occurrence and distribution of hydrothermal alteration minerals is show in figure 7. The samples were analyzed by using binocular magnifying microscope, a petrographic- microscope and a XRD difractometer. The XRD analyses were carried mainly to determine the clay-mineralogy. In addition to the samples from the Tuzla field two samples from the Ömerbeyli high temperature field were studied. A total of 14 samples were run on XRD for clay analysis, and some 43 thin sections studied.

The analytical method used in Iceland for XRD clay mineral analysis has been described by Hardardottir (1984).

2.2. LITHOLOGY OF WELL T-2.

The lithology of well T-2 was studied at MTA office shortly after drilling. This has been reviewed and a simplified geological profile is shown in fig. 6, as well as the depths to zones of lost circulation. Due to the use of rotary drill bits mainly rock cuttings are available from the well. The cuttings were sampled at 2 m interval. Six cores were also taken from within lost-circulation zones and other critical locations. The following description of the stratigraphy is based on the present study and preliminary MTA reports.

The strata cut by well T-2 are divided into 6 units.

<u>Unit 1 : 0 - 30 m depth</u>. Alluvium. In the uppermost part of the well the sediment layer ranges in grain size from sand to gravel. Volcanic fragments of trachyte, ignimbrite and tuff are found in some parts of the gravel. Primary minerals in these volcanic rock fragments include K-feldspar, plagioclase and biotite.

Unit 2 : 30 - 130 m depth. Rhyodacitic ignimbrite intercalated with lithic tuff and tuff layers. The ignimbrite is extensively altered and clay replacement of the glass is the most prominent mineralization. Primary minerals are andesine, oligoclase and biotite.

Unit 3 : 132 - 212 m depth. Altered trachyte lavas. Quartz, K-feldspar (sanidine), plagioclase and big crystals of biotite are clearly seen. Matrix is highly altered. Secondary minerals include clays, calcite and hematite. Pyroxene pseudomorphs may be formed as well as opaque minerals and apatite.

Unit 4 : 214 - 462 m depth. Highly altered porphyritic trachyandesite. The phenocrysts are feldspar, highly altered amphibole and biotite, and micro-phenocrysts of sanidine. In a core sample from 413.50-415.30 m depth the following minerals were determined by Gultekin Elgin "MTA" Laboratory: Altered feldspar microliths and small phenocrysts of sanidine, altered biotite, volcanic glass, opaque minerals, accessory apatite. Hydrothermal minerals include quartz and calcite in matrix and mineral veins. The veins additionally include chalcopyrite ($CuFeS_2$), pyrite (FeS_2) and iron oxide (hematite).

462 - 583 m depth. No cuttings are available from this depth interval due to total circulation loss. A core was taken between 530 - 535 m depth. The core sample is composed of highly altered andesite or trachyandesite, suggesting that main unit 4 continue down to at least 535 m. Similarly the penetration rate, down to 582 m, suggests that the andesite may continue down to that depth.

Monzonite intrusion : 583 - 591.70 m depth. Drill core mostly consisting of Quartz monzonite intrusion. The monzonite 583.50-589.50 m is composed of plagioclase (oligoclase), orthoclase, highly altered pyroxene, augite, biotite, minor quartz, and accessory minerals of titanite, apatite, opaque minerals (pyrite and sparser chalcopyrite). Metamorphic basement rock micaschist, marble and dolomite is found in the upper and lower parts of the core.

Unit 5 : 590 - 702 m depth. Metamorphic basement rock. The upper part of the rock is in contact with monzonite while the lower part is in contact with a granodiorite. In both cases an increase in typical contact metamorphic mineralisation is found (e.g. garnet, pyroxene, and magnetite). The metamorphic basement rock itself consists of quartz, orthoclase, albite, oligoclase, biotite and, muscovite.

Unit 6 :702 - 1020 m depth. Granodiorite intrusive. Granodiorite intrusion consisting of quartz, orthoclase, albite, oligoclase and biotite.

2.3. LOST CIRCULATION DURING DRILLING.

Circulating drilling mud was lost completely four times during drilling. In all cases the circulation loss was plugged by cement slurry. The loss-zones are listed below and the apparent nature of aquifer discussed in each case.

I . 214 - 234 m depth. About 10 m^3 of drilling mud was lost into this aquifer, which occurs at the boundary between units 3 and 4 (trachyte to trachyandesite). The water table sank to 25 m depth suggesting, a pressure of about 20 bars in this aquifer. 8 tons of cement were used in two cementing jobs. Compared with well T-1 at a 1 km distance from T-2 circulation loss also occurred at this boundary, suggesting a horizontal (or stratification) aquifer.

II. 336 - 360,50 m depth. About 30 m^3 of drilling mud was lost into this aquifer, which apparently occurs at lava boundaries. The water table sank to 56 m depth suggesting, a pressure of near 27 bars. This aquifer was cemented 3 times, and 10 tons of cement were used. Both aquifers were cased off by a 9 5/8" cemented casing down to 396 m depth.

III. 412 - 440 m depth. About 55 m³ of drilling mud was lost into this aquifer, which occurs in an open fault, dipping about 50°, as seen in core sample from 413 m depth. First the water table sank to 73 m depth, but went up to 22 m as drilling continued. 5 tons of cement were used to plug the aquifer.

IV. 462 - 583 m depth. This depth interval was drilled with a total circulation loss. The nature of this aquifer is not clear, but one of two cores showed slickensides and fault clay at fracture surface. This may indicate a fault zone. Water table sank to 22 m depth suggesting a connection with aquifer III above. The well was cased with 6 5/8" down to 590.25 m depth. The deepest part of well is uncased (barefooted).

2.4. MINERAL DISTRIBUTION.

The mineral distribution of well Tuzla-2 is shown in Fig. 7, and below the individual minerals are discussed.

Calcite is present at all depths in Tuzla-2. Even within the granodiorite at the bottom of the well, narrow mineral veins are found to contain calcite and quartz. It has a widespread occurrence mode like quartz, and is found in veins, amygdales and as a replacement mineral of primary plagioclase, biotite, interstitial matrices and volcanic glasses at all depth levels. Sometimes Fe-oxide (hematite) quartz and calcite appear to be a contemporaneous mineralization (e.g. in samples from 112 m, 589.5 and 670 m depth) sometimes including pyrite. Carbonatization is commonly extensive.

Quartz is also present at all depths. It is common as a vein and an amygdale mineral, and is commonly associated with calcite, hematite, clay, iron oxides, pyrite, smectite and also epidote and chlorite at deeper levels. At 412 m depth a vein contained calcite, quartz, and barite. All the core samples show quartz, calcite and clay mineral assemblage in veins. In the cores from 531 m and 588 m and 591.50 m a conspicuously green clay is added to this assemblage. This clay was analyzed by XRD and turned out to be smectite. The reason for the colour change probably relates to chemical composition.

Secondary iron oxide (referred to as hematite) is present at all depths. It is common with pyrite. Biotite is commonly altered to hematite. The secondary iron oxides show reddish-brown colour in thin section and have grown in a botryoidal fashion or irregularly in veins and cavities. In mineral veins the iron oxide is generally of dark brown colour. The iron oxide replacing biotite shows light-brown colour. Hematite also replaces primary magnetite and glass. Hematite and/or limonite, were the first minerals to be produced everywhere within the Tuzla area, and can be related to an oxidizing environment of the percolating ground water. In the upper part of the well both hematite and sparser pyrite are present, while pyrite abundance increases with depth.

<u>Pyrite</u> was found throughout the well. By using the reflection property of pyrite, it is easily recognized by its bright yellow reflection in addition to its cubic form. Pyrite is an alteration product of the primary ore and glass and is also found in veins. Near the granodiorite margin ore mineralization is noticeable.

<u>Kaolinite</u>, is found by XRD analyzes as shown in fig. 7. The kaolinite is observed by sequentially XRD-analyzed dry, glycolated and heated samples. The XRD- peaks in $CaCl_2$ air-dried samples are 7.12 , 7.51, or 7.10 A°. Upon glycol saturation these remain unchanged, but disappear when heated to 600°C (Brown and Brindley 1980). The most common of the clay minerals are those of the kaolinite group and they are formed principally by the alteration of feldspars. Kaolinite has been reported in the Philippine geothermal fields to replace plagioclase in a highly altered volcanic breccia, rich in quartz, where little of its original texture is left (Reyes 1979). Kaolinite is considered to be a hydrothermal mineral in New Zealand where it occurs at shallow levels at temperatures less than 100°C (Bagamasbad 1979). In Otake in Japan, kaolinite is considered to be a hydrothermal mineral, formed in acidic conditions with pH= 2-5, and temperatures in the range of 80 - 200°C (Hayashi and Oinume 1965). Dickite in an acid hydrothermal alteration assemblage
may indicate temperatures of 120 - 260°C (Reyes 1986), or within the temperature limits measured in well T-2. However, dickite can not be separated from Kaolinite by standard XRD analyses.

<u>Illite</u> occurs at all depths in the well as mixed layer in the form of illite-montmorillonite. Surface alteration survey also shown the same mineral composition (Gevrek and Sener 1985). It is formed as an alteration product of silicic glass and primary plagioclase, and is mainly associated with calcite, quartz, other clay minerals, hematite and pyrite. Illite was

mainly recognized by XRD analyses. Its XRD peaks in air dried samples are 10.10 or 10.20 A°, and remain unchanged in glycolated and heated samples. It was detected from surface to bottom of the well Tuzla - 2. The illite is assumed to derive its potassium from the breakdown of potassium feldspar. Illite is also associated with hydrothermal mica, chlorite, mixed layer clay and smectite.

Smectite- Mixed layer clay are the most prominent clay minerals occurring from the bottom up to the top of the well. Those minerals are recognized by XRD analyses. Smectite occurs as replacement mineral in tuffs and volcanic glass and lavas; in vesicles and as vein infillings and as feldspar replacement mineral. The mixed layer clays are between smectite-illite in the upper part,and also smectite-chlorite in the lower part..

Chlorite is only found with XRD analysis within the metamorphic rocks below 600 m depth. In XRD analysis chlorite shows basal reflections at 13.58 - 14.28 A°.

Calc-silicate mineralization. Within the metamorphic basement rock high temperature hydrothermal mineralization is found, including epidote, sphene, magnetite, garnet, actinolite, diopside and prehnite. Those minerals occur at a depth of 583 m and then below 725 m depth. It appears that this assemblage relates to a contact metamorphism (e.g. garnet, magnetite, diopside) near the margin of the granodiorite and monzonite intrusions. In well T-1 the metamorphic basement rock did not include this mineral assemblage.

Apatite, Barite and gypsum. These three minerals occur in Tuzla-2 well at different depths. Apatite was found in thin sections and may be a primary mineral. Barite occurs as a vein mineral with calcite and quartz. Gypsum was analyzed in one samples at about 590 m depth.

2.5. MINERAL EVOLUTION AND DISCUSSION.

In the present study an effort was made to map the hydrothermal evolution in cores and cuttings of well T-2 of the Tuzla field. A practical training in mapping hydrothermal evolution had been gained earlier this summer in the fossil alteration zones of the Geitafell volcano, described by Fridleifsson (1983, a, b). Thin sections from the core samples of well T-2 were made to include any apparent time relation feature, like cross-cutting mineral veins and amygdales. The same features were looked for in the cutting samples. The result of this study showed that time - relation features were rather sparse in the samples brought to Iceland. This may warrant a further study of the samples being kept in Turkey.

In the upper 600 m of the well cross cutting veins suggest two chief hydrothermal episodes. The earlier is characterized by hematite, with or without calcite and quartz. The later is characterized by calcite and quartz and clays, and apparently relates to the present day hydrothermal system. The clay minerals in veins between 320 m and 600 m were analyzed separately by XRD, as a darkening in colour from light to dark green had been noticed. The XRD results did not reveal the possible presence of dickite, which in acid hydrothermal alteration assemblages occurs at temperatures between 120-260°C (Reyes 1986). The Tuzla geothermal waters are of near neutral pH (table 2), while acid alteration may form, contiguous with neutral pH alteration, assemblages (Reyes 1986). The change in colour of the clay minerals from 300-600 m depth in T-2 well should be studied by different methods, a.g. by microprobe.

In the lower part of the well, calcite-quartz veins are found in the granodiorite and monzonite intrusions, while clear cross-cutting evidence was not found between these and the high-temperature calc-silicate minerals. The high temperature calc-silicate mineralization, however, is lacking in well T-1, as are intrusive rocks, which is then taken to imply that the calc-silicate mineralization in T-2 is related to an episode of contact metamorphism. Therefore, two hydrothermal mineralizing periods are realized from the lower part of well T-2; that of an early contact metamorphism (garnet, magnetite and diopside) and associated high-temperature hydrothermal system (chlorite, epidote, sphene, actinolite), followed by the superimposition of the present-day calcite-quartz-clay mineralization. In spite of a lack of cutting samples between 462-583 m depth, due total circulation loss, a core sample (530-535 m) from this depth interval does not show high-temperature mineralization. An evidence of a high-temperature hydrothermal system established by the granodiorite and monzonite intrusive activity is therefore not found in the overlying subaerial volcanics. This implies that the high-temperature hydrothermal activity of late Tertiary age pre-dates the volcanic extrusive rocks, which more or less confirms the chronological order of volcanic rocks gathered from outside the Tuzla field (Chapter 1). Evidently this rules out the other possibility of a contemporaneous origin of the intrusive and extrusive rocks in the Tuzla field.

A high-temperature hydrothermal system of late Miocene age, related to the 28 m.y. old granodiorite intrusion is found below 600 m depth within the Tuzla field. The high-temperature mineral assemblages suggest temperature above 300°C (e.g. Browne 1984). Assuming hydrostatic condition to prevail this high temperature would imply a pressure of approximately 100 bars. Therefore a considerable erosion in the order of 1 km is visualized prior to the early Pliocene volcanism. The Pliocene volcanics appear to have been only weathered and oxidized up to the time the present-day hydrothermal system became active, the age of which is unknown. The mineral assemblages related to this system are relatively simple, involving carbonates, sulphides, oxides and intermediate and low-temperature clay minerals.

A geothermal model of the Tuzla field is presented in Figure 8. This model can be compared to the geological cross section across the Tuzla in Figure 6, while the basic element in Fig. 8 is the isothermal pattern within the field, based on downhole temperature measurements in T-1 and T-2.

The geothermal model indicates an upflow along the N-S striking fault west of the drillholes and a horizontal flow to the west and east along stratification boundaries. Furthermore, the isothermal pattern suggests that the fault east of the drillholes, cut by well T-2, may introduce cold surface water into the hydrothermal system.

3. CONCLUSION

A geothermal model presented of the Tuzla field indicates an upflow of hot water along N-S striking fault in the western part of the Tuzla field and a subhorizontal outflow along stratification boundaries to the east and west. Cold water inflow from faults east of the field is also suggested.

The hydrothermal alteration pattern of the field shows that a fossil high-temperature hydrothermal system of late Tertiary age rests unconformably below the Pliocene volcanic rocks.

The hydrothermal minerals related to the present-day hydrothermal system form a relatively uniform mineral assemblage of calcite, quartz, pyrite, hematite and clay minerals. No distinctive mineral zonation is found within the system, while colour changes of the clay minerals with depth requires further study. Otherwise, the main difference in hydrothermal alteration from the surface to depths involves a slow but progressive increase in the amount of hydrothermal alteration minerals. No obvious correlation between aquifers and hydrothermal minerals was found, but in some cases an increase in vein mineralization was seen close to the aquifers.

Further drilling in the field should be aimed towards cutting the N-S upflow zones in the western part of the field at a greater depth to meet fluids above 200°C.

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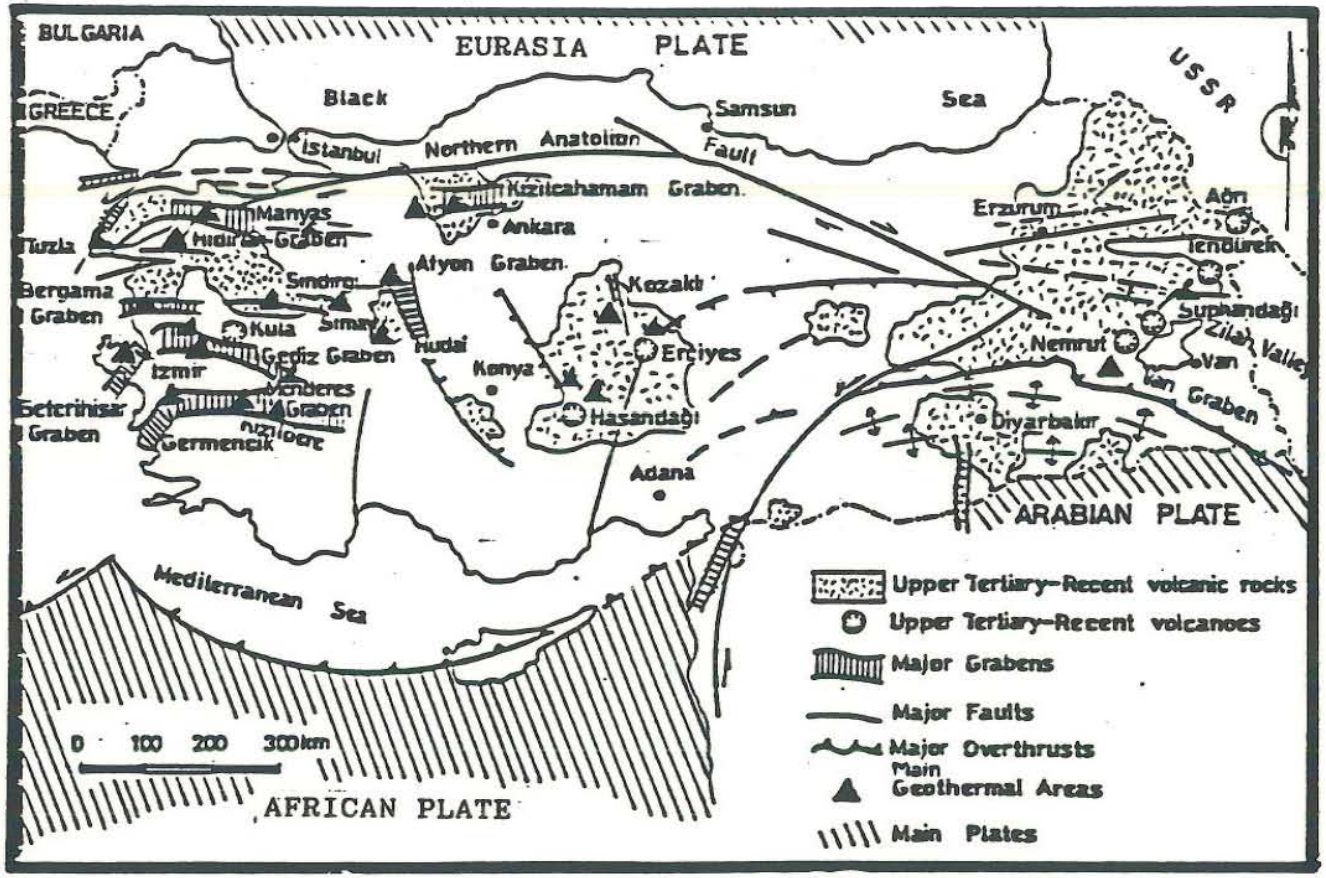


Figure 1 : General tectonic and volcanic features of Turkey
(Modified from Simsek, 1985)

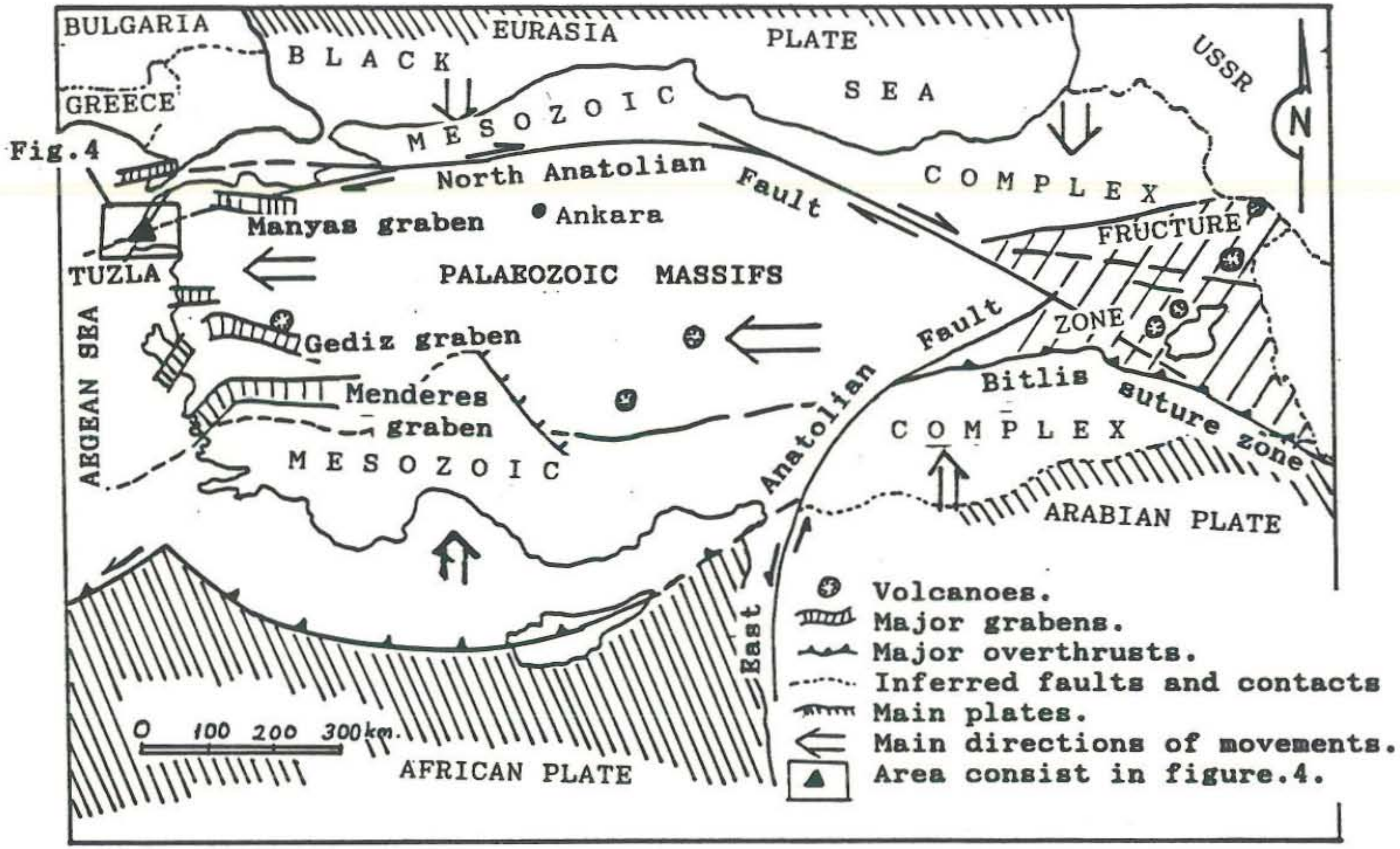


Figure 2 : General movement of young crustal blocks in Turkey. (Modified from Ketin, 1968., Dewey and Sengor 1979., McKenzie, 1972., Simsek, 1985).

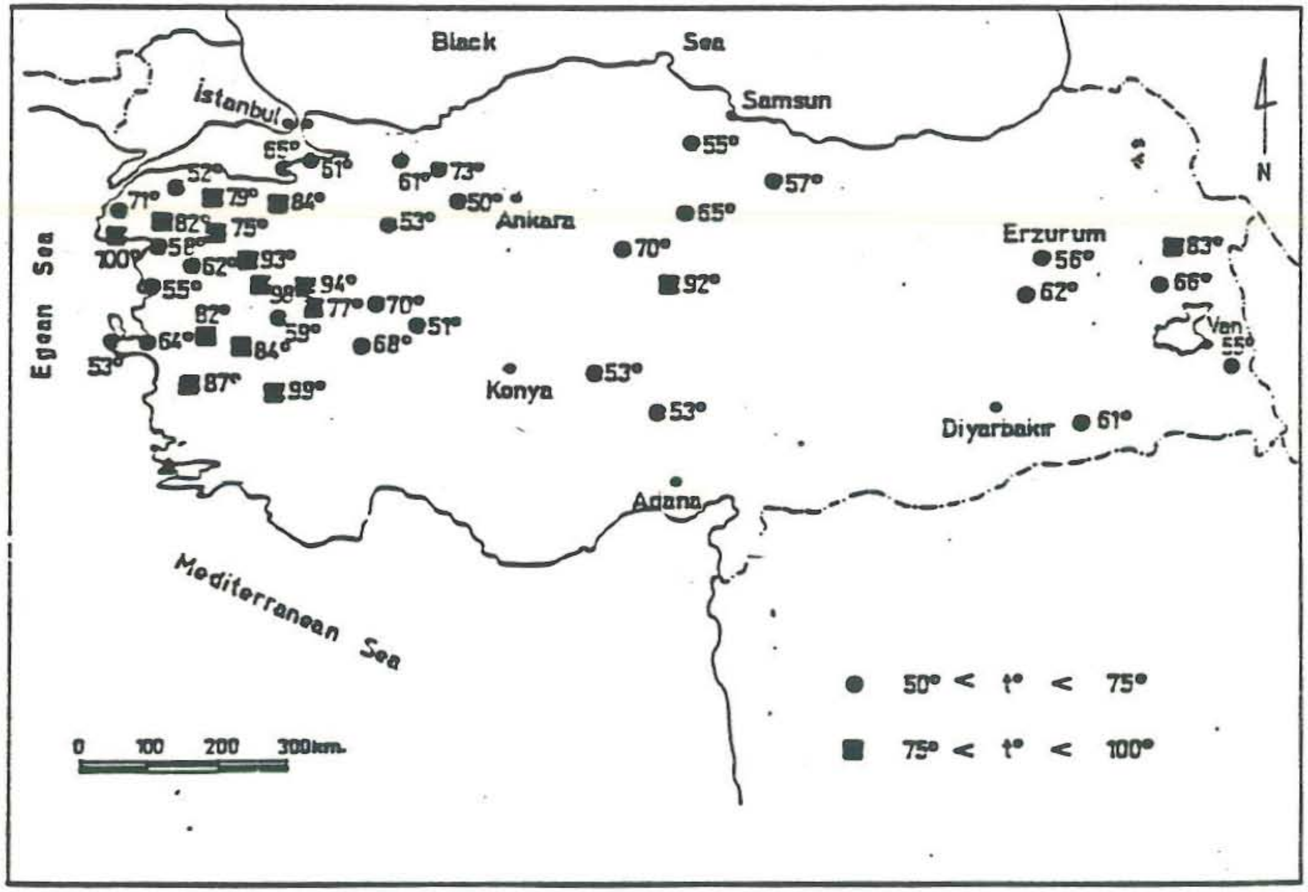
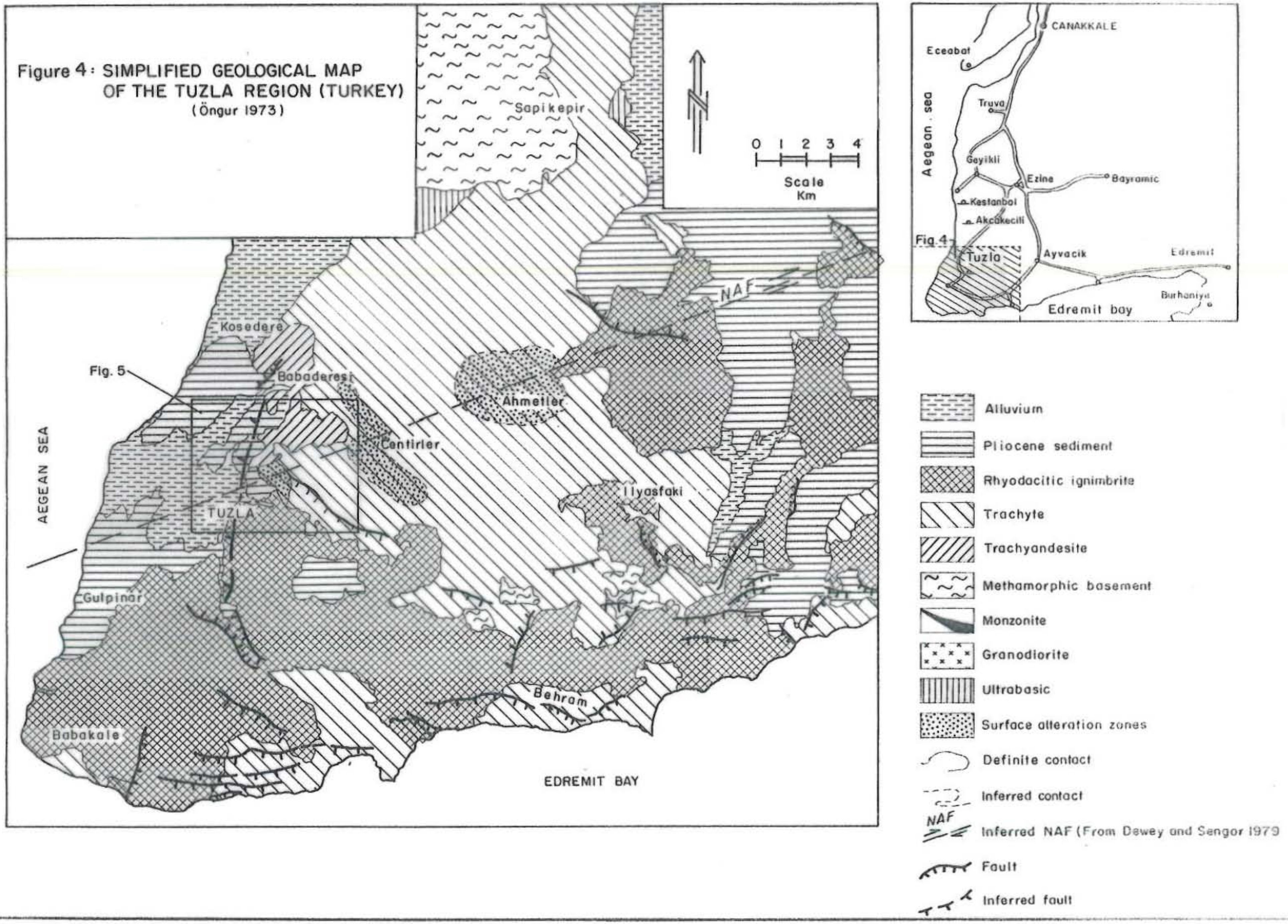


Figure 3 : Distribution of hot springs in Turkey.
(Modified from, Kurtman & Samilgil 1985)

Figure 4: SIMPLIFIED GEOLOGICAL MAP OF THE TUZLA REGION (TURKEY)
(Öngur 1973)



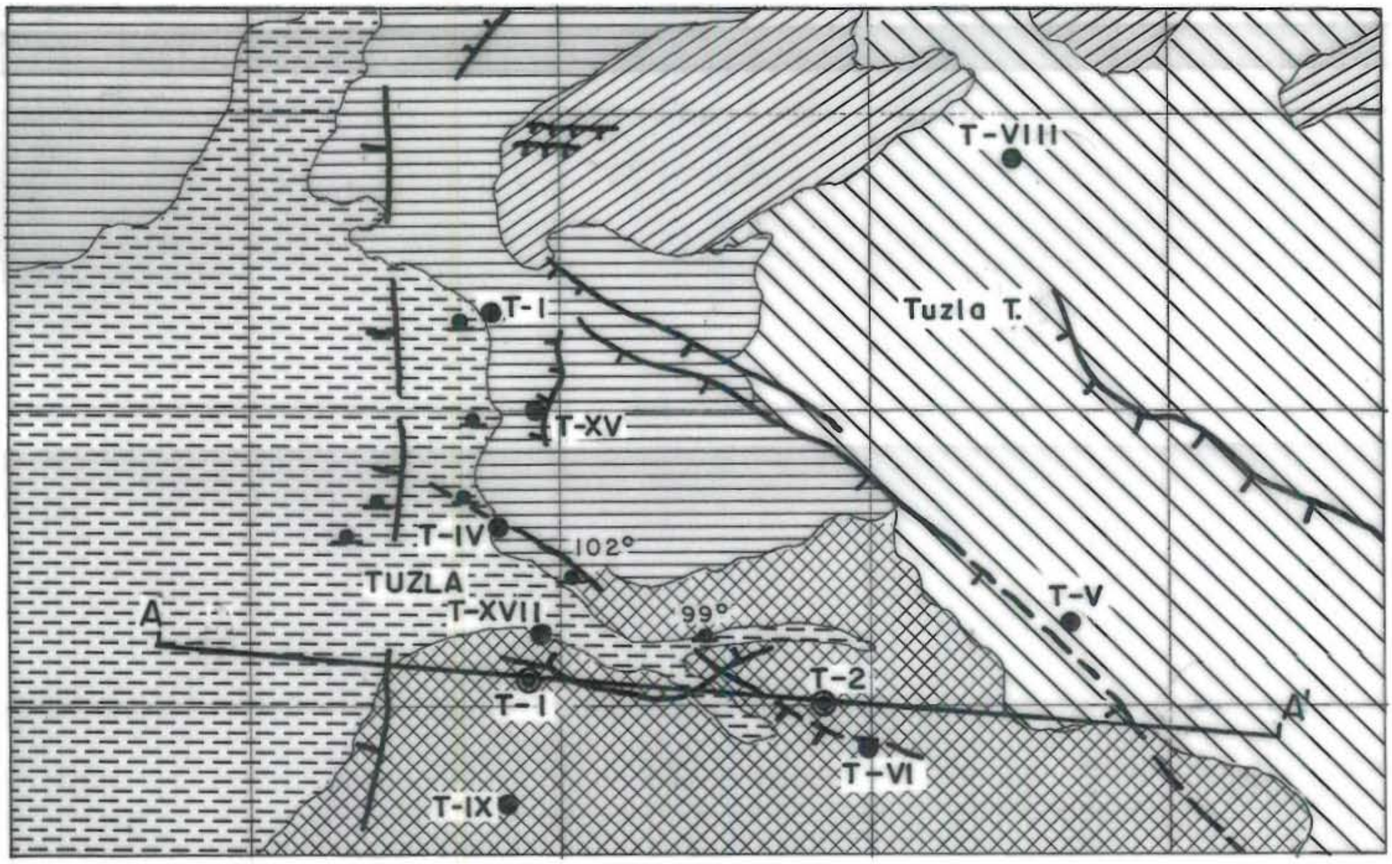


Figure 5: GEOLOGICAL MAP OF THE TUZLA FIELD

LEGEND

▤	Alluvium	A ⎵ A'	Profile
▤	Pliocene sediment	◎ T – I	Deep well
▩	Rhyodacitic ignimbrite	● T-XV	Gradient well
▧	Trachyte	⏏	Hot spring
▨	Trachyandesite		
⌒	Definite contact		
┬┬	Fault		
┬┬	Inferred fault		

0 500 1000m

SCALE : 1/25000

N

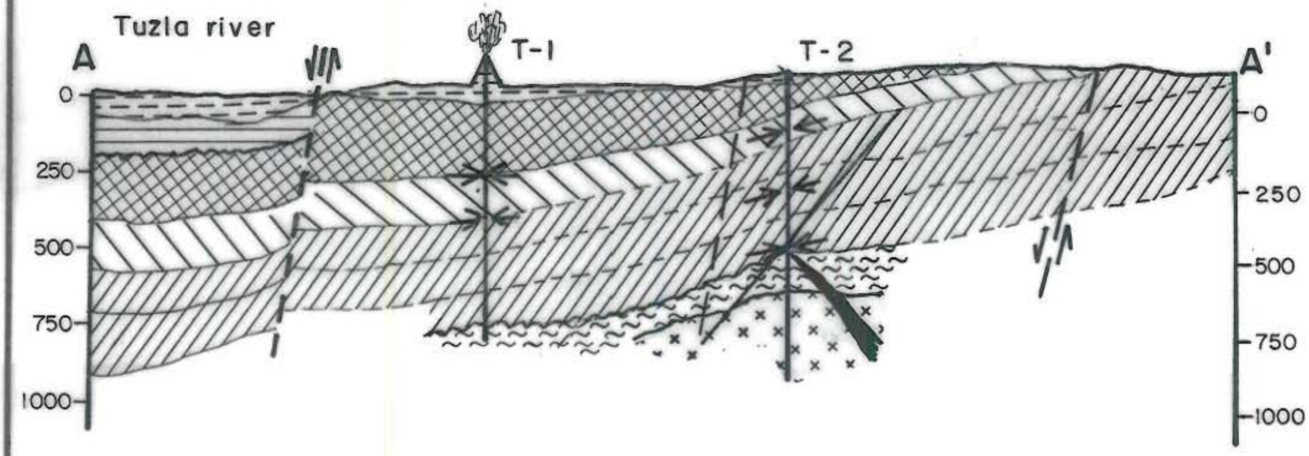
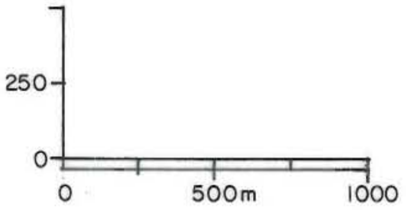


Figure 6: Cross section between T-1 and T-2 in Tuzla field.

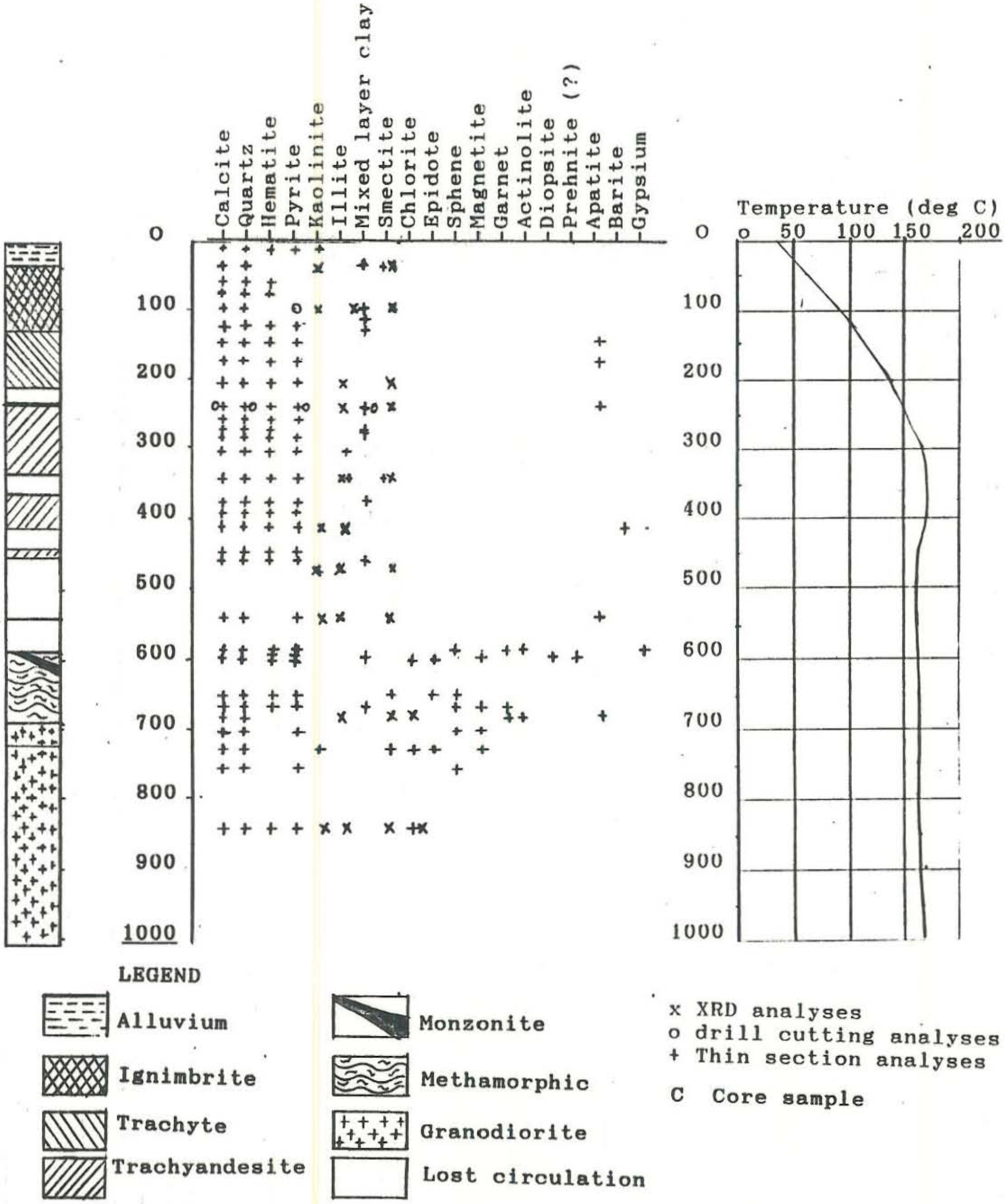
LEGEND

▤ Alluvium
☰ Pliocene sediment
▦ Rhyodacitic ignimbrite
▧ Trachyte
▨ Trachyandesite
◣ Monzonite
〰 Methamorphic basement
⊠ Granodiorite
→← Lost circulation
// Fault
/ / Inferred fault
— Definite contact
〜 Unconformity



Scale: 1/25000

Figure 7 : DRILLHOLE T-2, distribution of secondary minerals, temperature profile and simplified geological section.



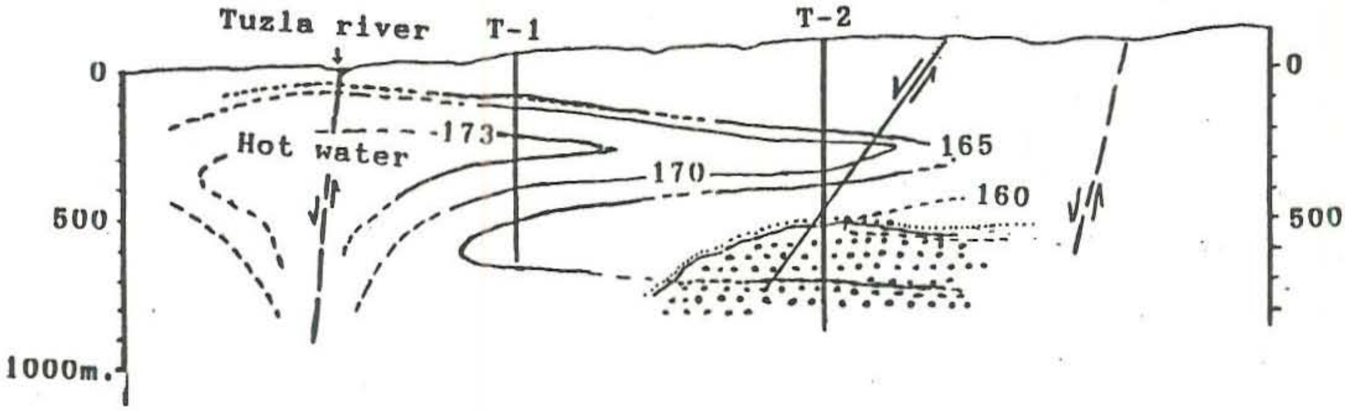


Figure 8 : A geothermal model of the Tuzla field showing main upflow zone at N-S striking fault zone.

LEGEND

— Isoterms

☐ Present day hydrothermal mineralization characterized by calcite, quartz and clay minerals.

▨ Tertiary high-temperature activity.

	T - 1	T-K 102	T-K(99)	T-K(102)	R.field,	Stan.Sea
toC	173	102	99	102	295	
pH/oC	7	7.3		7.3	4.75	8.0
SiO2	123	113	93.90	91.76	584	3
Na	22250	19000	16640	17820	9120	10800
K	2125	1800	1280	1976	1387	390
Ca	5715	3080	2920	3095	1476	410
Mg	101	30	70.70	70.00	0.87	1290
CO2					1842	102
H2S					58	-
SO4	176	172	150	150	18	2710
Cl	44140	35500	33600	33600	17634	19400
F	4.3	2.7	4.40	4.40	0.15	1.3
Fe	<0.1	<0.1	1.95	1.95	0.70	0.004
Br					90	67
Total diss		58700			30272	-

Table 2 : Chemical composition of hot water from the Tuzla geothermal field, Tuzla well-1, Reykjanes high temperature fields from Kristmannsdottir 1986 and Mean Oceanic Sea water from Turekian 1969 are shown for comparison.

T-1 and T-K 102°C from Samilgil 1984.
T-K (99°C) and T-K (102°C) 30.Sep.1982. analysis.
Reykjanes high temperature from Kristmannsdottir 1986.
Stan.Sea. from Turekian 1969

Table 3 : List of temperature measurements oC of three wells of Tuzla geothermal area. Well number T-XVII gradient well. T-1 and T-2 are deep wells.

Well numb [Depth] m.	T - XVII	T-1	T - 2
10	34		
35	67		
50		75.1	62.8
80	109		
85	120		
100		107.3	91.5
150		152.7	
200		171.1	134.5
250		173.7	
300		173.6	167.5
350		172.4	
400		170.8	171.7
450		168.3	163.5
500		165.8	162.1
525		165.9	
550			161.6
600			161.1
650			162.1
700			162.5
750			162.9
800			163.6
850			165.1
900			165.8
950			167.4
992			168.5