EC FUNDED RESERVOIR TESTING - CASAGLIA(FERRARA,ITALY)

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Key words: Italy,low enthalpy,reservoir testing,fluid properties.

ABSTRACT

Reservoir testing of a doublet in Casaglia(Ferrara, Italy) confirmed the potential of an important geothermal field with 100°C water and enabled to proceed successfully with the development of the Ferrara district heating project.
Testing(described in the paper) was carried out by AGIP as operator for the AGIP-ENEL joint-venture and was partially funded by EC XVII under the THERMIE program.

INTRODUCTION

The Casaglia geothermal field,underlying the town of Ferrara,in the Eastern Po Valley of Italy,was discovered by the Casaglia 1 well drilled for oil and gas exploration in 1956.
At the end of 1980 the well,which had been plugged and abandoned,was reentered and completed for geothermal use in the 1119-2000 m interval. A production test carried out in January 1981 was successful notwithstanding evidence of formation damage.
A new well(Casaglia 2) was therefore drilled in 1981 at the distance of about 1 Km from the previous borehole with very good results.
In 1983 an extensive reservoir test,together with a set of chemical and physical analyses,pressure measurements,reservoir behaviour studies and corrosion investigations were successfully carried out under EC XVII contract GE 512/83.
A description of the test,equipment and results is given in the paper.

GEOTHERMAL OUTLINE

Ferrara is a town of about 150,000 inhabitants,located in the Po Plain,130 Km SW of Venice,Italy.
A gravimetric survey in the 1930's outlined a very prominent positive anomaly in the territory of Ferrara which was interpreted as a shallow ridge of Mesozoic carbonates within the subsiding Upper Tertiary and Quaternary basin of the Po Valley.Two dry oil wells were drilled.
After the war the structure was still considered an attractive target for oil and gas exploration and,after seismic surveys confirmed a large faulted anticline,well Casaglia 1,about 5 Km from Ferrara,was drilled to the depth of 3799 m. It evidenced an overthrust of major importance(Fig.1). Drilled section is as follows:

0-202 m gravel and sand QUATERNARY
202-932 m marls,marly limestones OLIGOCENE-CRETACEOUS
932-1217 m limestones UPPER JURASSIC
1217-3620 m dolomites,dolomitic limestones JURASSIC-U.TRIASSIC(?)
3260-3799 m marly limestones UPPER CRETACEOUS

No hydrocarbons were detected but salt water with a temperature of 100°C was produced from the upper part of the Jurassic reservoir.
During the Seventies the Italian State oil company AGIP in joint-venture with the national utility ENEL undertook a comprehensive geothermal exploration program in Italy.
The resources discovered at Casaglia were evaluated for a district heating project in Ferrara. The Casaglia 1 well,which had been plugged and abandoned,was reentered in 1980 and completed with a bottom plug at 2000 m and setting a new 9 5/8" casing at 1119 m. The 1119-2000 m open hole section was tested with satisfactory results (productivity index 330 m^3/d/bar) even if there was evidence of formation damage by the drilling mud.

Because of the need to reinject the produced fluids after heat extraction due to their salinity (TDS 69 g/l), it was decided to drill a second well 1080 m East of Casaglia 1. Well 2 was completed in 1981 at the depth of 1960 m. A 9 5/8" liner was set between 399 and 890 m, inside the 13 3/8" casing; the underlying productive interval is in 8 1/2" open hole.

The geological section is very similar to that of Casaglia 1, the top of the Mesozoic limestones being 100 m higher. Correlation between the two sections indicates the possible presence of low-angle thrust planes between 1400 and 2000 m.

Pump testing carried out in July 1981 evidence a very good productivity index (2500 m^3/d/bar). Temperature is the same as in Casaglia 1 (103°C).

RESERVOIR TESTING PROGRAM

Given the favourable results of the wells, it was decided to run a special testing program in order to define the parameters of the geothermal field and assess its behaviour under operating conditions. EC Directorate for Energy (DG XVII) supported this effort under the 1983 THERMIE program (contract GE 512/83).

Well Casaglia 2 was chosen as producer and fluids were to be reinjected in Casaglia 1.

The main aspects tackled by the test are the following:

Reservoir physics (size, type of permeability, net pay, productivity, thermal behaviour, etc.).

Fluid chemistry and physics (including chemical composition of liquid and gasseous phases, saturation pressure, characteristics of suspended solids, scaling properties of fluid).

Corrosion behaviour (and inhibitors testing).

On the basis of interpreted data, production modeling was to be attempted.

TEST EQUIPMENT

The arrangement of test equipment is shown in Fig.3.

A submersible pump with maximum delivery 235 m^3/h was set in Casaglia 2 at 200 m depth, static water level being 58 m below ground.

The main line connected the 2 3/8" production tubing to the surface gas separator and thence a pit tank for temporary storage and cooling of the degassed water.

A parallel line collected gas produced at the well pump gas separator and gas in the surface separator, conveying it to an incinerator where the gas was burned.

Degassed geothermal water was pumped from the Casaglia 2 pit tank to a second pond at the Casaglia 1 location through a transfer line.

Water from this reservoir or coming directly from the Casaglia 2 pit was pumped via a last line to a filter unit and thence into the Casaglia 1 well. If needed, biocide products (stocked in a nearby tank) were added to the water before injection.

A corrosion test package and a scaling test section were inserted on the main line. Corrosion and scaling spools were set both on the main line and on the transfer line.

A service string could be introduced in the production tubing to the depth of 900 m for recording and sampling with high-precision probes.

TEST PROCEDURE

The test was carried out between October 31st and November 20th, 1983 in 3 successive phases:

Phase A - Production at variable flow rates (180-220 m^3/h) from Casaglia 2. Monitoring at Casaglia 1. Length: 54 hours.

Phase B - Injection in well Casaglia 1 at varying flow rates (260-360 m^3/h). Monitoring at Casaglia 2. Length: 19 hours.

Phase C - Continuous production from Casaglia 2 and simultaneous injection of water (cooled down to 30°C) in Casaglia 1, interrupted periodically for fall-off measures. Length: 13 days.

During the first two phases an interference test was carried out.

Throughout the experimentation period the wells were monitored for pressure and temperature.

Flowmeter logs indicated the contribution of different reservoir levels to production and injection capacity.

Several bottom fluid samples were collected and analyzed for chemical composition, gas/liquid ratio at different pressures, etc. Modification

of chemical equilibria in case of degassing or cooling was investigated.
Corrosion and scaling effects were examined and some inhibitors tested.

RESULTS

The reservoir test was carried out according to programs and, based on data obtained and their interpretation, was quite successful, even if not all questions could be answered.
The main results are discussed hereunder.

Reservoir physics and performance

Interpretation of the interference test (Fig.4) indicates that the aquifer is common to both Casaglia wells. The two boreholes have also a similar hydraulic behaviour, according to pressure transient data. Transmissivity and productivity index are quite favourable, but much higher in Casaglia 2 (T=13,000 E-9 m^3/Pa s; PI=1,040 E-9 m^3/Pa s) than in well 1 (T=660 E-9 m^3/Pa s; PI=91 E-9 m^3/Pa s). However transmissivity calculated from the interference test (5,300E-9 m^3/Pa s) is on the high side, indicating favourable conditions in most of the investigated reservoir.
The pattern of composite transients (build-up - fall-off) is indicative of a multi-layer reservoir. Flowmeter runs have evidenced several strongly absorbing levels, especially in the 1200-1500 m interval (Fig.5). In Casaglia 1 65% of the flow is absorbed by a 50 m layer around 1300 m; the 1180-1275 m interval in well 2 takes 33% of the fluid.
Skin effect is apparent in both boreholes, especially in Casaglia 1. While Casaglia 2 can produce 400 m^3/h with modest draw-down, an overpressure of 1.1 MPa is needed at Casaglia 1 to inject the fluid.
The interference test did not last long enough to detect possible permeability barriers. Reinjection of the produced fluid will determine an almost permanent hydraulic regime so that unknowns about the aquifer are not a critical factor.

Thermal behaviour was monitored by running at different times static and dynamic temperature logs and measuring values at set depths.
It was thus possible to observe rock-fluid thermal exchange phenomena, confirm absorption zones, etc.
While maximum reservoir temperature is 103°C at 1700-2000 m in both wells, values are almost as high around 1200 m (101.3°C in Casaglia 1; 102°C in Casaglia 2), indicating that the reservoir begins at this depth, in support of flowmeter data.
Temperature measurements at Casaglia 1 (Fig.6) show that all the 1220-1820 m interval is involved in the thermal exchange, indicating flow redistribution. This occurs notwithstanding the marked absorption at the top of the reservoir confirmed by the temperature minima between 1280 and 1380 m in the static log of November 5.
Extrapolation of this favourable reservoir situation beyond Casaglia 1 is not possible on the basis of available data, but represents a reasonable assumption.

In modeling the Casaglia reservoir in order to estimate the progressive cooling of the aquifer due to reinjection, three cases were studied: the most favourable of a 600 m porous section; the second, conservative, of 65% of the flow channelled in a 50 m layer; the last, extremely pessimistic and unrealistic because not supported by the test data, of a fracture connecting the two wells. Reinjection temperature was fixed conservatively at 30°C and two production rates were considered: 400 m^3/h and 200 m^3/h.
Results of the simulation, excluding the fracture hypothesis disproved by the successive production history of the field, indicate that cooling of the produced fluid from 100°C to 90°C with a flow of 400 m^3/h will take 40 years in the 600 m pay case and 5 years in the second case. Initial thermal contamination would occur respectively in 30 and 4 years. Reducing the production rate to 200 m^3/h would double the above time values.
Considering that a quite conservative factor was applied in the model to take into account reservoir dishomogeneities and that Casaglia 2 has a more balanced and better distributed absorbing capacity than well 1, a satisfactory thermal behaviour throughout the life of the project should be expected. Thermal decay will also be slower than calculated because the present and foreseen temperature of reinjected fluid is higher than the theoretical value used in the simulation.

FLUID CHARACTERISTICS

Fluids produced from Casaglia 2 were sampled both in the well and at surface at different times during the test. Analyses and measurements on the water and gas phases were carried out. An important parameter to be verified was bubble point. Composition of water samples taken before and after separator is rather constant. Total salinity is 69 g/l, over 90% of which is NaCl. Sizable presence of iron (around 1 g/l) is mostly due to corrosion. Other significant elements are Ca^{+} (1.8g/l); K^{+}(1.3 g/l);SO_4^{--}(1.1 g/l);boric acid (1.2 g/l).
Gas is made up mainly of nitrogen,methane,carbon dioxide and hydrogen sulphide in proportions varying according to separation pressure. At 1.5-3 bar 26-32% CO_2,28-32% CH_4 and 6-8% H_2S are present. Gas/water ratio measured at the separator(p=2-2.2 bar) is 0.18-0.2 Nm^3/m^3.
Interpretation of pressure measurements in well 2 and an estimate from fluid data indicate a bubble point in the range of 11-13 bar.
Somewhat lower values were obtained from bottom samples (gas/water ratio 0.15 Nm^3/m^3 or less; bubble pressure 10 bar).
The suspended solid content of the produced fluids at Casaglia 2 remained relatively constant and low (in the order of 1-2 mg/l) throughout the test. It consisted of iron salts (product of corrosion) and calcium and magnesium salts (from the host rock). Suspended solids at the injection pad turned out to be more abundant (5-10 mg/l) and composed of iron and calcium salts. It appears that iron particles did not settle in the pit tanks while calcium carbonate precipitated from an oversaturated solution during stocking of the water. Filtering was not very effective because of the fineness of the particles.

BACTERIAL CONTAMINATION

A slight bacterial contamination was detected in the Casaglia 1 reinjection tank,amounting to some 50 units per milliliter,of which up to 10 units are of the sulphate-reducing type. In contrast, fluids at the well-head of the production well was found to be bacteria-free. Contamination is thus limited to the surface facilities. Injection of bactericides in Casaglia 1 well proved effective.

SCALING

A check-up of surface facilities at the end of the test evidenced deposits only at the Casaglia 2 pad. They were located at the pit tank,where a powdery layer of calcite was present,and in the last section of the main line to the pit tank,where the outer surface of the pipe showed sodium chloride deposits and a hard layer(3 mm thick)of calcite and aragonite was evidenced inside the pipe. The rest of Casaglia 2 facilities presented a thin film of corrosion by-products. Casaglia 1 equipment was totally free from scale.

CORROSION

A 2 mm thinning of the Casaglia 2 13 3/8" casing at the water-table level(70 m)was recorded by a caliper run,34 months after setting the casing. The 2 3/8" tubing presented local corrosion pits of some mm depth,mainly below 750 m,where temperature is above 80°C;corrosion rate was 1.4 mm/y All field and laboratory tests evidenced a generalized corrosion rate of 0.1-0.2 mm/y in carbon steel and 0.02-0.09 mm/y in Al bronze. Localized 0.5 mm deep corrosion pits formed in the carbon steel coupons of the in-line test package during the short (40 days) test period. Titanium and inox alloys on the contrary were undamaged.
Two inhibitors were tried with inconclusive and contradictory results.

CONCLUSIONS AND FOLLOW-UP

Casaglia reservoir testing was completed successfully. On the basis of data obtained and their interpretation a specially tailored engineering lay-out was prepared and appropriate equipment for the geothermal plant selected. In particular choice of Casaglia 2 as producing well was confirmed. The need to protect the pumping unit from corrosion led to a design which limited production to 200 m^3/h. Use of titanium heat exchangers was found advisable. Further product tests led to the choice of a suitable inhibitor.
The Casaglia geothermal plant was put in operation in 1990 and has operated regularly ever since at the maximum flow-rate of 200 m^3/h with a reinjection temperature of 60°C.

ACKNOWLEDGEMENTS

The author has drawn freely from his previous paper (Carella et al.,1983) and from AGIP report for EC (Dionisio et al.,1985). I wish to thank DG XVII of EC for entrusting me with preparation of the paper and AGIP and ENEL for allowing its publication.

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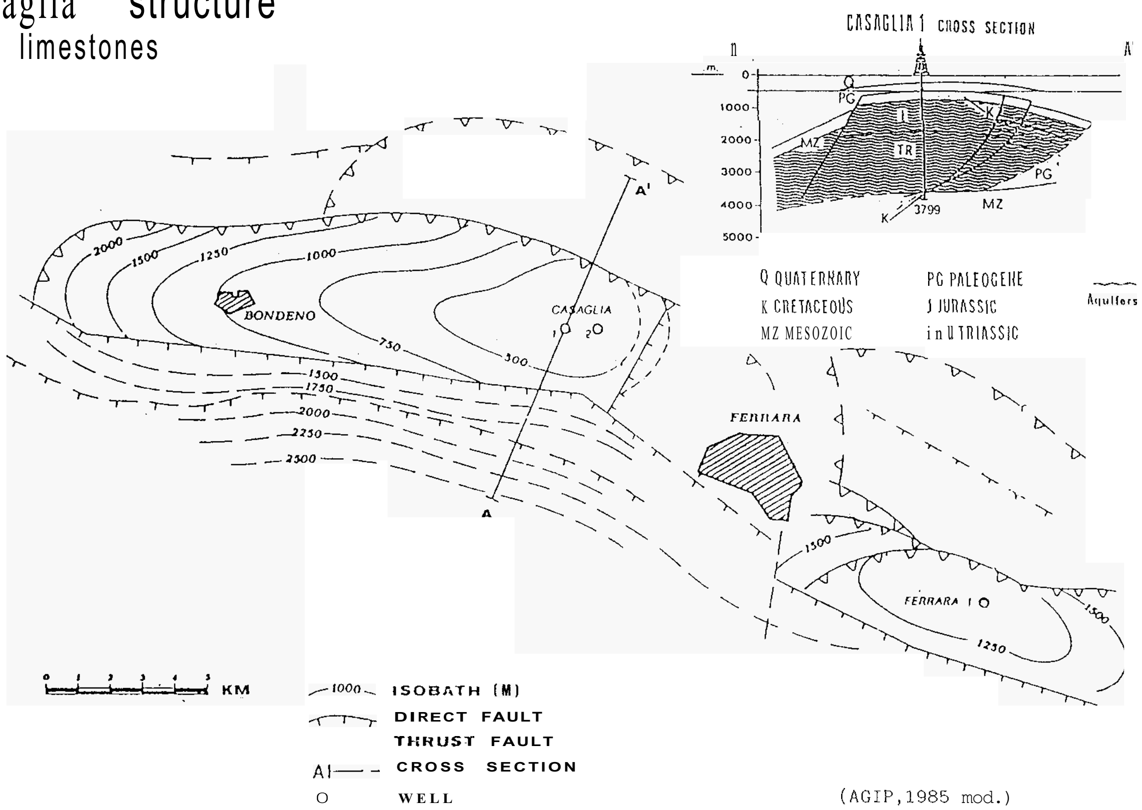
Casaglia structure
top limestones

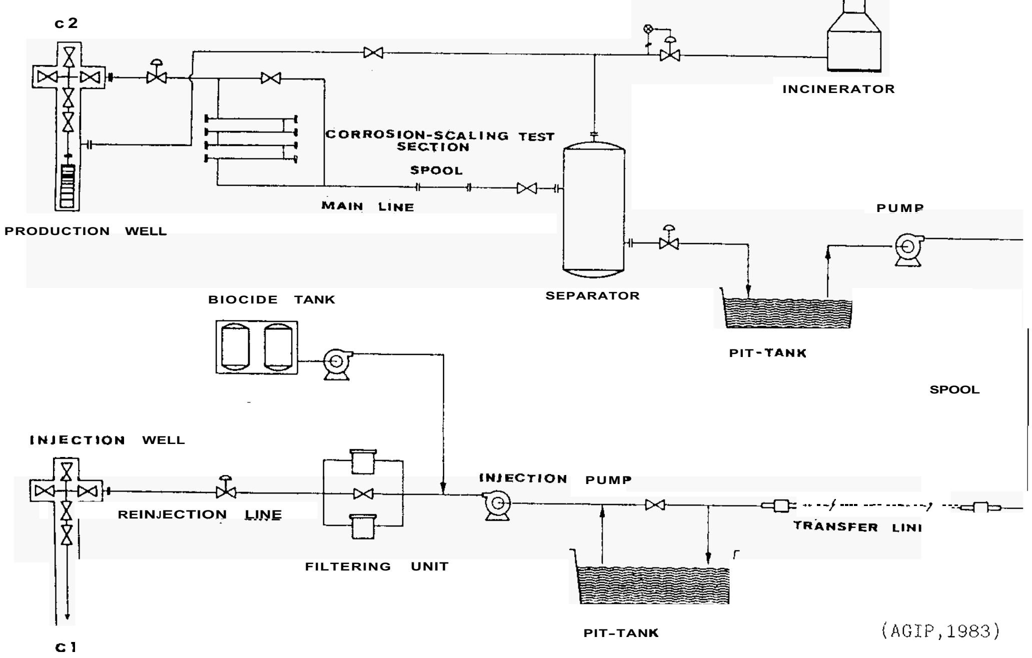


(AGIP,1985 mod.)

FIG 1

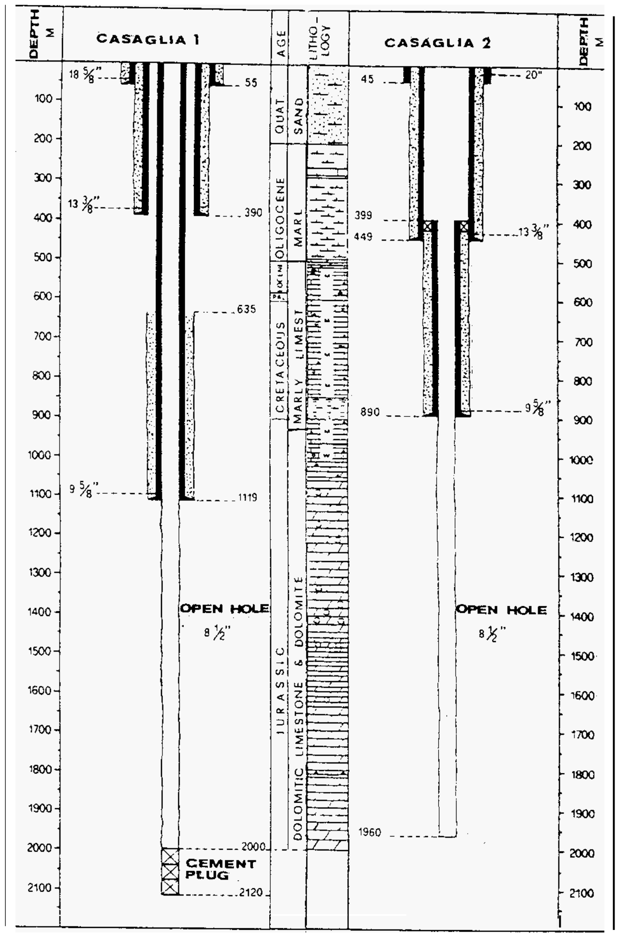
CASAGLIA 1-2 :Reservoir test equipment

FIG.3



(AGIP,1983)

CASAGLIA 1-2 WELLS FIG2



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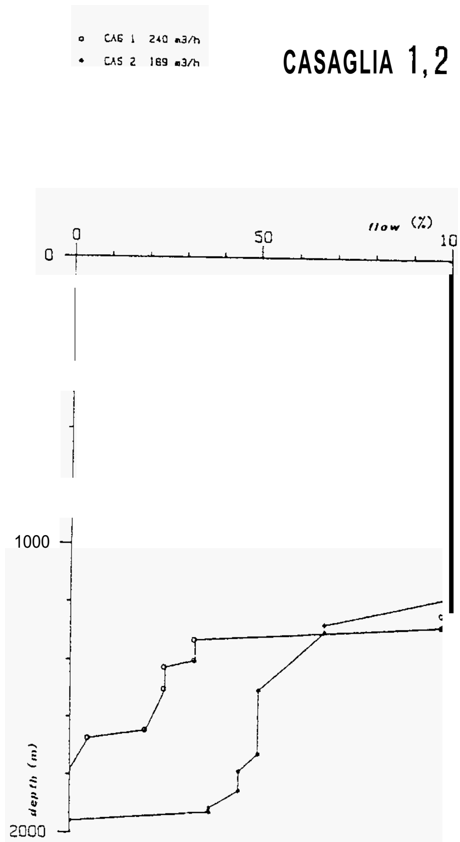
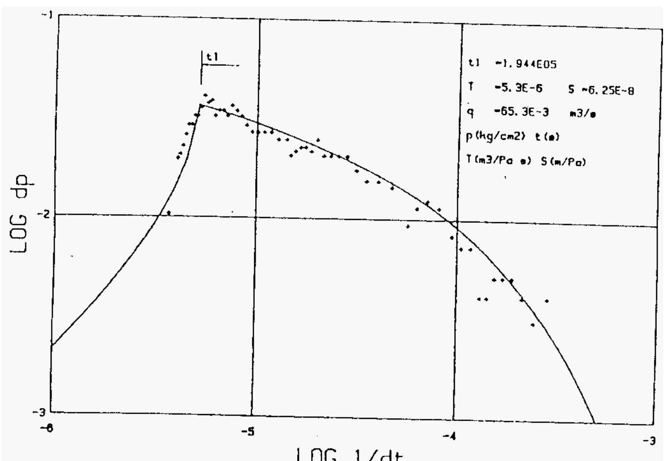


FIG 5

FLOWMETER TESTS (AGIP,1985)

FIG 4 **CASAGLIA 1** - INTERFERENCE TEST



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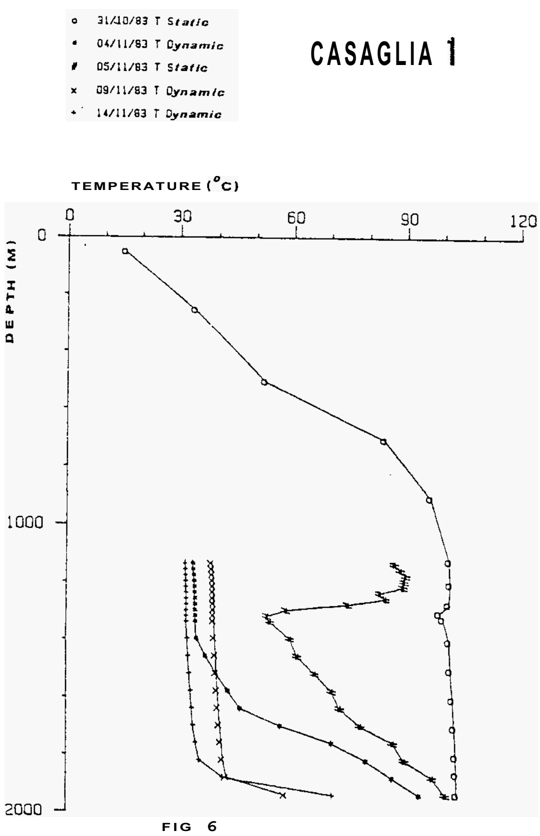

FIG 6

TEMPERATURE PROFILES

CQOLING DURING INJECTION (AGIP,1985)