GL04057

PRELIMINARY GEOTHERMAL ASSESSMENT OF THE TATTAPANI THERMAL AREA, MADHYA PRADESH, INDIA

J. L. Thussu
J. N. Moore*
R. M. Capuano*

Geological Survey of India
*Earth Science Laboratory Division/Univ. of Utah Research Institute

ABSTRACT

The Tattapani geothermal field, located in northeastern India has been the site of exploration efforts designed to evaluate its geothermal potential since 1978. These efforts have included geologic, hydrologic and geochemical investigations, and recently the drilling of shallow thermal gradient wells.

The Tattapani area contains numerous hot springs which issue from fractured metamorphic and sedimentary rocks. The springs discharge water ranging in temperature from 55-98°C. Several of the springs actively are depositing siliceous sinter around their vents. Most of the hot spring waters are dilute Na HCO_3-Cl-SO_4 fluids with a total dissolved solid content of approximately 550 ppm. Cation geothermometers applied to chemical analyses of the waters suggest that temperatures of approximately 150°C could be encountered at depth.

INTRODUCTION

Geothermal exploration was started in India in 1973 by the Geological Survey of India. About 350 hot springs with temperatures ranging from 30° to 98°C are known to occur throughout the country. No recent volcanism or plutonic igneous activity has been recognized and consequently all of the hot spring systems are considered to be the result of deep circulation of local groundwaters. Krishnaswamy (1975) gave a detailed account of the hot spring occurrences and divided them into two groups on the basis of their tectonic setting: an orogenic group, represented by warm springs in the Himalayas and a non-orogenic group, represented by the warm springs in peninsular India. The Tattapani geothermal area is located in peninsular India about 450 kms east-northeast of Nagpur (Fig. 1, insert).

In 1978, geologic, geochemical and hydrologic investigations of the Tattapani thermal field were initiated to evaluate the geothermal potential of this area. As a result of this work the area was targeted for additional study which has included the drilling of several shallow thermal gradient wells and further sampling and analysis of the hot spring waters. This paper presents the results of chemical and isotopic analyses conducted on fluids from the Tattapani field.

GEOLOGICAL SETTING

The Tattapani area is underlain by Archean metamorphics and a thick sedimentary sequence belonging to the Gondwana Super Group. The Archean rocks consist of gneiss, granulite, amphibolite, schist, carbonaceous phyllite, and quartzite. These are intruded by two generations of granite with associated pegmatite and quartz veins. The rocks comprising the Gondwana Super Group include sandstone, shale and siltstone deposited during late Carboniferous to Jurassic time within faulted troughs. A 20 meter thick fault breccia dips northerly at a steep angle and separates the Archean rocks from rocks of the Gondwana Super Group in the southern part of the area (Fig. 1). The breccia zone is offset by north-northeast trending faults. A thermal gradient well located between warm spring 7 and 8 penetrated 110 meters of sandstone and shale of the Gondwana Super Group before intersecting the Archean rocks.

THERMAL SPRING ACTIVITY

Thermal activity is spread over an area of approximately 500 square meters, part of which is marshy. The location of the seven springs sampled in the area are included on Figure 1. Four of the springs sampled issue from breccia (1, 7, 9, and 11), two discharge from rocks of the Gondwana Super Group (8 and 10) and one from Archean rocks (12). One cold well (C, 20 feet deep) located one kilometer from the study area was also sampled. Thermal springs 1, 8, 9 and 10 are actively depositing amorphous silica around their vents. With the exception of spring 12 and the cold well, all the springs discharge minor amounts of unidentified gases.

WATER CHEMISTRY

Chemical analyses of waters from the Tattapani thermal area are presented in Table I and displayed on a trilinear plot in Figure 2. Three types of water have been recognized. Type I water is sodium chloride in character and is represented by spring 12 which has a measured temperature of 70°C. Type II water is sodium bicarbonate-chloride-sulfate in character and includes

Table I
Chemical analyses(1), of waters from the Tattapani thermal area
(Analyzed at Los Alamos National Laboratory and USGS, Menlo Park, CA)

Water Type Character	Type I Na Cl			Type II Na HCO_3-Cl-SO_4				Type III Ca HCO_3
Spring No.	12	1	7	8	9	10	11	
Surface Temp. °C	70	84	98	84	55	84	84-89	20
Na	140	150	140	150	140	150	160	16
K	8	12	8	9	7	8	10	1.7
Ca	4	4	4	7	5	5	5	21
Mg	0.10	0.32	0.31	1.36	0.38	0.96	0.53	7.6
HCO_3(2)	29	156	151	176	152	108	166	117
SiO_2	119	128	132	128	122	123	120	5
Li	0.19	0.22	0.21	0.23	0.21	0.21	0.24	0.01
B	0.25	0.33	0.25	0.43	0.35	0.36	0.36	0.11
F	17.8	19.0	19.6	18.7	18.3	18.1	20.2	2.75
Cl	132	72.2	59.3	76.5	63.6	87.3	75.6	8.7
SO_4	65.7	72.0	65.7	78.9	63.6	91.3	78.4	4.92
PO_4	1.0	<0.4	<0.2	<0.4	<0.2	<1.0	<0.4	<0.1
NO_3	<0.05	<0.2	<0.1	<0.2	0.87	<0.5	<0.2	0.44
Br	1.67	<0.2	<0.1	<0.2	<0.1	<0.5	<0.2	<0.05
TDS (calculated)	501	535	503	557	496	537	552	134
Depositing silica		yes		yes	yes	yes		
Bubbling gas		yes	yes	yes		yes	yes	
Geothermometers-°C(3)								
Na-K-Ca (Mg)	162	166	149	100	149	106	142	
α-Cristobalite	97	101	103	101	98	99	97	
Quartz (cond.)	147	151	153	151	141	149	148	
Isotope Values								
δD (°/oo)	-38.65	-38.86	-41.90	-30.20	-41.86	-33.44	-33.44	-37.68
$\delta^{18}O$ (°/oo)	-4.68	-3.91	-4.59	-3.09	-2.94	-5.02	-3.88	-5.67

(1) Concentrations in mg/l.
(2) HCO_3 has been calculated by cation and anion balance.
(3) Geothermometers calculated by the methods of Fournier and Potter (1979), Fournier (1977) and Fournier (1981).

and includes the remainder of the warm springs sampled (1, 7, 8, 9, 10 and 11). Type I and Type II waters are distinctly different. Type II water has lower Cl and higher HCO_3 and Mg contents than Type I water and near equal molar concentrations of SO_4 and Cl. Both fluid types, however, have similar cation and total dissolved solid (TDS) contents.

Type III water is represented by the cold well which has a temperature of 20°C. This water is calcium bicarbonate in character and is substantially different from both Type I and Type II waters. Type III water is characterized by higher contents of Ca, HCO_3 and NO_3 and a lower TDS content compared to water discharged from the warm springs.

SUBSURFACE TEMPERATURE

The Na-K-Ca (Mg) and silica geothermometer temperatures were calculated for all water samples collected to estimate the subsurface reservoir temperature in the Tattapani field. The silica geothermometer employed for each sample was that of the least supersaturated polymorph. This approach provides a minimum estimate of the base temperature. Figure 3 shows that the least supersaturated polymorph for all of the samples is α-cristobalite. The temperatures calculated based on this polymorph indicate a base temperature of at least 100°C. The Na-K-Ca (Mg) and quartz (conductively cooled) geothermometers on the other hand generally predict similar reservoir temperatures of approximately 150°C for these waters. The enthalpy-chloride relationships, illustrated in Figure 4, suggest that with the exception of spring 12 the warm springs could be derived from a common parent reservoir fluid. For example, warm waters represented by springs 1, 7, 8, 9, 10 and 11 could be derived by steam loss and mixing of a parent water, having a temperature of 200°C and chloride content of 70 ppm, with the local groundwater. The relationship between sample 12 and other hot spring waters is not clear. Despite differences in HCO_3, Mg and Cl contents between sample 12 and other warm water samples, similar temperatures and Na, Li, B, and TDS contents among all the warm water springs suggest that sample 12 is not related to the other samples simply by dilution.

ISOTOPE DATA

All the samples were analysed for their oxygen and deuterium contents. The results of the analysis are shown in Figure 5. All of the samples display isotopic shifts from the meteoric water line. Warm spring 9 which has a temperature of 55°C at the surface displays the greatest $\delta^{18}O$ shift, while the hottest spring 7 has values comparable with other warm springs. Warm spring 12 which differs from the other warm springs chemically, does not differ isotopically. Regional isotope values of the area are not known and hence it is difficult to assess the relationship between the cold and thermal waters of the area water at this preliminary stage.

CONCLUSIONS

Geological and geochemical investigations indicate that the Tattapani thermal field is underlain by a moderate temperature structurally controlled geothermal resource. The dominant structure is an easterly trending fault which has localized most of the hot springs and juxtaposes Archean metamorphic rocks against the overlying sedimentary rocks of Carboniferous to Jurassic age. This fault represents the main conduit for the upwelling fluids. Northeast trending faults offset the main easterly trending structure and locally channel fluids northward from the main conduit.

The springs discharge fluids representing a mixture of near surface cold water and upwelling thermal water. The hot spring waters are relatively dilute fluids ranging in temperature from 55-98°C. Two types of thermal waters have been recognized. Most of the hot spring waters are sodium bicarbonate-chloride-sulfate in character with a TDS content of approximately 550 ppm. The second fluid type is represented by a single spring located in the northeast part of the thermal area. The water contains a higher content of Cl and a lower HCO_3 concentration compared to the other springs.

Cation geothermometers suggest that the fluids could have equilibrated with reservoir rocks having a temperature of 140-160°C. These temperatures could be attained by conductive heating of downward circulating groundwaters to a depth of 4-5 kms if an average geothermal gradient of 30°C/km for this area and an ambient ground water temperature of 20°C is assumed. Several shallow thermal gradient wells are currently being drilled. One, has encountered fluids at depths of 152 and 164 meters in the subsurface extension of the major easterly trending fault which crosses the thermal field. At these depths, the reservoir consists of Archean metamorphic rocks.

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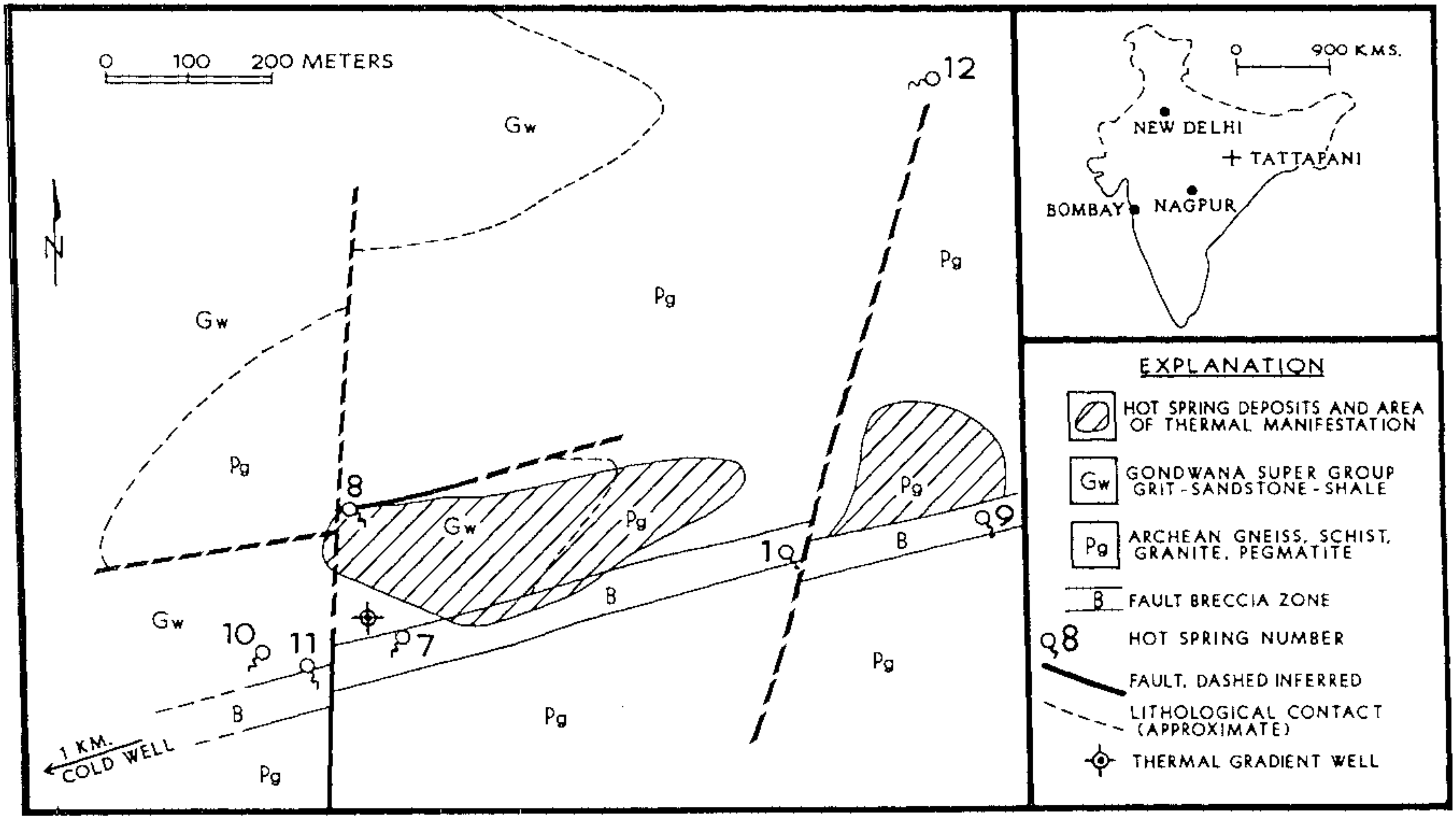

FIGURE 1

SCHEMATIC GEOLOGICAL MAP OF TATTAPANI, THERMAL AREA MADHEY PRADESH, INDIA

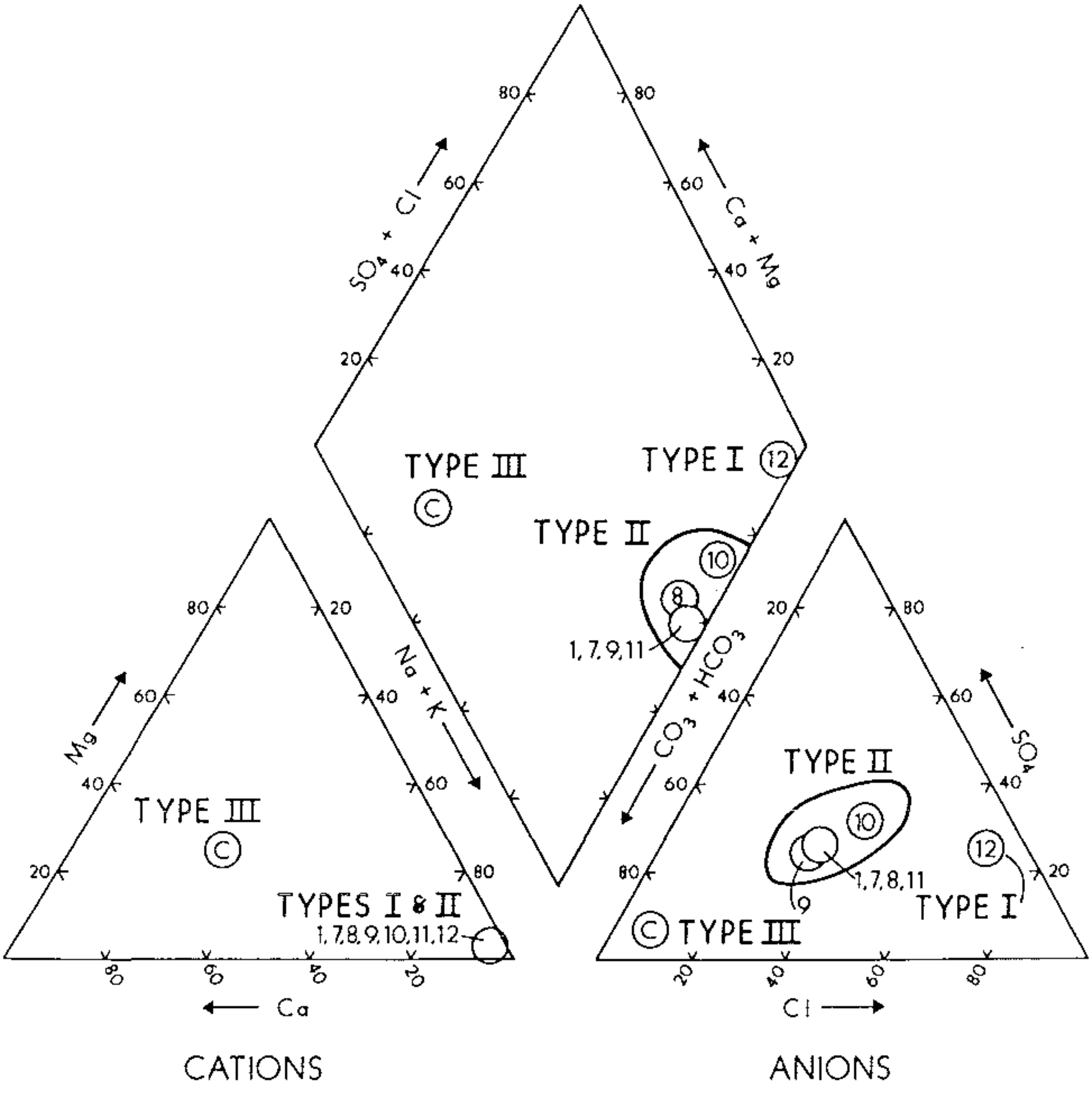

FIGURE 2. THE CHEMICAL CHARACTER OF WATER IN THE TATTAPANI THERMAL AREA. TRILINEAR PLOT OF THE PERCENTAGE OF TOTAL MILLIEQUIVALENTS PER LITER OF CATIONS AND ANIONS.

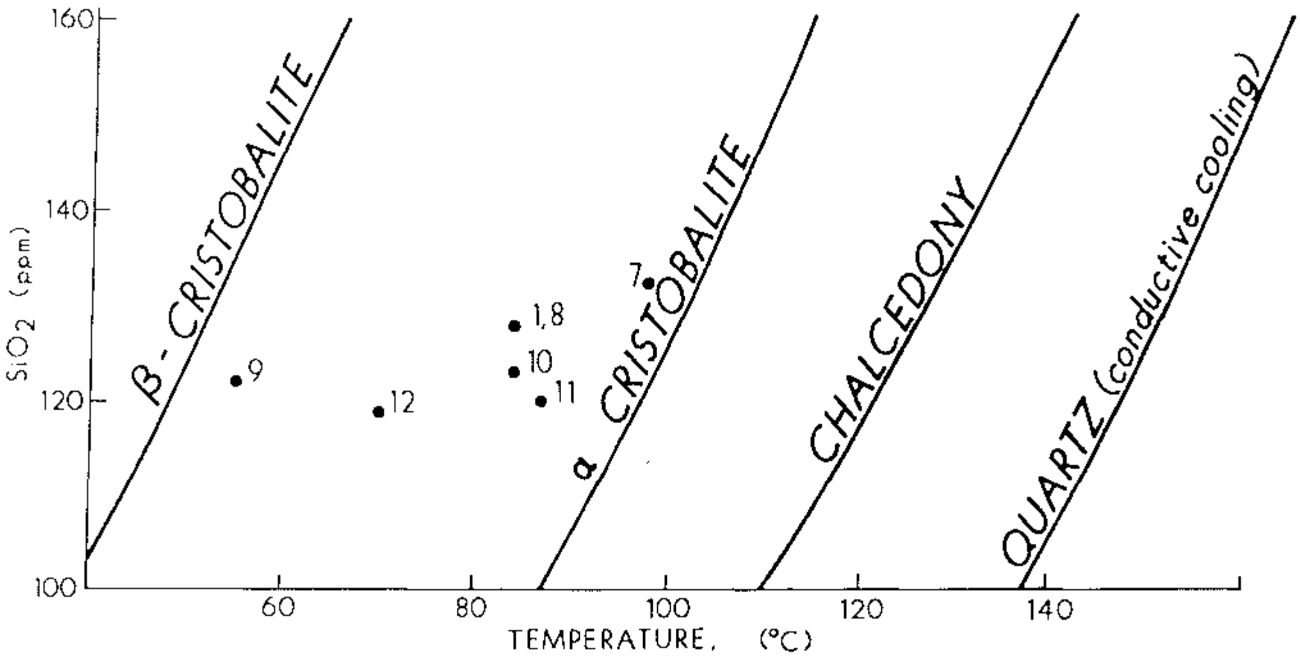

FIGURE 3. CONCENTRATION VERSUS TEMPERATURE DIAGRAM OF TATTAPANI WARM SPRINGS, MADHEY PRADISH, INDIA (MINERAL SOLUBILITIES AFTER FOURNIER, 1977).

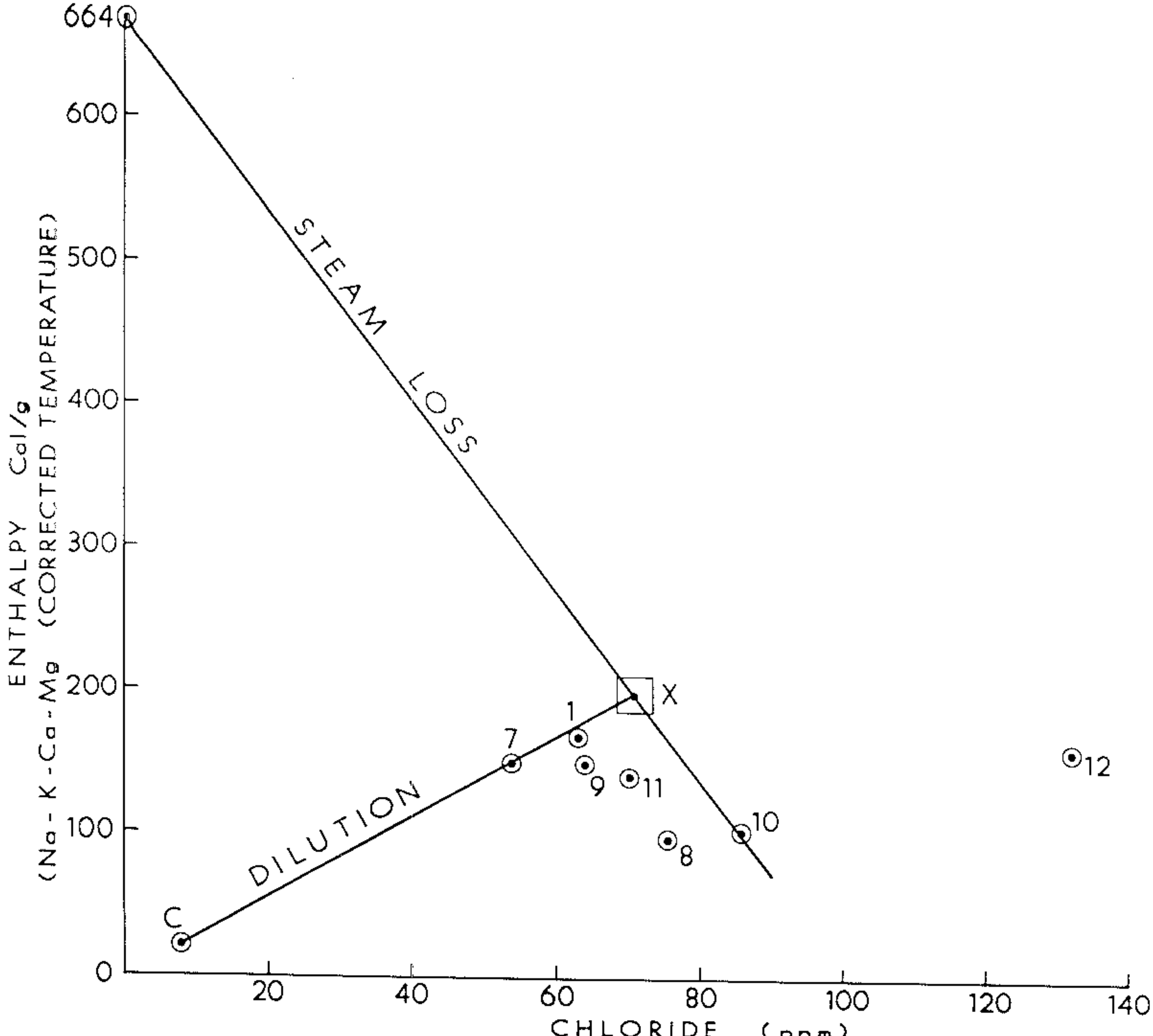

FIGURE 4. CHLORIDE VERSUS ENTHALPY PLOT OF THERMAL SPRINGS OF TATTAPANI AREA: MADHEY PRADESH, INDIA, SHOWING PROBABLE CHLORIDE AND TEMPERATURE OF DEEP WATER (POINT X).

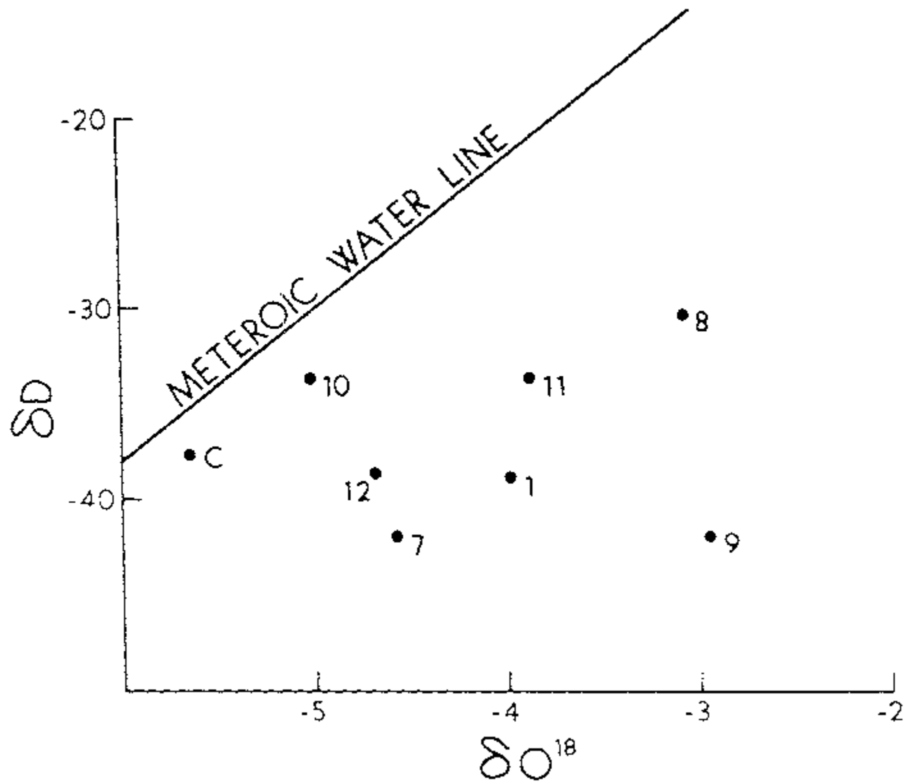

FIGURE 5. ISOTOPE ANALYSIS OF THERMAL WATER OF TATTAPANI AREA, MADHEY PRADESH, INDIA (METEORIC WATER LINE AFTER CRAIG, 1961)