Verh. Geol. B.-A.	ISSN 0016—7819	Jahrgang 1981	Heft 2	S. 19—29	Wien, Dez. 1981

Geological Setting and Chemical Geothermometry of Some Hot Springs in the Wakhan (NE Afghanistan)

By MANFRED F. BUCHROITHNER*)

With 2 figures und 3 tables

Schlüsselwörter
Afghanistan
Thermalquellen
Lineamente
Hydrochemie
Geothermometrie

Abstract

The geological setting of some geothermal springs in the Eastern Wakhan (NE Afghanistan) is described in detail. The springs are related to structural lines. Chemical analyses of water samples and Na—K—Ca geothermometry suggest a mixed-water model. Heated water of about 80—90° C from a reservoir in some 1.000 to 1.750 m depth is supposed to mix with cold water from shallower levels. These calculated figures, however, only represent rough minima and have to be seen in the light of the determinative marginal conditions which are given in this paper.

Zusammenfassung

Aus dem östlichen Wakhan (NE-Afghanistan) werden einige an tektonische Linien gebundene Thermalquellen in ihrer geologischen Position detailliert beschrieben. Aufgrund chemischer Wasseranalysen und anhand des Na—K—Ca-Geothermometers werden ein Modell für die Quellentstehung erstellt und Reservoirtemperaturen berechnet. Es dürfte sich um Thermen mit gemischtem heißem und kälterem Wasser aus verschiedenen tiefen Niveaus handeln. Die Untergrundtemperaturen von etwa 80—90° C sowie die errechneten Reservoirtiefen zwischen 1.000 und 1.750 m stellen nur grobe Minimalwerte dar, deren Bewertung eine Kenntnis der in dieser Arbeit geschilderten Randbedingungen impliziert.

Introduction

Hot springs have long been known to occur in the Wakhan (fig. 1 and 2) but have not been studied very closely up till now, especially from the geoscientific point of view. BUCHROITHNER (1978b and 1980b) gives first precise descriptions and some quantitative chemical data of thermal springs in the Eastern Wakhan. The present paper, however, mainly wants to set forth the geological and geothermal aspects. Field work was carried out by the author in 1975. The methodic procedures are described by BUCHROITHNER (1978b; cum lit.). It shall be mentioned that the discharge rates given here only represent a rough guess which is based on comparisons with well known home springs. It is also impossible to give data about the fluctuation of discharge. Gassy springs are subject to fluctuations in a high grade and short periodicity. Besides, earthquakes might influence the flow rate.

*) Author's address: MANFRED F. BUCHROITHNER, Österreichische Akademie der Wissenschaften, Institut für Kartographie, Abteilung für Satellitenkartographie, Bäckerstraße 20/III, A-1010 Vienna, Austria.

The Springs and their Geological Setting

Comprehensive presentations of the geology of the Great Afghan Pamir and the Eastern Hindu Kush are given by BUCHROITHNER (1978a, 1980a) and BUCHROITHNER & GAMERITH (1978). Additional references, also concerning geophysical papers, are quoted by BUCHROITHNER (1979). Moreover, the very important publications by CHATELAIN, ROECKER, HATZFELD & MOLNAR (1980), PREVOT, HATZFELD, ROECKER & MOLNAR (1980) and by ROECKER, SOBOLEVA, NERSESOV, LUKK, HATZFELD, CHATELAIN & MOLNAR (1980) shall be mentioned here. In the following all local geological terms refer to these papers. Another geological description seems to be unnecessary.

Before giving details about the springs investigated two other occurrences of thermal water in the Afghan Pamirs shall be mentioned briefly. One is located in the Tila Bay Valley at an altitude of some 4,160 m on the eastern bank of the brook. It delivers a lukewarm, sulphurous but tasteless water which makes the existence of the toad *Bufo latastii* still possible at this altitude. The spring is situated at the structurally controlled border line of the Afghan Pamirs Batholith but still within the Issik Granite (former Issik Granodiorite; BUCHROITHNER, 1978a, 1980a). At the Kotal-e Wazit (about 4,550 m), in the western part of the Great Afghan Pamir,

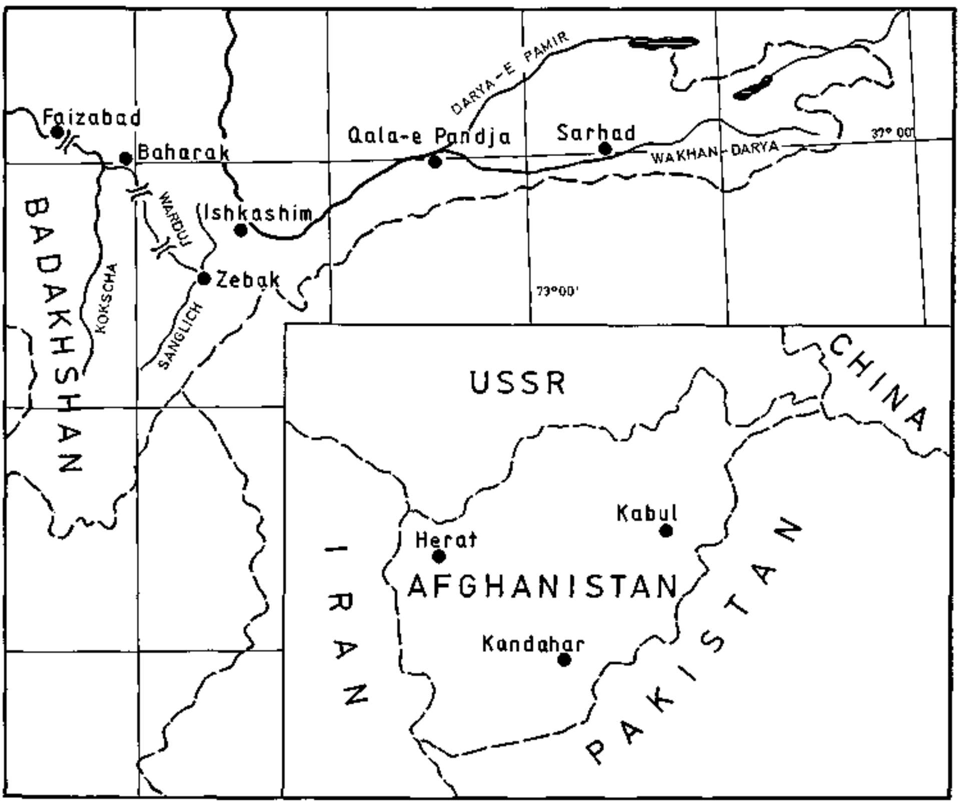

Figure 1. Location map of the studied area. Scale approx. 1 : 3,500,000

there are two little lakes with a water temperature of 13° C even in late autumn. This fact is doubtlessly due to the feeding by hot springs. They are situated in "undifferentiated crystalline" rocks (Buchroithner & Gamerith, 1978), i.e. most probably in gneisses.

These two hot springs are related to traverse faults trending ± perpendicular or in an obtuse angle to the general strike direction of the mountain ranges resp. to the Wakhan Fault and Southern Pamir Fault (Barkhatov, 1963). Moreover, they are situated at intersection points of two major lineaments (fig. 2); a fact that can be clearly seen in LANDSAT imagery.

The thermal spring of Sarhad is situated about one km NW of the village at an altitude of ca. 3,320 m on the eastern bank of the little brook draining the Sarhad Valley. Six main sources are situated in a sandy to muddy grey soil resp. swampy meadow at the foot of a vast alluvial fan. The water comes out of holes with a diameter of about 50 cm, sometimes showing bubbles (probably mainly hydrogen sulphide or carbon dioxide). The estimated mean discharge rate is less than 0.5 l/sec. The wells are randomly distributed in an E-W oriented area of about 50 by 30 m. Between them there are some other filtration springs resp. swallow holes which deliver lukewarm water (sensu Thurner, 1967) at irregular intervals. The second biggest source is situated in a little stone hut. Inside there is a square basin which is just big enough to provide room for a two persons' hip bath. Water of 39° C comes up between the slate plates in the north-western corner of the basin, sometimes showing bubbles. About 2 m S of this spring the main spring of Sarhad is captured in a little basin of 50 cm square and a depth of some 20 cm. The temperature is 35.5° C, the discharge rate is estimated to be between 0.5 and 1 l/sec. Possibly the "baths" was originally built over the formerly strongest spring which lost intensity later.

A few meters E of the hut black slates of the Wakhan Formation (Buchroithner, 1978a) crop out of the recent fine-clastic sediments. Corresponding to the general trend they strike E-W but dip steeply to the N (360/80), in contrast to the average dip angle of the Wakhan Formation along the S slope of the Great Afghan Pamir (± 45° N). This considerable displacement can be explained by the Wakhan Fault which runs between the northern slope of the Wakhan-Darya Valley and the springs — at least with one branch of its fault bundle. Perpendicular to the strike we find vertical joint planes (255/85) in distances of some dm.

The richest geothermal springs of the Wakhan are situated just NNW of the village of Baba Tangi (3,040 m), right by the northern riverside of the Wakhan River which shows a width of about 20 m there. Because of the high water-level you can only reach them over the bridge at Sargaz, about 2 km downstreams, except in late autumn and winter maybe. On an exposed path leading further on to the village of Rorunq one gets to a 35—40° steep, slightly overgrown talus fan placed between country rocks. In its eastern corner there is a landslide of some 15 m height and 10 m width, at the base partly grown with big hursts of the grass *Lasiagrostis splendens*. There the springs arise in six levels. The lowest is situated 120 cm above the river (waterline in Sept. 1975). Here we find the biggest springs: hot water pours out of two openings with a diameter of 20 to 25 cm in a distance of about 7 m between incrustated stones. The discharge rate is certainly more than 10 l/sec. Between these two boundary springs there are ten smaller holes with a diameter of about 10 cm and some swallow holes, both rimmed by sulphurous incrustations. In sinterdeposits some meters upstream from these springs one can observe bulges which could indicate intermittent discharge rates. Especially gassy springs often show intermittent flow,

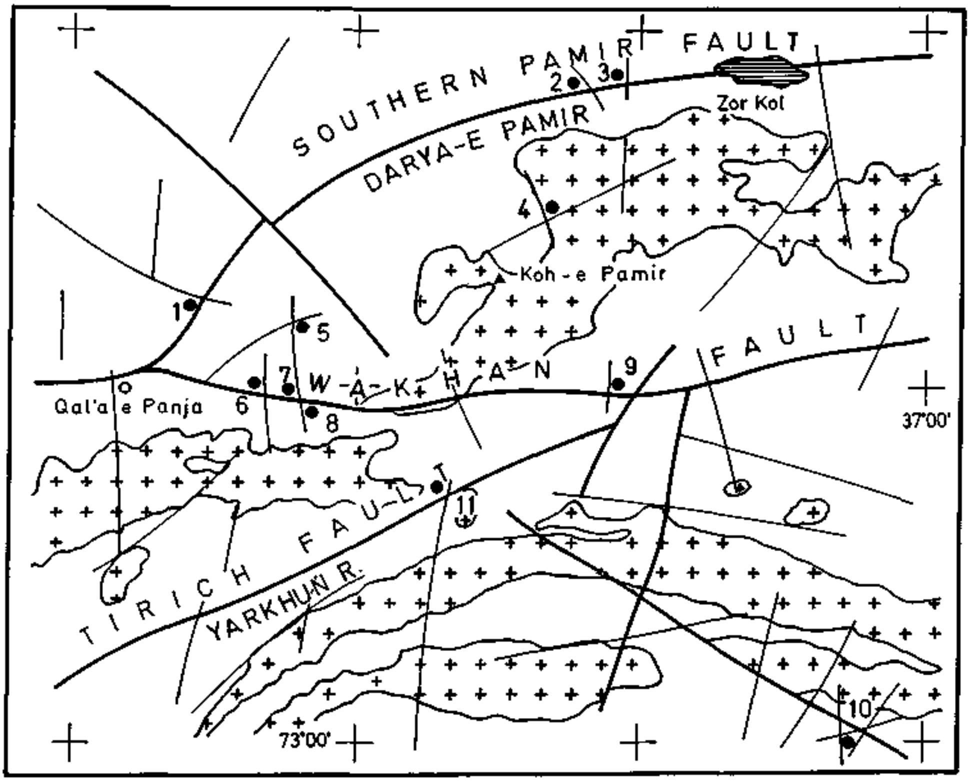

Figure 2. Sketch map showing the relation between geothermal springs, granitic batholiths and structural lines in Northern Pakistan, the Eastern Wakhan and the bordering area of the USSR. The hot springs are located at intersections of major faults. Compiled from BUCHROITHNER (1978a, 1978b), BUCHROITHNER & GAMERITH (1978) and ABU BAKR 1965). Lineations taken from LANDSAT imagery. Scale approx. 1 : 1,220,000. — 1: Issar, 2: Yal-Kunak, 3: Ljangar, 4: Tila Bay, 5: Kotal-e Wazit, 6: Sherk, 7: Sargaz, 8: Baba Tangi, 9: Sarhad, 10: Ishkuman, 11: Pechus

a phenomenon which is demonstrated by the scanty discharge in the small holes situated within these sinter deposits of some square meters in size.

The western one of the two main springs was tapped by the natives by a small horseshoe-shaped stone wall of 15 to 20 cm height. Sometimes passing travellers cook meat for their meals as the author could see himself. After about one hour a piece of mutton of the size of a fist is properly cooked. The mineral content of the water hardly infuences the taste. Temperatures were not taken here because of danger of damage of the thermometer (scale range). According to the indications of skin blistering and coagulation of animal protein we can estimate a temperature of at least 80° C.

The second spring level is located about 3.5 m above the river. Beside 5 sandy filtration springs delivering bubbles — similar to those of Sarhad — we find still another strongly pouring spring here. The temperature of the latter is ± 85° C (cf. BUCH-

ROITHNER; 1978b, 1980b), whereas the mean temperature of the filtration springs is about 50° C showing a maximum of 53.0° C and a minimum of 47.5° C. *).

About 6.5 m above the river there is a smaller, captured boundary spring of about the same temperature as the biggest of the lower level. It is drained by a small channel. 1.5 m higher a scarcely flowing source of 51.0° C, rimmed by slight calcium carbonate incrustations, is located. 2.5 m higher, just below the head of the land slide is another scantly pouring "cold" spot of white sinterings.

W of the source area there is a little flat-roofed hut by the riverside sheltering a basin of some 3 m square. It gives a desolate impression.

As mentioned before, the geothermal springs of Baba Tangi are situated in a talus fan. The latter is surrounded by steep rock walls consisting of an alternate bedding (tectonic wedging ?) of perlitic (augen-) gneisses (Qal'a-e Ust Gneiss; DESIO, GUJ & PASQUARÈ, 1968) and foliaceous dark grey slates as well as reddish quartzites of the Wakhan Formation in a range of some dm to m. The dip angle is ± 300/80, i. e. diverging from the general dip. There are many subparallel joints, all trending almost perpendicular to the main strike direction (± 230/80), like in Sarhad.

Just 2.5 km NW of this place the geothermal springs of Sargaz (3.000 m) occur, about 500 m E of the village, on the southern side of the Sargaz Valley, just beside the brook Joy-e Pamir. Some 50 cm above brook level tasteless water of 51.5° C comes out of native rock with an estimated discharge rate of less than 0.5 l/sec. Some meters upstream (E) water of 46.0° C seeps into a roughly built enclosure of loose stones. The water of the main source runs out of a ca. 25 cm long metal pipe pinned into a joint. A semicircular basin of 1.5 m in diameter and 0.5 m depth is bordered by the cliff on one side.

The hot springs of Sargaz come out of fine-grained, intensely cleaved (342/45) and quartz-poor Qal'a-e Ust Gneisses. Here the joint planes are almost perpendicular to the strike direction, too (260/±90). The main lineament of the Wakhan Fault follows the valley of the Joy-e Pamir beside which the springs are located.

In big black fans of slates of the Wakhan Formation one can observe yellow and white efflorescences and sintered filtration springs ca. 200 m above (NE) the village of Sargaz which are most probably caused by geothermal sulphurous springs.

The most famous spring of the Wakhan is that of Sherk. This "baths" — a well-kept building with a basin — is located NE of the village at an altitude of about 2,950 m at the upper end of a mountain pasture. The temperature is 43.0° C, the estimated discharge rate between 0.5 and 1 l/sec. For several meters round one can perceive a suphurous smell. About 4.5 m SW of the "baths" a warm filtration spring with algae and a sintered runoff is located. On the mountain pastures S of the hot spring there are frequently sources rimmed with sinter deposits down to about 2.850 m. Their waters, however, are cold and run down the meadow in broad strips (Sept. 1975).

About 15 m above the "baths" of Sherk there is a 20-m high rock precipice consisting of intensely tectonically stressed rocks of the Wakhan Formation, i.e. black slates and light-grey quartzites alternating in a range of some mm to cm ((312/45). This value coincides with the dip angle of a dislocation plane which limits the native rock towards the fan. 7 m E of the hut black slates crop out in a small exposure (350/90) below the spring.

*) The water temperatures of Baba Tangi, Sargaz and Sherk were measured at an external air temperature of 23, 21 and 25° C, that of Sarhad at 24° C outdoor temperature.

Geochemistry

By means of atomic absorption spectroscopy and emission spectroscopy it was possible to get chemical analyses showing the most important cations resp. trace metals out of rather little water samples ($\pm$ 1/8 l). Unfortunately no sample could be taken in Sherk.

Table 1. Concentrations of main ions in thermal waters of the Eastern Wakhan

	Concentration in mg/l						Molal concentration		
Locality	Chloride	Sulphate	Magnesium	Sodium	Potassium	Calcium	Sodium	Potassium	Calcium
Sarhad	27.0	53.5	1.2	25.0	4.0	6.0	1.08743×10^{-3}	1.02296×10^{-4}	1.49700×10^{-4}
Baba Tangi	14.9	47.5	2.1	30.5	6.5	12.0	1.32668×10^{-3}	1.66232×10^{-4}	2.99401×10^{-4}
Sargaz	14.2	35.2	1.6	29.0	6.0	8.0	1.26143×10^{-3}	1.53444×10^{-4}	1.99600×10^{-4}
Comp. fig. (global means)*)	7.8	11.2	4.1	6.3	2.3	15.0			

*) References see text.

Concerning the concentrations of the main ions one can see a considerable increase of chloride, sulphate, sodium, and potassium compared with the global means (LIVINGSTONE, 1963) which are mainly determined by the chemical composition of the big streams (as Amazonas e. g.). On the other hand we find relatively low contents of magnesium and calcium. The latter are very well correlable with the geological setting. i.e. carbonate-poor rocks. In general the concentrations of minerals are rather low — except perhaps the iron contents of Baba Tangi and Sarhad — so that these hot springs may be called "acratothermal".

Table 2. Temperatures, pH values and concentrations of some trace elements (in μg/l)

Locality	T in ° C	pH	Iron	Manganese	Zinc	Copper	Lead	Cadmium
Sarhad	36, 39	6.9	4,700	66	23	2.9	4.0	0.2
Baba Tangi	48 — ~ 85*)	7.9	10,000	78	35	1.4	2.5	0.2
Sargaz	46, 52	7.6	900	102	30	3.0	2.8	0.3
Comp. fig. (global means)**)			670	7	10	3.0	0.5	0.2

*) Samples were only taken from waters between 48 and 53° C.
**) References see text.

As far as trace elements are concerned an obvious increase of iron and manganese concentrations can be stated in comparison with the global mean figures (Fe: LIVINGSTONE, 1963; Mn: TUREKIAN, 1969). Yet, we have to consider that the water samples were perlocated by a 0.45 micron diaphragm filter. In this connection it has often been observed that colloidal iron and manganous hydroxide material easily passes this mesh size and simultaneously conveys incorporated heavy minerals into the filtrate. In this way the partially high contents of iron under the mentioned pH conditions could be explained as well as the increase of zinc and lead in comparison with the — very variable — back ground data (WEDEPOHL, 1972, 1974). Copper and cadmium do not show great difference with the comparative figures (Cu: WEDEPOHL, 1972, 1974; Cd: LODEMANN & BUKENBERGER, 1973). Data concerning cadmium concentrations, especially in not yet polluted regions, are still rather fragmentary, most likely because the danger of this metal and its compounds for mankind has only been discovered not too long ago (FÖRSTNER & MÜLLER, 1974; KOBAYASHI, 1971).

Moreover, it shall be noted that the distribution of trace elements in the analyzed water samples shows an overall coincidence with the corresponding concentrations in slates and hornfelses of the Wakhan Formation (BUCHROITHNER & KOLMER, 1979).

Geothermometry

As no treatments of the water samples could be made in the field (TARAS, GRENBERG, HOAK & RAND, 1971) it was not possible to determine the silica content. Thus we are not able to check the Na-K-Ca geothermometer by another method. Of course, bore hole data are also missing from this remote area.

The various restrictions and precautions related with the application of the Na-K-Ca geothermometer have been discussed several times (FOURNIER & TRUESDELL, 1973; MILLER, BARNES & PATTON, 1975; TRUESDELL & FOURNIER, 1975; FOURNIER, 1976; ELLIS & MAHON, 1977; ELLIS, 1979). They shall only be mentioned here as fas as they definitely have an impact on the interpretation of the results.

For calculations of subsurface temperatures from Na-K-Ca concentrations (FOURNIER & TRUESDELL, 1973) the equation for temperatures $T_{4/3}$ above 100° C or $\sqrt{m_{Ca2+}} : m_{Na+} \leqq 1$ is

$\log_{10}(m_{Na+}/m_{K+}) + 1/3 \log_{10}(\sqrt{m_{Ca2+}}/m_{Na+}) = 1{,}647/T - 2.240$ where

T = temperature in degrees Kelvin,

m_{Na+} = molality of sodium ion,

m_{K+} = molality of potassium ion, and

m_{Ca2+} = molality of Calcium ion.

For temperatures T below 100° C and $\sqrt{m_{Ca2+}} : m_{Na+} \geqq 1$ the equation is $\log_{10}(m_{Na+}/m_{K+}) + 4/3 \log_{10}(\sqrt{m_{Ca2+}}/m_{Na+}) = 1{,}647/T - 2.240$.

The results of these calculations are given in table 3.

The equilibrium constant K* for all possible reactions is

$$\log_{10}K^* = \log_{10}(m_{Na+}/m_{K+}) + \beta \log_{10}(\sqrt{m_{Ca2+}}/m_{Na+}),$$

in which the value of β depends on the stoichiometry of the reaction. β can be determined by using the empirical curve for geothermometry of natural waters displaying K* versus the reciprocal of absolute temperature (FOURNIER & TRUESDELL, 1973: fig. 6).

Table 3. Calculated reservoir temperatures of hot springs in the Eastern Wakhan and their determinative parameters

Location	$\sqrt{m_{Ca}}$	$\log(m_{Na}/m_K)$	$\log(\sqrt{m_{Ca}}/m_{Na})$	$\log K^*, \beta = 4/3$	$T_{estim.}$
Sarhad	0.01224	1.02654	1.05121	2.42816	80° C
Baba Tangi	0.01730	0.90205	1.11536	2.38920	83° C
Sargaz	0.01413	0.91491	1.04922	2.31387	89° C

Discussion

A study of the geological setting of hot springs in the Wakhan and Northern Pakistan shows a close correlation between the occurrence of hot springs and lineaments of at least regional importance resp. intersections of tectonic lines. Moreover, one can state that they are all situated in the surrounding of plutons or even more or less at their boundaries (cf. BUCHROITHNER & GAMERITH, 1978; fig. 2).

A tentative model suggested by the available information on the geological setting and the meager geochemical data of the hot springs in the Wakhan is as follows. The thermal springs are the results of deeply circulating, locally derived meteoric water that has perlocated through the fractured granitic plutons and the surrounding wall rocks to the depht of some thousand meters, became heated due to the geothermal gradient and found access to the surface along fractured and faulted zones. On its way upwards, however, it mixed with cold water from shallower ground water levels. The latter process was described in detail by FOURNIER & TRUESDELL (1974b). It results in springs which may have temperatures ranging from very low to almost boiling. The mixed-water nature is indicated by some of the features mentioned by FOURNIER & TRUESDELL (1974a): 261 and FOURNIER & TRUESDELL (1974b): 263. As no loss of enthalpy could be observed in the area studied, model 1 of FOURNIER & TRUESDELL (1974b): fig. 1A has to be applied to the hot springs in the Eastern Wakhan.

No data on the geothermal gradient in the Wakhan or Northern Pakistan was attainable for the author. CHOUDHURY (1964), however, mentioned that there is no evidence for high subsurface temperatures in the Afghan Pamirs and in the Eastern Hindu Kush. For an area not too far away (relatively!), i. e. E 72° 07'—72° 29' and N 40° 29'—40° 45', JESSOP, HOBART & SCLATER (1976) give some data based on Soviet Russian measurements, which lie between 23 and 29 mK/m and yield a mean of 26.4 mK/m. Extrapolation from the Russian geothermal map (Karta geotermičeskogo režima zemnoi kory territorii SSSR, 1978), which only reaches right to the Soviet border, shows a temperature gradient in the range of 25—30 mK/m for the Eastern Wakhan. Therefore it seems to be justified to use these figures as limiting values for depth calculation.

If no addition of magmatic water or heat and no mixture with cold meteoric water is considered, the subsurface temperatures indicated by the chemical geothermometer suggest that the water must have reached depths of some 1,200 to 1,750 m on the basis of a geothermal gradient of 25 mK/m, and some 1,000 to 1,450 m if 30 mK/m are assumed. These values clearly fall into the range of depth roughly estimated by BUCHROITHNER (1980b) for the hot springs in the Eastern Wakhan.

As already mentioned before, the thermal springs studied present outflows of mixed, heated and cold water. As no data on silica concentrations is existent it is more or less impossible to determine the proportion of hot to cold water and the initial enthalpies of each respectively (FOURNIER & TRUESDELL, 1974b). Thus the figures given above can only be rough minima of calculated reservoir depths, a fact which is also indicated by the application of the magnesium correction to the Na-K-Ca chemical geothermometer (FOURNIER & POTTER, 1979). If, on the other hand, heat from an underlying magma had been added to the system the water might derive from a shallower depth than that calculated from the above geothermal gradients.

The estimated subsurface temperatures most likely represent minima, too (FOURNIER & TRUESDELL; 1970, 1973, 1974b). The author is fully aware that the Ca corrected Na/K ratio has to be applied with great caution, and that especially the sulphate and chloride concentrations under consideration may suppress the reliability of the Na-K-Ca geothermometer. But nevertheless the calculated figures of reservoir temperatures and depth may be taken as rough approximations.

Although the information available on the geological setting and chemistry of the hot springs in the Eastern Wakhan is rather poor, it suggests that these hot springs are characterized by reservoirs of limited extent and relatively low temperatures in comparison with temperatures of geothermal systems presently exploited for power generation (cf. MILLER et al., 1975). Anyway, the subsurface energy would be high enough for the use with working fluids such as freon or isobutane (FACCA, 1970). This the more as we may assume even higher reservoir temperatures than the calculated ones owing to the dilution with relatively shallow, cold ground water.

Therefore these springs may have potential for limited power generation as well as for space heating and agricultural uses, that is worth a more detailed feasibility study (GILLILAND, 1975). As the Wakhan is one of Asia's least developed and poorest regions (NAUMANN, 1974; SENARCLENS DE GRANCY & KOSTKA, 1978) this way of using cheap and "clean" energy could help the natives to live under those rough high-altitude conditions, especially during winter time, without disturbing the environment too much. And maybe it could even prevent the complete migration of people out of the Wakhan, and thus save a very old and original culture.

References

ABU BAKR, M.: Thermal springs of Pakistan. — Rec. Geol. Surv. Pakistan, **16**, 3, 1—4, Karachi, 1965.

BARKHATOV, B. P.: Tectonica Pamira. — Leningradskiy ordena. Lenina Gosudarsteenniy Universitet, Leningrad, 1963.

BUCHROITHNER, M. F.: Zur Geologie des Afghanischen Pamir. — In: Grosser Pamir. (SENARCLENS DE GRANCY, R. & KOSTKA, R. ed. s:) 85—118, Graz: Akad. Druck- u. Verlagsanstalt, 1978 a.

BUCHROITHNER, M. F.: Ein Beitrag zu den Thermen des östlichen Wakhan. — In: Grosser Pamir. (SENARCLENS DE GRANCY, R. & KOSTKA, R. ed. s:) 151—165, Graz: Akad. Druck- u. Verlagsanstalt, 1978 b.

BUCHROITHNER, M. F.: Progress in the geology of Afghanistan 1972—1978. — Zbl. Geol. Paläont. Teil I, **1979**, 5/6, 328—376, Stuttgart, 1979.

BUCHROITHNER, M. F.: An outline of the geology of the Afghan Pamirs. — Tectonophysics, **62** (1980), 13—35, Amsterdam, 1980 a.

BUCHROITHNER, M. F.: On the geothermal springs of the Eastern Wakhan (NE Afghanistan). — Unpubl. typescript, 1—16, Enschede, 1980 b.

BUCHROITHNER, M. F. & GAMERITH, H.: Pamir-e Wakhan—Dardistan. Geological map of Selsela Koh-e Wakhan (Pamir-e Wakhan) and parts of the High Hindu Kush, Hinduraj and Western Karakoram. Scale 1 : 250,000. — In: Grosser Pamir. (SENARCLENS DE GRANCY, R. & KOSTKA, R. ed. s:) enclosure, Graz, 1978.

BUCHROITHNER, M. F. & KOLMER, H.: Notes on the Wakhan Formation of the Great Afghan Pamir and the Eastern Hindu Kush. — Afghanistan J., **6**, 2, 54—61, Graz, 1979.

CHATELAIN, J. L., ROECKER, S. W., HATZFELD, D. & MOLNAR, P.: Microearthquake Seismicity and Fault Plane Solutions in the Hindu Kush Region and Their Tectonic Implications. — J. Geophys. Res., **85**, **B** 3, Washington, 1980.

CHOUDHURY, M. A.: A review of seismic studies in the Hindu Kush—Pamir Region. — In: Geophysics of the Karakorum (MARUSSI, A. ed.). — In: Italian Expeditions to the Karakorum (K 2) and Hindu Kush. (DESIO, A. ed.:) Sci. Rep., **II**, **1**, 189—211, Leiden: Brill, 1964.

DESIO, A., GUJ, P. & PASQUARÈ, G.: Notes on the geology of Wakhan (North-East Afghanistan). — Rend. Accad. Naz. Lincei, **VIII/9**, 2, 37—52, Rome.

ELLIS, A. J.: Chemical geothermometry in geothermal systems. — Chem. Geol., **25** (1979), 219—226, Amsterdam, 1979.
ELLIS, A. J. & MAHON, W. A. J.: Chemistry and Geothermal Systems. — 1—392, New York: Academic Press, 1977.
FACCA, G.: General report of the status of world geothermal development. — In: United Nations Symposium on Development and Utilization of Geothermal Resources., 49 p. of proof, Pisa, 1970.
FÖRSTNER, U. & MÜLLER, G.: Schwermetalle in Flüssen und Seen als Ausdruck der Umweltverschmutzung. — 1—225, Berlin—Heidelberg—New York: Springer, 1974.
FOURNIER, R. O.: Chemical geothermometers and mixing models for geothermal systems. — Geothermics, **5**, 41—50, London, 1976.
FOURNIER, R. O. & POTTER, R. W. II: Magnesium correction to the Na-K-Ca chemical geothermometer. — Geochim. Cosmochim. Acta, **43**, 1543—1550, London, 1979.
FOURNIER, R. O. & TRUESDELL, A. H.: Chemical indicators of subsurface temperature applied to hot spring waters of Yellowstone National Park, Wyoming USA. — In: United Nations Symposium on Development and Utilization of Geothermal Resources. Proc., **2**, 1, Geothermics, Special Issue, **2**, 529—535, Pisa, 1970.
FOURNIER, R. O. & TRUESDELL, A. H.: Empirical Na—K—Ca geothermometer for natural waters. — Geochim. Cosmochim. Acta, **37**, 1255—1276, London, 1973.
FOURNIER, R. O. & TRUESDELL, A. H.: Geochemical indicators of subsurface temperature — Part 1, Basic assumtions. — J. Res. U. S. Geol. Surv., **2**, 3, 259—262, Washington, 1974 a.
FOURNIER, R. O. & TRUESDELL, A. H.: Geochemical indicators of subsurface temperature — Part 2, Estimation of temperature and fraction of hot water mixed cold water. — J. Res. U. S. Geol. Surv., **2**, 3, 263—270, Washington, 1974 b.
GILLILAND, M. W.: Energy analysis and public policy. — Science, **189**, 4208, 1051—1056, Washington, 1975.
JESSOP, A. M., HOBART, M. A. & SCLATER, J. G.: The world heat flow data collection — 1975. — Geotherm. Serv. Canada, Geotherm Ser., **5**, 41—42, Ottawa, 1976.
Karta geotermičeskogo režima zemnoj kory Territirii SSSR. Masštab 1 : 10,000,000. — Ministerstvo geologii SSSR, Vsesojuznyj ordena Lenina naučno-issledovatel'skij geologičeskij Institut (VSEGEI), Moscow, 1978.
KOBAYASHI, J.: Relation between the "Itai-Itai" Disease and the Pollution of River Water by Cadmium from a Mine. — Adv. Water Poll. Res., Proc. 5th Intern. Conf. San Francisco and Hawaii 1970, **1**, I, 25, 1—7, San Francisco, 1971.
LIVINGSTONE, D. A.: Chemical Composition of Rivers and Lakes. — In: Data of Geochemistry, 6th ed. (FLEISCHER, M. ed.:) U. S. Geol. Surv. Prof. Paper, **440-G**, Washington, 1963.
LODEMANN, C. K. W. & BUKENBERGER, U.: Schwermetallspuren im Bereich des oberen Neckars. — GWF-Wasser/Abwasser, **114**, 417—437, 1973.
MILLER, TH. P., BARNES, I. & PATTON, W. W. Jr.: Geologic setting and chemical characteristics of hot springs in West-Central Alaska. — J. Res. U. S. Geol. Surv., **3**, 2, 149—162, Washington, 1975.
NAUMANN, C. M.: Pamir und Wakhan. Kurzbericht zweier Expeditionen (1971 und 1972) nebst einigen allgemeinen Bemerkungen. — Afghanistan J., **1**, 4, 91—103, Graz, 1974.
PREVOT, R., HATZFELD, D., ROECKER, S. W. & MOLNAR, P.: Shallow Earth Quakes and Active Tectonics in Eastern Afghanistan. — J. Geophys. Res., **85**, B 3, 1347—1357, Washington, 1980.
ROECKER, S. W., SOBOLEVA, O. V., NERSESOV, I. L., LUKK, A. A., HATZFELD, D., CHATELAIN, J. L. & MOLNAR, P.: Seismicity and Fault Plane Solutions of Intermediate Depth Earthquakes in the Pamir — Hindu Kush. — J. Geophys. Res., **85**, B 3, 1358—1364, Washington, 1980.
SENARCLENS DE GRANCY, R. & KOSTKA, R. (ed. s): Grosser Pamir. — 1—400, Graz: Akad. Druck- u. Verlagsanstalt, 1978.

TARAS, M. J., GRENBERG, A. E., HOAK, R. D. & RAND, M. C.: Standard Methods for the Examination of Water and Wastewater, 13th Ed. — Amer. Publ. Health Assoc., Washington, 1971.

THURNER, A.: Hydrogeologie. — Vienna—New York: Springer, 1967.

TRUESDELL, A. H. & FOURNIER, R. O.: Calculation of deep temperatures in geothermal systems from the chemistry of boiling spring waters of mixed origin. — In: United Nations Symposium on the Development and Use of Geothermal Resources. Proc., 2, 1, 837—844, San Francisco, 1975.

TUREKIAN, K. K.: The oceans, streams and atmosphere. — In: Handbook of Geochemistry. (WEDEPOHL, K. H. ed.:) vol. 1, Berlin—Heidelberg—New York: Springer, 1969.

WEDEPOHL, K. H. (ed.): Handbook of Geochemistry. Copper, Lead, Zinc. — Berlin—Heidelberg—New York: Springer, 1972 and 1974.

Manuskript bei der Schriftleitung eingelangt am 20. November 1980.