COBISS: 1.01

HYDROCHEMIC CHARACTERISTICS AND TECTONIC SITUATION OF SELECTED SPRINGS IN CENTRAL AND NW YUNNAN PROVINCE, CHINA

HIDROKEMIČNE ZNAČILNOSTI IN TEKTONSKI POLOŽAJ IZBRANIH IZVIROV V OSREDNJEM IN SZ YUNNANU, KITAJSKA

Stanka ŠEBELA[1] & Janja KOGOVŠEK[1]

Abstract UDC 556.3:54(510)

S. Šebela & J. Kogovšek: Hydrochemic characteristics and tectonic situation and of selected springs in central and NW Yunnan province, China

The Yunnan Province lies on the eastern rim of the collision zone between the Indian plate and Eurasia. This region is characterized by complex Cenozoic structures and active seismotectonics. In the year 2004 the areas north from Kunming and the NW part of Yunnan were studied. The measurements of the temperature, conductivity and the analyses of carbonate, phosphate and nitrate were performed in Quinglongtan spring and in the accumulation lake that is situated lower than the spring. The springs are situated in the wider zone of the Xiaojiang fault along which left horizontal movements are taking place. Along the wider zone of the Zhongdian fault between the town of Zhongdian and the Yangtze River on the south there are more springs. Tiansheng Qiao (T = 57.5°C) and Xiageiwenquan (T = 48,3 – 66.8°C) are thermal springs along which tufa is deposited. The Baishuitai spring has high mineralization and lower temperature (T = 11.1 – 13.3°C) and deposits calcium carbonate in the form of gours. All studied springs are connected with active fault zones. The studied areas mostly represent the contact areas between carbonate and non-carbonate rocks.

Key words: springs, tectonics, travertine, Yunnan, China.

Izvleček UDK 556.3:54(510)

S. Šebela & J. Kogovšek: Hidrokemične značilnosti in tektonski položaj izbranih izvirov v osrednjem in SZ Yunnanu, Kitajska

Provinca Yunnan leži na vzhodnem robu kolizijske cone med Indijsko in Evrazijsko ploščo. Za to ozemlje so značilne zapletene kenozojske strukture in aktivna seizmotektonika. V letu 2004 smo proučevali ozemlja severno od Kunminga in SZ del Yunnana. Meritve temperature, specifične električne prevodnosti in analize vsebnosti karbonatov, fosfatov in nitratov smo opravili na izvirih Quinglongtan in v nižje ležečem akumulacijskem jezeru. Izviri se nahajajo v širši prelomni coni Xiaojiang, ob kateri se vršijo levi zmiki. V širši prelomni coni Zhongdian preloma med mestom Zhongdian in reko Yangtze na jugu se nahaja več izvirov. Tiansheng Qiao (T = 57,5°C) in Xiageiwenquan (T = 48,3 – 66,8°C) sta termalna izvira, ob katerih se odlaga lehnjak, Baishuitai pa je močno mineraliziran izvir z nižjo temperaturo (T = 11,1 – 13,3°C), ki odlaga kalcijev karbonat in gradi ponvice. Vsi ti izviri so vezani na aktivne prelomne cone. Izbrani predeli večinoma predstavljajo kontakt med karbonatnimi in nekarbonatnimi kamninami.

Ključne besede: izviri, tektonika, lehnjak, Yunnan, Kitajska.

[1] Inštitut za raziskovanje krasa ZRC SAZU, Titov trg 2, 6230 Postojna, Slovenia, e-mail: sebela@zrc-sazu.si

Received / Prejeto: 20.01.2006

INTRODUCTION

Exposed karst areas in China comprise about 900.000 km^2 and the karst area in Yunnan includes 110.900 km^2. The Yunnan region in southwest China is located in the boundary area between the active Tibetan Plateau to the west and the stable South China platform to the east. This region is characterized by complex Cenozoic structures and active seismotectonics.

The studied area is part of the Three parallel rivers of Yunnan Protected Areas, which is inscribed in the UNESCO's World Heritage List. The area represents geological history of at least 50 million years associated with the collision of the Indian Plate with the Eurasian Plate, the closure of the ancient Thethys Sea, and the uplifting of the Himalayan Range and the Tibetan Plateau.

The site consists of 15 protected areas (in eight geographic clusters) in the mountainous northwest of Yunnan Province and extends over a total area of 1.698.400 ha, encompassing the watershed areas of the Yangtze (Jinsha), Mekong (Lacang) and Salween (Nu Jiang) rivers. The rivers pass through steep gorges, in places up to 3.000 m deep. At their closest the three gorges are 18 km and 66 km apart.

Our research work in this region was performed within the Slovene-Chinese project with Yunnan Institute of Geography from 18-29th October 2004. In the previous years most researches were oriented to the area around Kunming (Lunan) and SE from Kunming (Xichou, Qiubei, Guangnan) (Figure 1). Shilin, fengcong, fenglin, karst caves were studied (Knez & Slabe 2002; Šebela *et al.* 2004) and water tracing tests were performed (Kogovšek *et al.* 1997; Kogovšek & Liu Hong 2000). In the year 2004 it was the first time that the areas of NW Yunnan were visited and some thermal and non-thermal springs with tufa deposits related to active tectonics were studied.

TUFA DEPOSITS

Tufa as a general name covers a wide variety of calcareous freshwater deposits, which are particularly common in late Quaternary and Recent successions. Tufa is the product of calcium carbonate precipitation under a cool water regime and typically contains the remains of micro- and macrophytes, invertebrates and bacteria. The term travertine is restricted to all "freshwater" thermal and hydrothermal calcium carbonate deposits dominated by physico-chemical and microbial precipitates, which invariably lack in situ macrophyte and animal remains. Tufas are usually distinguishable from travertines, even in ancient deposits, by the comparatively high diversity of contained plants, including macrophytes, and animals (Ford & Pedley 1996).

In China's vast karst landscapes there are many tufa deposits. They are known in Sichuan, Guizhou, Guangxi and Tibet Provinces. Some of the tufa cascades in Guizhou are broadly comparable with the Plitvice barrages (Ford & Pedley 1996). Frančišković, Bilinski *et al.* (2003) analysed the tufa from Guangxi. One tufa sample originated in the Pleistocene, and the others in the Holocene.

The travertines in China are divided into two major geochemical groups: the meteogenes and thermogenes. The thermogenes are essentially hydrothermal deposits, where $CaCO_3$ is precipitated from high-CO_2 groundwaters. Most of this CO_2 comes from deep within the crust as a result of magmatic degassing or limestone decarbonation with DIC (dissolved inorganic carbon) values typically >>10 mM/l. They are usually found in tectonically and/or volcanically active regions (Pentecost & Zhang 2001).

Tibet, in spite of its cold dry climate and high altitude, has a scatter of tufa deposits, mostly either calcareous crusts on colluvium or associated with geothermal springs (Waltham 1996).

TECTONIC SITUATION

Tectonic development of the SE Asia includes the Indian subcontinental collision, which represents the penetration of a rigid block (representing India) into layers of plasticine in a partly confined block (Asia) (Tapponnier *et al.* 1982). The Red River Fault zone (Figure 1) is the major geological discontinuity that separates South China from Indochina. Today it corresponds to a great right-lateral fault, following for over 900 km the edge of four

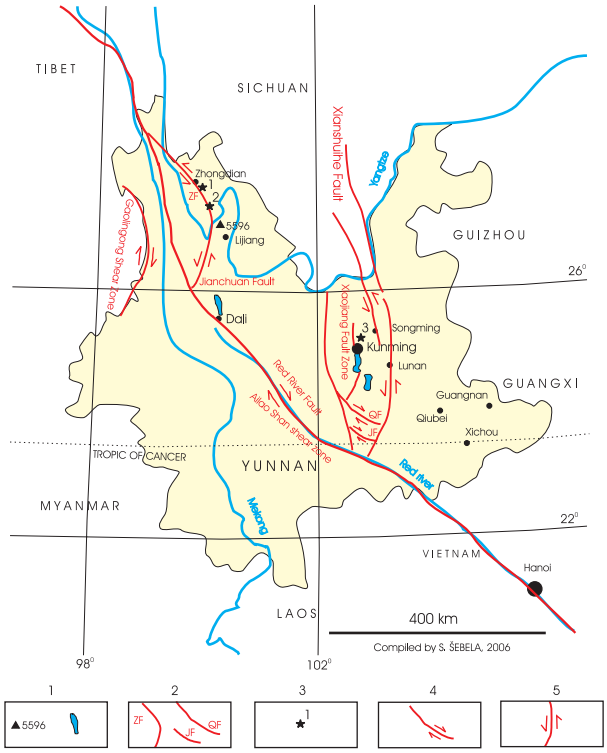

Fig. 1: Tectonic situation of Yunnan (after Burchfield & Wang 2003). 1 = Yulong Snow mountain 5596 m above sea level; lake, 2-ZF = Zhongdian fault, JF = Jianshui fault, QF = Qujiang fault, 3 = studied areas, 1 = Tiansheng Qiao and Xiageiwenquan springs, 2 = Baishuitai tufa deposits, 3 = springs north of Kunming, 4 = right-lateral slip along the fault, 5 = left-lateral slip along the fault.

Slika 1: Tektonske razmere Yunnana (po Burchfield & Wang 2003). 1 = Yulong Snow mountain 5596 m nad morjem; jezero, 2-ZF = Zhongdian prelom, JF = Jianshui prelom, QF = Qujiang prelom, 3 = raziskovana mesta, 1= izviri Tiansheng Qiao in Xiageiwenquan, 2 = Baishuitai ponvice, 3 = izviri severno od Kunminga, 4 = desni zmik ob prelomu, 5 = levi zmik ob prelomu.

narrow (<20 km wide) high-grade gneiss ranges that together form the Ailao Shan-Red River metamorphic belt (Leloup *et al.* 1995).

The movement along the Red River Fault has been dominantly right lateral since the close of the Tertiary. The best evidence comes from offsets of tributary streams of up to 5-6 km in the last 2 to 3 Ma (amounting to slip rates of 2-5 mm/yr). No significant earthquake has occurred along the fault in the last 2000 years (Allen *et al.* 1984). Tapponnier *et al.* (1982) surmise reversal of movement on the Red River Fault from the initial left-lateral sense during the first 20 to 30 Ma following the onset of the Indian collision. A different regional stress pattern now favors adjustment by dextral slip. The orientation of the fault is consistent with N-S shortening and E-W extension.

Geological relations near the NW termination of the Ailao Shan suggest the Red River fault had a minimum of 14 – 48 km of right-lateral displacement in pre-Pliocene (and presumably post -17 Ma) time and only 5-6 km of displacement in Quaternary time (Allen *et al.*, 1984; Wang *et al.*, 1998). Active right-lateral displacement on the eastern part of the Red River fault zone is interpreted to be caused by a segment of the fault zone being rotated counterclockwise by shear related to the left-lateral Xiaojiang fault system (Wang *et al.* 1998).

Stating that the Red River fault has been displaced by the Xiaojiang fault, it can be concluded that with respect to its present kinematics, the eastern part of the Red River fault does not accommodate large motions nowadays (Michel *et al.* 2000). The northwest-striking Jianshui and Qujiang faults (Figure 1) and probably the Zhongdian fault show evidence for different amounts of middle Cenozoic (pre-Pliocene and post-early Paleogene) left-lateral displacement that range from 6-25 km. The age and orientation of the left-lateral faults suggest that the faults are related to a regional deformational event associated with important left-lateral shear on the Ailao-Shan shear zone (Burchfiel & Wang 2003).

The Zhongdian fault (Figure 1) appears to have undergone only left-lateral displacement, some of which may be middle Cenozoic in age and some post-Miocene in age. Active displacement on the Zhongdian fault is interpreted to mark the eastern boundary for a small crustal fragment that rotates clockwise around the eastern Himalayan syntaxis (Burchfiel & Wang 2003).

Active right-lateral movement on the Jianshui fault (Figure 1) can be documented by numerous geological (offset structures) and geomorphic (deflected rivers and pull-apart basins) features. Active right-lateral displacement of the Quijiang fault is demonstrated by numerous scarps and offset Holocene feature and seismic activity (Burchfiel & Wang 2003).

SE of Zhongdian the Zhongdian fault passes through a series of basins filled with Quaternary sediments and the analysis suggests left-lateral stream deflections indicating the fault is active. The fault bends south at the Jinsha River and merges with the active left-lateral Jianchuan fault (Burchfiel & Wang 2003).

Quaternary basins and lakes north of Dali and within the southern part of the Xiaojiang fault zone are areas of local active extension (Wang & Burchfiel 2000). Only the Jianshui fault and possibly the Quijiang fault contain evidence for right-lateral reactivation of older left-lateral faults (Burchfiel & Wang 2003). The Xiaojiang fault system is at least 2-4 m.y. old, and possibly as old as 6-8 m.y., which suggests rapid right-slip did not begin on the

Quaternary Jianshui and Quijang faults until left-lateral shear within Xiaojiang fault system was well underway (Burchfiel & Wang 2003).

The Pliocene-Quaternary sedimentary fill in pull-apart basins associated with left-lateral Xianshuihe-Xiaojiang fault system indicated that this fault system was initiated by at least 2-4 Ma (Wang *et al*. 1998).

Kunming is moving due south with respect to Sundaland-South China indicating sinistral movement along the Xiaojiang fault system with a rate of 11 ±4 mm/yr. The Xianshuihe-Xianjiang fault system suffers pure sinistral strike slip faulting in its central part with respect to South China (Michel *et al.* 2000).

SEISMICITY

In the broad sense, strike-slip faults and earthquakes in SW China result from the eastward motion of the Earth's crust that is driven by the collision of the Indian and Eurasian continental plates beneath the Himalaya Mountains and the Tibetan Plateau to the west.

There is an obvious difference between the southern segment and northern segment of the Red River Fault from the viewpoint of modern seismicity. The most disastrous earthquakes occurred in the northern segment. Feigl *et al*. (2003) report that the Red River Fault did not slip faster than 1 or 2 mm/yr between 1994-2001 near Thác Bà, Vietnam.

A strong earthquake occurred in Lijiang area in Yunnan Province on February 3, 1996 (M = 7.0). The epicenter was determined to be in the seismically active region of the Hengduan mountains, which belong to the Alpine-Himalaya seismic belt.

Kunming is situated in the middle and southern part of seismically active Xiaojiang-Fault. In the year 1833 earthquakes (M = 8.0) were located in the area of Songmin (Figure 1).

The focal mechanisms of the 1966 earthquakes on the N-S-striking Xiaojiang fault imply left-lateral slip along it. A normal component of slip on the roughly N-S faults south from Kunming has created several Quaternary half-grabens, some of them filled by lakes (Tapponnier & Molnar 1977).

An earthquake of M = 7.7 occurred on the Quijiang fault in 1970 (Tunghai earthquake). The event produced a 60-km-long surface break and with a maximum right-lateral displacement of 2,7 m (Liu *et al*. 1988; Ma, 1989).

SPRINGS NORTH FROM KUNMING

Upper Devonian, Carboniferous and Permian shallow-water carbonates build the south China tower karst, south from Kunming. Near Kunming basalt rock is interbedded with the Upper Permian limestones.

Within the frame of the fieldwork the accumulation lake and Quinglongtan spring (Figure 2) north from Kunming were studied on 21st October 2004. The water from several springs is lead to a common channel that runs into the accumulation lake that was made for irrigation and water supply of Kunming. The springs are located in the wider zone of Xaojiang fault (Figure 1), which is still tectonically active.

The measured temperature and conductivity (SEC) of the three main springs showed that the water from the springs belong to the same source (temperature 14.7°C and SEC 277 μS/cm). The water in the accumulation lake was warmer (19.4°C), while the SEC measurement was within the values of the Quinglongtan spring. The carbonate concentration in accumulation lake and in the springs was low; just 135 mg $CaCO_3$/l (2.7 mekv/l) what means it was a little bit lower than total hardness (146 mg $CaCO_3$/l or 2.92 mekv/l, Figure 3). In Tianshengan area we measured such low values of hardnesses in karst springs at high hydrological conditions (Kogovšek 1998).

The phosphate concentration in accumulation lake and in the spring was under the detection limit of the method (<0,01 mg PO_4^{3-}/l), the nitrate concentration was 4,6 or 4,4 mg NO_3^-/l, what shows good water quality.

Fig. 2: Qinglongtan spring (one of the several springs) north from Kunming (photo by J. Kogovšek).

Slika 2: Qinglongtan izvir severno od Kunminga (foto J. Kogovšek).

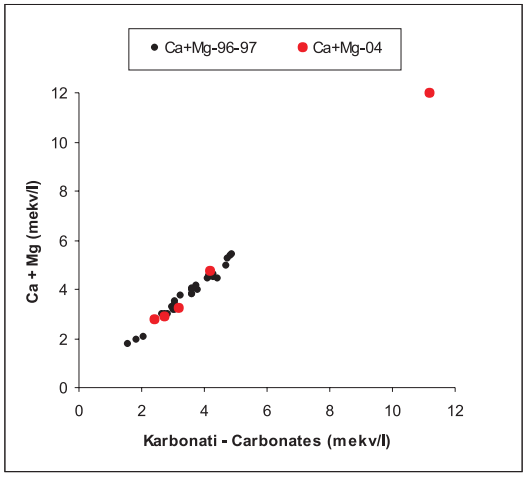

Fig. 3: Total and carbonate hardness of sampled springs in year 2004 and sampled karst waters in Tianshengan area in the years 1996 – 97 at different hydrological conditions.

Slika 3: Celokupna in karbonatna trdota vzorčevanih izvirov v letu 2004 in vzorčevane kraške vode na področju Tianshengan v letih 1996-97 v različnih hidroloških pogojih.

SPRINGS NORTH FROM LIJIANG

The water supply for the Lijiang derives from the nearer Zhenzhuquan spring (Figure 4), where the water is cached in a smaller lake that is regulated for tourism. Part of the water is accumulated into the channels that run through the Lijiang town. On the principal spring there is a pumping area (Figure 5) that is still used for water supply of the Lijiang. During our visit on the 24th October 2004 we met many natives who come to take the water from the spring. The water temperature was 14.8°C, SEC 370 µS/cm, carbonate hardnesses 158 mg $CaCO_3$/l (3,16 mekv/l), and the total hardness 162 mg $CaCO_3$/l (3,24 mekv/l). These measurements fall well with characteristics of groundwater and karst springs in Tianshengan area near Stone forest (Kogovšek *et al.* 1997, Kogovšek 1998). The water had good quality regarding the low chloride concentration (1 mg Cl^-/l), the nitrate concentration (1,3 mg NO_3^-/l), and the o-phosphates (< 0.01 mgPO_4^{3-}/l).

Fig. 4: Zhenzhuquan spring near Lijiang (photo by J. Kogovšek).

Slika 4: Izvir Zhenzhuquan pri Lijiangu (foto J. Kogovšek).

Yulong Snow Mountain (5596 m) consists of Paleozoic carbonate rocks and in the eastern area of Tertiary clastic rocks with marlites and calcareous rocks (Huang Chuxing 2004). Bai Shui He river that runs on the northern slope of the mountain showed the temperature of 9,6°C (23rd October 2004), low SEC (196 µS/cm), low carbonate hardness (109 mg $CaCO_3$/l or 2.17 mekv/l) and just 1 mg NO_3^-/l. The pH measurement showed value 8.2.

Fig. 5: The pumping area at Zhenzhuquan spring (photo by J. Kogovšek).

Slika 5: Črpališče na izviru Zhenzhuquan (foto J. Kogovšek).

Fig. 6: Xiageiwenquan thermal spring (photo by J. Kogovšek).

Slika 6: Termalni izvir Xiageiwenquan (foto J. Kogovšek).

SPRINGS SOUTH FROM ZHONGDIAN

About 42,2% of the Zhongdian County represents carbonate surface. Most of the carbonate rocks are from Devonian and Cretaceous. Some are from lower Permian and the middle and lower Triassic (Huang Chuxing 2004). In the wider zone of the Zhongdian fault near the town of Zhongdian and Yangtze river there are more tectonic depressions that are developed inside carbonate rocks but border also to other rocks as magmatic, sandstones and marbles. In such cases we don't deal with the true karst poljes. All depressions are related to active tectonic faults that are NW-SE oriented with active sinistral horizontal movements.

In the area of the active Zhongdian fault there are more springs (Figure 1). Some are thermal springs others have lower temperature and many of them precipitate tufa deposits. The spring waters are supposed to come from the depths. During our field studies we visited the Xiageiwenquan thermal springs, Tiansheng Qiao thermal spring, and Baishuitai tufa deposits. All three locations are tourist attractions.

Xiageiwenquan (Figure 6) is situated about 10 km east from the Zhongdian town and represents about 10 smaller and bigger thermal springs in the distance of 300 m. In the area there are older and younger still active travertine deposits. The area is built of Triassic limestones, sandstones and mudstones. Yuan Daoxian (2002) mentioned 9 springs with discharges between 0,5 to 1 l/s and temperature between 36,6 and 67,4°C. The SEC values of the springs were between 1676 and 2660 μS/cm.

Our measurements taken on the 26th October 2004 detected the temperature being between 48,3 and 66,8°C, and minimal discharges. The SEC values were from 1260 to 1510 μS/cm (measurements were performed with WTW instrument LF 90 at ref. temperature 20°C).

Tiansheng Qiao is situated some km south from Xiageiwenquan, along the active sinistral horizontal Suoge-Xuejiping fault on the western side of the Jinsha river. The fault is a deep and wide fault formed in the early stage of Permian but still active today. A hot liquid of the gabbro plasma effuses up through this fault. And it is the precondition to form tufa landscapes (Huang Chuxing 2004).

The attraction of the Tiansheng Qiao is the natural bridge with Shuodugang river running below it (Figure 7). The limestone natural bridge is 40 m high, 10 m wide and 15 m long. In the area there is also the Tiansheng Qiao thermal spring with travertine deposits. Huang

Fig. 7: Natural bridge of Tiansheng Qiao (photo by J. Kogovšek).

Slika 7: Naravni most Tiansheng Qiao (foto J. Kogovšek).

Chuxing (2004) speaks about sulphur springs, formed in different stages. The east side is from the earlier stage and the west side from the later stage. Travertine deposits at a relatively high speed with the estimated sedimentation 1-5 cm/year. By comparison with other in the surrounding areas the travertine of Tiansheng Qiao did not form earlier than 5000 years ago.

The thermal water of the Tiansheng Qiao spring is accumulated into the thermal pools (Figure 8) used by

Fig. 8: Thermal spring of Tiansheng Qiao is accumulated into the pools (photo by J. Kogovšek).

Slika 8: Termalni izvir Tiansheng Qiao je speljan v bazene (foto J. Kogovšek).

tourists. The Shuodugang river had (25th October 2004) the temperature of 10°C and low SEC (115 µS/cm). The water of the thermal spring had the temperature of 57,5°C and high SEC (1805 µS/cm), high carbonate concentration (20 mekv/l) higher chloride values (27 mg Cl^-/l) and the sulphate values of 26 mg SO_4^{2-}/l. High SEC value means high concentration of dissolved substances. The water probably contains other substances but our analyses were limited to the analyses mentioned above.

The scenic spot is the gathering place between the surface and underground water, and also the converging place of the N-S trending Suoge-Xuejiping fault and another E-W trending fault (Huang Chuxing 2004).

Baishuitai spring contain high mineralizated waters with regular temperatures. Baishuitai is situated about 20-30 km north from the Yangtze river. The area is built of Triassic rocks (limestones and sandstones) as well as of Permian rocks and Quaternary (delluvium) rocks.

Because the spring water is oversaturated it deposits dissolved mineral substances. In this sense the slopes are covered by mostly white tufa. The tufa dams and gours (Figure 9) are covering the areas of Lower and Middle Triassic limestones. The water resurges from different springs. The spring area is covered by deciduous trees, which are the source for pollution and also the food for

Fig. 9: Tufa gours of Baishuitai (photo by J. Kogovšek).

Slika 9: Baishuitai ponvice (foto J. Kogovšek).

algae growth. The springs are decorated with Buddhist symbols. Many people visit the spring area and walk over the tufa deposits what causes dams' destruction. The park administration is trying to protect the area.

The springs' temperature is between 11,1 and 13,3°C. The SEC measurements showed a little bit over 1000 µS/cm what means that the water has a lot of dissolved carbonates. Total hardness was 600 mg $CaCO_3$/l (12 mekv/l) and carbonate concentration 560 mg $CaCO_3$/l (11,2 mekv/l). The ratio Ca/Mg of the water was equal to 4,4, what shows that the Mg values are 4,4-times lower then the Ca and that the water is coming from the hinterland. The water had low nitrate and phosphate concentrations and 40 mg SO_4^{2-}/l of sulphates.

The temperature and conductivity measurements of the water in the gours along the water flow showed the

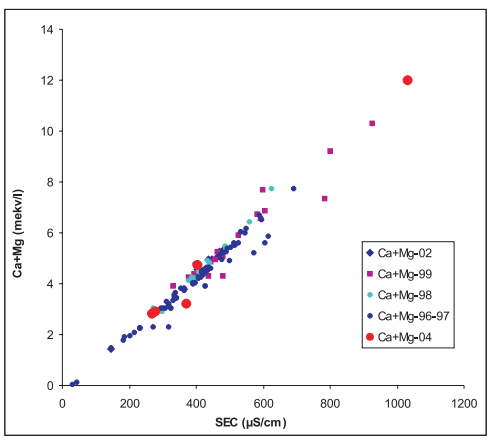

Fig. 10: SEC and total hardness of karst waters from different parts of Yunnan (Kogovšek 1998) and in the article mentioned springs.

Slika 10: Specifična električna prevodnost in celokupna trdota kraških voda iz različnih delov Yunnana (Kogovšek 1998) in v članku omenjenih izvirov.

increase of temperature and lowering of the SEC values, what is typical of intensive carbonate precipitation. At the bottom of the slope the water is led into the channel that runs to the nearest village where it is used for water supply and irrigation. Total hardness of this water was only 240 mg $CaCO_3$/l (4,8 mekv/l), with 210 mg $CaCO_3$/l belonging to carbonates (4,2 mekv/l). The ratio Ca/Mg was 3, suggesting mainly the calcium carbonate precipitation (from 1 liter of water up to 360 mg $CaCO_3$ was deposited) while magnesium remains in the solution. The same results were obtained in tufa precipitation at Podstenjšek spring in Slovenia (Kogovšek 2006). The lower concentration of sulphates (5 mg/l) compared with the values of the higher spring shows partial sulphate precipitation only. These are our first results, which should be expanded, as the nice and attractive gours need to be protected from numerous visitors. Liu Zai-Hua *et al*. (2004) reported about researches of geochemical indicators (saturation index, pH, CO_2 partial pressure) in calcite-precipitating stream and channel at Baishuitai.

Baishuitai tufa deposits in Yunnan are comparable with the Plitvice travertine dams in Croatia. They are probably thermogene (Pentecost & Zhang 2001).

CONCLUSIONS

The Yunnan Province lies on the eastern rim of the collision zone between the Indian plate and Eurasia. This region is characterized by complex Cenozoic structures and active seismotectonics.

The Quinglongtan spring (T = 14,7°C and low values of SEC, carbonate and total hardnesses) are situated north from Kunming. Similar values were detected in the area of Tianshengan, Yunnan at high hydrological conditions. The Zhenzhuquan spring near Lijiang had the same temperature but higher values of the SEC and hardnesses.

Quinglongtan and Zhenzhuquan springs and accumulation lake had low levels of phosphate (under 0,01 mg PO_4^{3-}/l) and low nitrate concentrations (from 1,3 to 4,6 mg NO_3^-/l) and are showing good water quality. The springs are situated inside the Xiaojiang fault zone along which sinistral horizontal movements are still active (Figure 1). Most probably they are karst springs.

In the wider zone of the Zhongdian fault between Zhongdian town and the Yangtze river there are more tectonic depressions, which are developed inside carbonate and non-carbonate rocks. In this sense they are not the true karst poljes. All depressions are developed inside NW-SE and N-S oriented active fault zone with sinistral horizontal movements.

In the wider zone of the Zhongdian fault there are more springs related to active tectonics. Tiansheng Qiao (T = 57,5°C) and Xiageiwenquan springs (T = 48,3 – 66,8°C) are thermal springs with tufa deposits. Baishuitai is very mineralized spring with lower temperature (T = 11,1 – 13,3°C), which deposits mostly calcium carbonate. The ratio of Ca/Mg decreases along the precipitation path, what means that Mg remains in solution. Also the sulphates are partly precipitating. Baishuitai travertines are probably thermogene (Pentecost & Zhang 2001).

Because carbonate tufas are very sensitive to water and climate Huang Chuxing (2004) performed the geomorphological investigations to provide scientific basis for the protection of tourist tufa resources of Tianshengqiao.

The study was performed within the Slovene-Chinese project with Yunnan Institute of Geography between 18-29th October 2004 and supported by Agencija za raziskovalno dejavnost RS.

REFERENCES

Allen, C.R., Gillespie, A.R., Han, Y, Sieh, K.E., Zhang, B. & Zhu, C., 1984: Red River and associated Yunnan province, China; Quaternary geology, slip rates, and seismic hazard.- Geological Society of America Bulletin 95, 686-700.

Burchfield, B.C. & Erchie, Wang, 2003: Northwest-trending, middle Cenozoic, left-lateral faults in southern Yunnan, China, and their tectonic significance.- Journal of Structural Geology 25, 781-792.

Feigl, K. L., Duong, Chi, Cong, Becker, M., Tran, Din, To, Neumann, K. & Nguyen, Quang, Xuyen, 2003: Insignificant horizontal strain across the Red River Fault near Thác Bà, Vietnam from GPS measurements 1994-2000.- Geophysical Research Abstracts, Vol. 5, 04707, European Geophysical Society.

Ford, T.D. & Pedley, H.M., 1996: A review of tufa and travertine deposits of the world.- Earth-Science Reviews 41, Elsevier, 117-175.

Frančišković Bilinski, S., Bilinski, H., Barišić, D. & Horvatinčić, N., 2003: Analysis of Karst Tufa from Guangxi, China.-Acta Geologica Sinica, vol. 77, no. 2, 267-275.

Huang, Chuxing, 2004: Characteristics and formation mechanism of tufa landscape at Tianshengqiao, Zhongdian County, Yunnan Province, China.- unpublished report, 1-8.

Knez, M. & Slabe, T., 2002: Lithologic and geomorphological properties and rock relief of the Lunan stone forests.- In: Gabrovšek, F. (ed.), Evolution of Karst: from Prekarst to Cessation. Ljubljana, Založba ZRC, 259-266.

Kogovšek, J., Petrič, M. & Hong, Liu, 1997: Properties of underground water flow in karst area near Lunan in Yunnan. In: KRANJC, Andrej (ed.). Tracer hydrology 97: proceedings of the 7th International Symposium on Water Tracing, Portorož, Slovenia, 26-31 May 1997. Rotterdam: A.A. Balkema, 255-261.

Kogovšek, J., 1998: Physical and chemical characteristics of groundwater of Tianshengan area (The wider area of the tracing experiments). South China Karst 1 (Zbirka ZRC, 19), Založba ZRC, 91-98, Ljubljana.

Kogovšek, J., & Hong, Liu, 2000: Water tracing test in the Tianshengan region, Yunnan – China at high water level.- Acta carsologica 29/2, 249-260, Ljubljana.

Kogovšek, J., 2006: Fizikalno-kemične značilnosti izločanja travertina – Primer Podstenjška (Slovenija). Acta carsologica, 35/1, 47-45, Ljubljana.

Leloup, P.H., Lacassin, R., Tapponnier, P., Schärer, U., Zhong, Dalai, Liu, Xiaohan, Zhang, Liangshang, Ji, Shaocheng, Phan, Trong Trinh, 1995: The Ailao Shan-Red River shear zone (Yunnan, China), Tertiary transform boundary of Indochina.- Tectonophysics 251, 3-84.

Liu, Y., Peng, X., Huang, Z., 1988: A deformational study after the Tonghai earthquake.- Journal of Seismological Research 4, 369-376.

Liu Zai-hua, Zhang Mei-liang, You Sheng-yi, Li Qiang, Sun Hai-long, Wang Jin-liang, Wu Kong-yun, 2004: Spatial and diurnal variations of geochemical indicators in a calcite-precipitating stream-Case study of Baishuitai, Yunnan.- Geochimica, vol. 33, no. 3, 269-278.

Ma, X., (Ed.) 1989: Lithospheric Dynamics Atlas of China.- Cartographic Publishing House, Bejing, China, 68 pp.

Michel, G.W., Becker, M., Angermann, D., Reigber, C. & Reinhart, E., 2000: Crustal motion in E- and SE-Asia from GPS measurements.- Earth Planets Space 52, 713-720.

Pentecost, A. & Zhang, Z., 2001: A review of Chinese travertines.- Cave and Karst Science Volume 28, number 1, 15-28.

Šebela, S., Slabe, T., Liu, Hong & Pruner, P., 2004: Speleogenesis of selected caves beneath the Lunan Shilin and caves of fenglin karst in Qiubei, Yunnan.- Acta Geologica Sinica, vol. 78, no. 6, 1289-1298.

Tapponier, P. & Molnar, P., 1977: Active faulting and tectonics of China.- J. Geophys. Res., 82, 2905-2930.

Tapponnier, P., Peltzer, G., Le, Dain, A.Y. & Armijo, R., 1982: Propagating extrusion tectonics in Asia: new insights from simple experiments with plasticine.- Geology 10, 611-616.

Yuan Daoxian, 2002: Karst Dynamic Systems of China. IGCP 299. Geological press, Beijing.

Waltham, A.C., 1996: Limestone karst geomorphology in the Himalayas of Nepal and Tibet.- Z. Geomorphol. N. F., 40 (1), 1-22.

Wang, E., Burchfiel, B.C., Royden, L.H., Chen, L., Chen, J. & Li, W., 1998: The late Cenozoic Xianshuihe-Xiaojiang, Red River, and Dali fault systems of southwestern Sichuan and Central Yunnan, China.- Geological Society of America Special Paper 327, 108.

Wang, E. & Burchfiel, B.C., 2000: Late Cenozoic to Holocene deformation in southwestern Sichuan and adjacent Yunnan, China, and its role in formation of the Southwestern part of the Tibetan Plateau.- Geological Society of America Bulletin, vol. 112, number 3, 413-423.

HIDROKEMIČNE ZNAČILNOSTI IN TEKTONSKI POLOŽAJ IZBRANIH IZVIROV V OSREDNJEM IN SZ YUNNANU, KITAJSKA

POVZETEK

Kitajska provinca Yunnan je tektonsko zelo zanimiva, še vedno je tudi tektonsko zelo aktivna, kar dokazujejo močni potresi. Leži na stičišču dveh velikih tektonskih plošč Azijske na severu in Indijske na jugu, ki se podrivata ena pod drugo. Prelom Ailao Shan – Red River je eden najbolj izrazitih prelomov na Kitajskem. Današnje gibanje ob prelomu je desnozmično za 2-8 mm na leto. Prelom najprej sledimo zahodno od mesta Dali, potem pa se nadaljuje proti JV Yunnana po dolini Rdeče reke (Slika 1). Sledimo ga vse do obale vietnamskega morskega zaliva Tonkin v Južnokitajskem morju.

Kunming se nahaja v Xiaojiang prelomni coni, znotraj katere se vršijo levi zmiki. V okviru terenskega dela 18. do 29.10.2004 smo si severno od Kunminga ogledali akumulacijsko jezero in više ležeči izvir Quinglongtan (Slika 1, točka 3), ki prispeva vodo v akumulacijo. To so zgradili za oskrbo Kunminga s pitno vodo in za namakanje. Meritve temperature in specifične električne prevodnosti (SEP) treh glavnih izvirov Quinglongtan so pokazale, da gre za isto vodo (temperatura 14,8°C in SEP 277 µS/cm). Voda v akumulaciji je bila toplejša (19,4°C), po SEP pa je le minimalno odstopala od vrednosti izvira Quinglongtan. Vsebnost karbonatov je nizka (135 mg $CaCO_3$/l) tako v izvirni vodi kot v akumulaciji in je bila le malo nižja od celokupne trdote (146 mg $CaCO_3$/l). V izviru in v akumulaciji je bila koncentracija fosfatov pod mejo detekcije (<0,01 mg PO_4^{3-}/l), koncentracija nitratov pa je bila 4,6 oz. 4,4 mg NO_3^-/l, kar kaže glede na omenjena parametra dobro kakovost vode.

SZ del Yunnanan je premrežen s številnimi prelomnimi conami. Severno do Dalija se od preloma Red River odcepi še ena močna prelomna cona. V skrajnem SZ delu Yunnana se ta prelom imenuje po tibetanskem mestu Zhongdian, ki leži na nadmorski višini nekaj čez 3.000 m. Prelom Zhongdian, ob katerem se vršijo levi zmiki, poteka vzporedno z dolino reke Yangtze, nato pa se obrne proti jugu, v smeri mesta Dali, kjer se razširi v širšo prelomno cono. Mesto Lijiang, ki je v UNESCO-vi kulturni dediščini od leta 1997 je 3.februarja 1996 stresel močan potres z magnitudo M = 7.0 po Richterju. Mesto se nahaja v širši prelomni coni generalne smeri sever-jug, ki povezuje Zhongdian prelom z Red River prelomom.

Mesto Lijiang se z vodo oskrbuje iz bližnjega izvira Zhenzhuquan (Slika 4), kjer so vodo zajezili v majhno jezerce, ki je turistično zelo obiskano. Del vode je speljan po kanalih skozi mesto, pred časom je bil to verjetno način oskrbe mesta z vodo. Na glavnem izviru je črpališče (Slika 5) za oskrbo mesta s pitno vodo. Ob našem obisku smo srečali številne domačine, ki so prišli na izvir po vodo. Dne 24.10.2004 je bila temperatura izvira 14,8°C, SEP 370 µS/cm, karbonatna trdota je bila 158 mg $CaCO_3$/l, celokupna pa 162 mg $CaCO_3$/l. Voda je imela nizko vsebnost kloridov, nitratov (1,3 mgNO_3^-/l) in fosfatov in je bila glede na te parametre dobre kakovosti.

Bai Shui He reka, ki priteka z območja Yulong Snow mountain (5596 m), je imela temperaturo le 9,6°C, nizko SEP (196 µS/cm) in nizko karbonatno trdoto (2,17 mekv/l), pH = 8,2 in je vsebovala le 1 mg NO_3^-/l.

V širši prelomni coni Zhongdian preloma med mestom Zhongdian in reko Yangtze je več tektonskih depresij, ki so razvite v apnencih, mejijo pa tudi na nekraške kamnine, kot so magmatske kamnine, peščenjaki. Tako ne gre vedno za prava kraška polja. Vse depresije so vezane na aktivne prelomne cone, ob katerih se vzdolž prelomov smeri SZ-JV vršijo levi zmiki.

V širši prelomni coni Zhongdian preloma se nahaja več izvirov, ki so močno mineralizirani in izločajo del raztopljenih snovi. Nekateri so termalni, drugi pa nimajo povišane temperature. Glede na raziskave kitajskih znanstvenikov gre za izvire, kjer voda prihaja na dan iz velikih globin. Izmed številnih izvirov je potrebno poudariti tri: naravni most s termalnim izvirom Tiansheng Qiao (Slika 1, točka 1), Xiageiwenquan (termalni izviri) (Slika 1, točka 1) in Baishuitai (ponvice) (Slika 1, točka 2). Vsa tri mesta so dobro obiskane turistične točke.

Xiageiwenquan se nahaja 10 km južno od Zhongdiana in obsega več termalnih izvirov, ob katerih najdemo starejše in mlajše plasti sige. Tudi ti izviri so vezani na aktivne tektonske prelome. Toplo vodo uporabljajo v terapevtske namene. Dne 26.10.2004 smo izmerili temperaturo na treh izvirih in ugotovili, da dosega voda od 48,3 do 66,8°C ter da vsebuje obilo raztopljenih snovi, saj je bila izmerjena količina raztopljenih snovi – SEP od 1260 do 1510 µS/cm.

Tiansheng Qiao se nahaja ob aktivnem levo zmičnem Suoge-Xuejiping prelomu na zahodni strani reke Jinsha. Naravni most (Slika 7), pod katerim teče reka Shuodugang, je zgrajen iz apnenca in je 40 m visok, 10 m širok in 15 m dolg. Neposredno ob naravnem mostu je termalni izvir Tiansheng Qiao, ki izloča travertin. Odlaganje travertina naj ne bi bilo starejše kot 5.000 let.

Voda termalnega izvira Tiansheng Qiao je imela 25.10.2004 temperaturo 57,5°C, zelo visoko SEP (1805 µS/cm), visoko vsebnost karbonatov ter povišane vrednosti kloridov in sulfatov. Verjetno vsebuje še številne druge snovi, vendar so bile naše meritve in analize omejene le na zgoraj omenjene parametre. Topla voda z izvira odteka v bazen v sklopu »toplic« (Slika 8), kjer ponujajo različne terapevtske usluge. Neposredno ob bazenu tekoča reka Shuodugang je imela tedaj temperaturo 10°C in nizko SEP.

Tudi **Baishuitai** izvir je vezan na aktivno tektoniko. Ker je voda na izvirih prenasičena, izloča ob polzenju po pobočju raztopljene mineralne snovi. Tako je celotno pobočje pokrito z belo prevleko, ki ga krasijo manjše in tudi zelo velike ponvice (Slika 9). Ponvice so se oblikovale na širšem področju spodnje in srednje triasnega apnenca. Voda izvira v več izvirih, del pa je priteka po manjšem kanalu iz višjega izvira. Izvirno področje je delno poraslo predvsem z listavci, tako da je odpadlo listje vir onesnaževanja oz. vir hrane za različne alge, ki motijo belino pobočja. Svoje dodaja tudi turistični obisk. Očitno se tega do določene mere zavedajo upravljalci, saj so na nekaj mestih napeli vrvi, ob našem obisku pa so se zanimali kaj merimo.

Meritve so na več izvirnih točkah pokazale, da je temperatura izvirov med 11,1 in 13,3°C. Meritve SEP, ki so dale vrednosti celo nekoliko nad 1000 µS/cm, so nakazale, da izvirna voda vsebuje veliko raztopljenih karbonatov, kar so potrdile kasnejše analize vode. Celokupna trdota je znašala 600 mg $CaCO_3$/l, od tega je bilo kar 560 mg $CaCO_3$/l karbonatov. Razmerje Ca/Mg vode je bilo enako 4,4. Voda je imela nizke vsebnosti nitratov in fosfatov, vsebnost sulfatov pa je bila 40 mg SO_4^{2-}/l. Meritve temperature vzdolž pobočja in v ponvicah so pokazale segrevanje vode in upadanje SEP in razmerja Ca/Mg ter vsebnosti sulfatov, iz česar smo sklepali na intenzivno izločanje kalcijevega karbonata ter delno sulfatov, medtem ko magnezij ostaja v raztopini. Podobno smo ugotavljali tudi za izvir Podstenjšek v Sloveniji. Do dna pobočja se je iz enega litra vode izločalo povprečno 360 mg $CaCO_3$. Voda je speljana nato po kanalu do bližnje vasi, kjer jo uporabljajo kot pitno vodo in vodo za namakanje.