Environ Geol (2006) 51: 83–90
DOI 10.1007/s00254-006-0306-1

ORIGINAL ARTICLE

Guangcai Wang
Chenglong Liu
Jihua Wang
Wuzhou Liu
Peiren Zhang

# The use of soil mercury and radon gas surveys to assist the detection of concealed faults in Fuzhou City, China

Received: 7 January 2006
Accepted: 12 April 2006
Published online: 6 May 2006


G. Wang (✉)
School of Water Resources
and the Environment, China University
of Geosciences (Beijing), 29 Xueyuan
Road, Beijing 100083, China
E-mail: wanggc@pku.edu.cn
Tel.: +86-10-62009346
Fax: +86-10-62326900

G. Wang · C. Liu · J. Wang
W. Liu · P. Zhang
Institute of Geology, China Seismological
Bureau, Deshengwenwai Street,
Beijing 100029, China

**Abstract** Soil gas approaches have been proven useful for detecting buried faults in field survey. How about their applicability in urban area? A trial soil gas survey has been conducted in an attempt to evaluate this in Fuzhou City, Southeastern China. The detection was performed by measuring the adsorbed mercury, free mercury and radon gases in soil in the sites such as crop soil, refilled soil and those with shallow groundwater levels. The resulting distributions show that anomalous concentrations of soil gases over faults are generally two to four times as much as those in the surrounding areas. The locations of peak values of absorbed and free mercury could possibly be applied to assist to determine the trend of faults. The background values of free mercury seems to be more stable and the anomalous zones narrower than those of radon gas, therefore, the free mercury method seems to be good for detection at this area, especially in those sites with shallow groundwater levels. The false gas anomalies may occur in such a site as refilled with external soil, refilled pond and abandoned construction bases.

**Keywords** Soil gas · Concealed fault · Urban area · China

## Introduction

The survey and precisely localizing of active faults beneath cities is one of key procedures for an ongoing China's program, which is aimed to assess the activity of faults and earthquake risk in some urban areas in China. Soil gas geochemistry as an aid for detecting faults has been involved in the program because of its low cost, ease of use and validity at field investigation (King et al. 1996; Ciotoli et al. 1998, 1999; Pauwels et al. 1999; Ajayi and Adepelumi 2002; Dehandshutter et al. 2002; Lewicki 2002). Unlike those at field sites, however, the detection of active faults in urban area is more complicated as there are additional unfavorable circumstances and conditions such as refilled soils, various surface and underground constructions etc. Among them, the disturbed soils could be a great concern as the uncertainties may occur when conducting the detection in those sites. Therefore, it appears that the applicability of detecting faults by geochemical approach in urban area still needs to be proven, though there have been a few of case studies (Guo et al. 1991; McCarthy and Kiilsgaard 2001). For this purpose and for further applications in other urban areas, a trial geochemical detecting for active faults has been conducted in Fuzhou City, Fujian Province, Southeastern China.

Fuzhou city is located at the Fuzhou basin. The Fuzhou basin is in the collision zone of Eurasia-Philippine Sea plates and is a tectonically active area. The area is underlain by volcanic clastic rocks of Jurassic age ($J$) with the depth of more than 1,300 m and sandstones of Cretaceous age ($K$ > 1,500 m) in the southern part of the basin (the south of Wulongjiang River). The overlying strata are Quaternary sediments mainly gravel soil and boulder-bearing clay layers with largest depth of 65 m (Fujian Second Term of Hydrogeology and Engineering Geology Explorations 1985). In the past years, two main active fault systems, Bayi-Shanggan and

Tongkou-Hongshanqiao, were identified within the fault-bounded basin through air-photo, geomorphologic and field seism-geologic investigation, etc. (Fig. 1). Those studies also showed that the two fault systems consist of several parallel secondary faults in some sections (Seismological Bureau of Fujian Province 2001). The present study uses soil gas to locate the concealed segments of two active fault systems masked by unconsolidated lithologies. Totally 18 of traverses of soil gas survey (31 km length in sum) were conducted. The paper shows the results of some traverses in or near downtown where two or more soil gas methods were employed or the geophysical exploration data is available and evaluates the validity of geochemical approaches.

## Methodology and detecting

The methods employed for geochemical survey include the adsorbed mercury, free mercury and radon gases in soil, etc. The soil samples for adsorbed mercury were collected at a depth of 0.8 m at sites and brought to indoor for seasoning. Then, 20 mg of soil samples were weighed for adsorbed mercury analysis after they were ground and sifted. The free mercury gas samples were collected by drilling a steel probe into the ground to a depth of 0.8 m. One thousand cubic centimeters of mercury gas was withdrawn from that depth into a capture tube containing a golden coil. Both the adsorbed mercury and free mercury samples were analyzed by an instrument (RG-1) equipping with a heating furnace. Radon gas samples were mainly determined at the sites by a portable detector described by King et al. (1996), and repeatedly measured in one of traverses by higher resolution scintillation method (Wang et al. 2002).

In the study, free mercury was designed as a main item and the adsorbed mercury and radon gas as assistant items. Totally 18 traverses of free mercury gas surveying have been conducted, along with eight traverses of radon gas (Traverses $A_3$, $A_6$–$A_8$, $A_{7\text{-}1}$, $B_1$ and $B_4$–$B_5$) and one traverse of adsorbed mercury gas (Traverses $A_3$) surveying (Fig. 1). The traverses for those three methods were overlapped and generally the lengths of the adsorbed mercury and radon gas measurement were shorter than those of free mercury. The traverses were arranged capable of controlling the inferred entire segments within the basin, as soil gas geochemical approach is considered as a favorite for scanning survey and for providing targets for geophysical exploration. Mercury and radon gases were investigated by the measurement along traverses fundamentally perpendicular to active fault segments. Soil gases were sampled along traverses at about 10-m intervals, and the distances were shortened to 1 m when the gas anomalies appeared. On average, about 60 samples per day were collected and/or analyzed.

The traverses were along or parallel to roads and trails, and covered different sites mainly including: (1) crop soil sites (paddy-, vegetable- and forest-field; ten traverses); (2) refilled soil sites (street green belts, six traverses); and (3) those with higher shallow groundwater levels (two traverses). Each traverse was designed possibly to be in the same sites (soil types) to try to keep the background accordant. The applicability of geochemical approach in urban area was one of the main concerns. Six of traverses (Sites 2) were distributed in afforesting zones and grassplots beside concrete roads in downtown area ($A_4$–$A_7$, $B_1$–$B_2$). Those sites were generally disturbed and refilled with 1-m thick soils for more than 4 years, and are the typical places available for soil gas surveying in urban area. The survey was started along traverses at the ends of active segments, where the sites mainly are crop soil and considered being similar to those in field, and gradually shifted to urban area. In this way, it is easier to get controlling points and identify the anomalous gases concentrations at the traverses between the ends, by considering the orientations of faults.

## Results and discussion

Data processing was conducted and anomalous threshold was determined to be $n + 2\sigma$ for each traverse (mean + 2 × standard deviation), considering scanning all possible fault anomalies and providing the targets for geophysical survey. The parameters of $n$ and $\sigma$ were computed for each individual traverse based on their own data, in order to mitigate the errors caused by background dispersion. The background values range from 0.0389 to 0.0735 ng/l for free mercury and from 2.896 to 12.985 Bq/l for radon gas, respectively. The smooth methods were used to draw the gas concentration curves and anomalous free mercury thresholds were displayed in the following figures.

### Traverse A3

This traverse is in the crop soil beside cement road at Xindian Town. All three kinds of geochemical methods were conducted in the traverse. Four anomalous free mercury concentration zones were identified as shown in Fig. 2 (A–D) and the higher concentrations appeared in the inferred faults (A, D).

It seems that anomalous concentrations of free and absorbed mercury appeared in pairs (A–A′, B–B′, C–C′, D–D′) and the locations of two peak values for most of pairs are not exactly the same: the peak locations of absorbed mercury are deflective to the right side of those of free mercury's. According to the previous studies, for individually distributed single fault, the location of the peak of free mercury usually reflects the projective

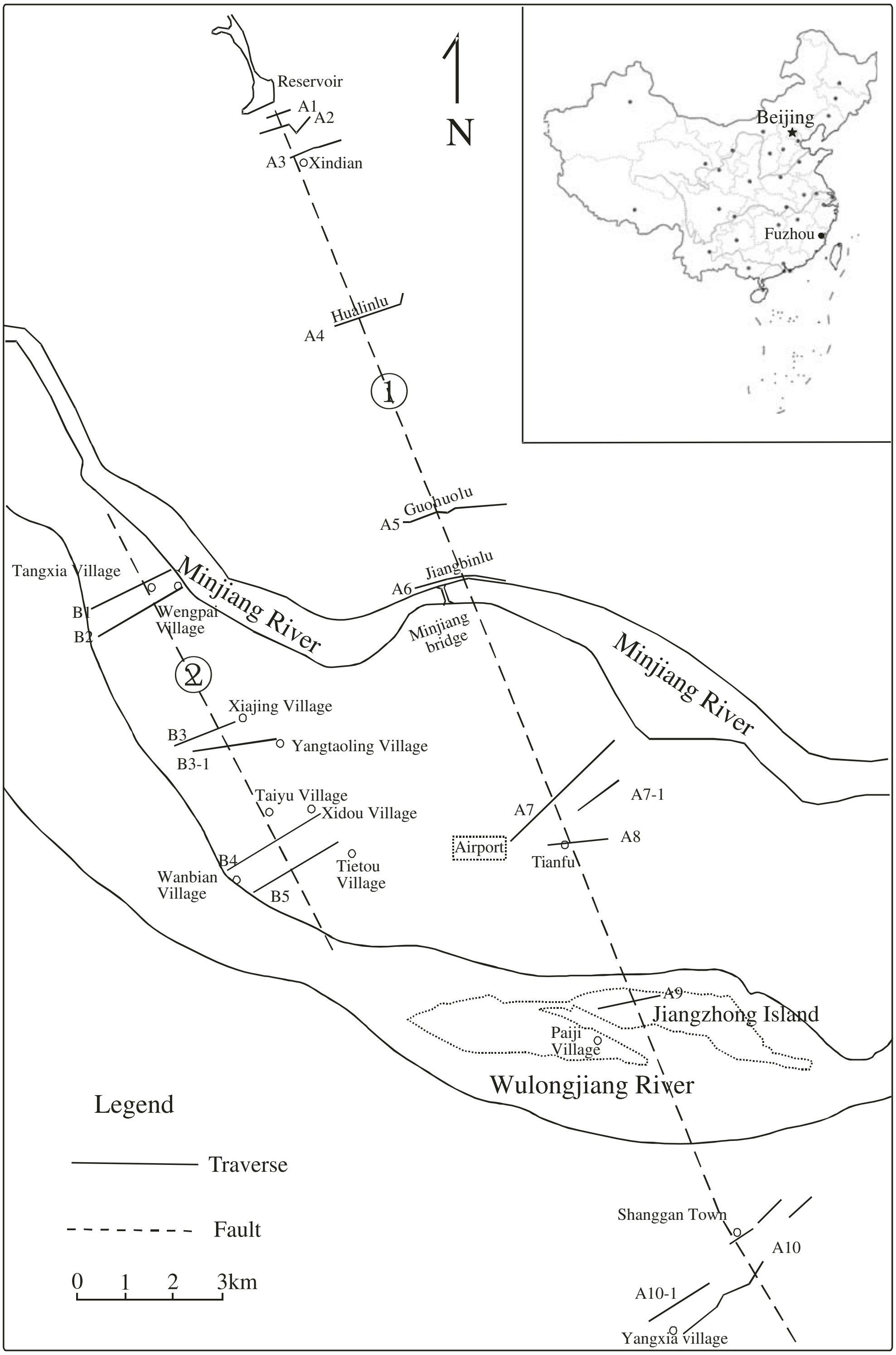


**Fig. 1** Locations of the sampling traverses and the faults determined by geology studies

location of upper end of fault on the ground surface (Wang et al. 1994); further, here it is supposed that the peak locations of absorbed mercury were "shifted" towards upper sides of faults with respect to those of free mercury's. That means those faults or fractures implied by gas anomalies seem to be inclined to NE. This is in accordance with the information of geology exploration, which delineated the faults and especially fractures with

NE trend were very developmental in those place (Fujian Second Term of Hydrogeology and Engineering Geology Explorations 1985). The possible reason for such a phenomenon is because of difference of fracture distributions, i.e., the fractures were more developmental in upper side than in lower side of faults (Fujian Second Term of Hydrogeology and Engineering Geology Explorations 1985). The higher density fractures provided more channels for gas bearing and migration in both vertical and horizontal directions beneath the overlying strata, and more mercury was adsorbed by soils in upper side accordingly.

It is also found that the peak locations of a pair (D–D′) are embedded: the location of free mercury anomaly is within that of absorbed mercury, and the breadth of absorbed mercury anomaly is much wider than that of free mercury. This is most likely to appear in three cases: fault with shallow upper end or bigger dip, or a place where different faults were intersected. In those cases, the mercury could more possibly migrate towards and adsorbed by soils in both sides of faults. In the present case, it indicates that faults with different strikes, NE–SW and NNW–SSE, were intersected in the place as determined by drilling exploration (Fujian Second Term of Hydrogeology and Engineering Geology Explorations 1985).

Concentrations of radon gas determined by portable detector and scintillation method are of good repeatability. It appears that the breadths and peaks of anomalous radon gas zones are wider and higher than those of free mercury zones. This phenomenon is often observed; and the more fluctuant and random distributions of radon gas were also observed especially when groundwater level is shallow (Wang et al. 1994; also see below). Those imply that radon gas seems to be more sensitive to faults than free mercury in same conditions, but more easily affected by environmental factors.

## Traverse A4

The traverse is in the afforesting zone between main concrete road and the sidewalk on the Hualin Street. Free mercury was measured in the traverse. The results of the free mercury and geophysical detecting are shown in Fig. 3. There are two free mercury anomalies in the traverse, which are corresponding to the faults $F_{a1}$, $F_{a2}$, $F_{a6}$ and possible, $F_{a5}$, determined by shallow seismic exploration (Liu et al. 2002). $F_{a1}$ and $F_{a2}$ are located in the inferred main faulting zone of Bayi-Shanggan fault system, where has a highest free mercury concentration distribution. The difference between two approaches is that the concentrations of free mercury are not anomalous over $F_{a3}$ and $F_{a4}$. It is tentatively attributed to the relative small scales of those two faults.

## Traverse A5

The traverse is in the afforesting zone between main concrete road and the sidewalk on the Guohuo Street. Two free mercury anomalies were detected. Compared with the result of shallow seismic exploration, higher anomalous concentration does not correspond with any fault (Fig. 4). Further investigation showed that there was a rearing pond in the place and refilled later when the street extended. Similar cases were found somewhere else (Wang et al. 2004). Whether the anomalous concentration is relative to the refilled pond is unknown and requires further study.

## Traverse A6

The traverse is by the Minjiang River and is in the grassplots in the Jiangbin Park along the Jiangbin Street.

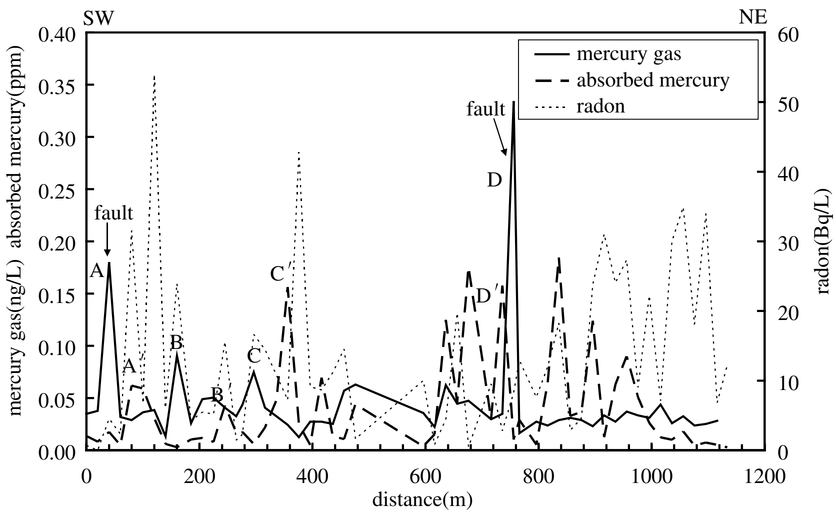


**Fig. 2** The distributions of gas concentrations in traverse $A_3$ (*the arrows* denote the locations of the faults determined by geology studies)

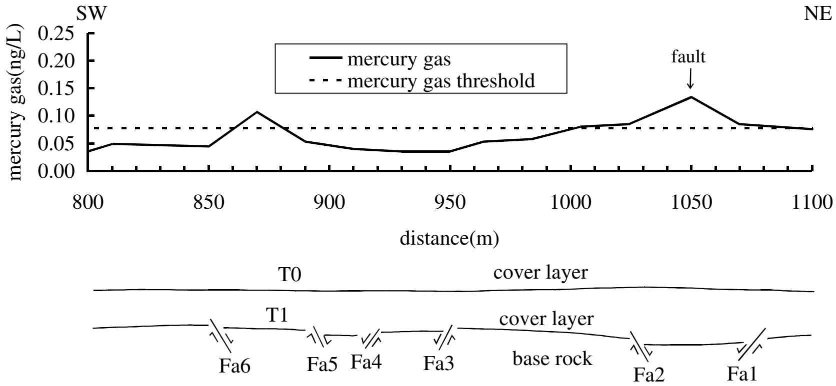


**Fig. 3** The results of mercury gas and shallow seismic detection in the traverse $A_4$ (*the arrow* over the gas concentration curve denotes the location of the fault determined by geology studies)

Free mercury and radon gas were measured in the traverse. Three anomalous free mercury zones were observed and their locations are comparable to those of faults detected by shallow seismic exploration and geological investigation (Fig. 5). The fluctuation of radon and free mercury concentrations is basically synchronous. However, the higher radon concentrations do not appear over the faults. It was found that the site was refilled by the red weathered/decomposed granite soil between 570 and 2,030 m in the traverse. The backfill soils may have higher radon concentration and this could be confirmed by the higher radon background values in the relevant part of the traverse (Fig. 5). It indicates that the refilled soil types and compositions could have the influence on the detection.

## Traverse A7

The site is in the grassplots and crop soil and was characterized by its shallow groundwater level (less than 1 m). One free mercury anomaly appeared over the faults and the shapes of radon and free mercury curves are similar to some extent. Nevertheless, the higher radon concentrations are inconsistent with the locations of the faults (Fig. 6). It suggests that the distribution of radon in soil could be strongly affected by groundwater and the great uncertainty may exist when conducting the detection in such sites (Wang et al. 1994).

## Traverse A8

The traverse is in the crop soil. It seems that the background values of the free mercury are different between two sectors bordered at 470 m in the traverse. The higher concentrations of mercury and radon appeared over the faults detected by the geophysical exploration (Fig. 7).

## Traverse B1

The traverse is in the afforesting zone and crop soil along the Lengzhou Street. Two free mercury anomalies were observed over the faults inferred from geology studies. The fluctuation of radon and free mercury concentrations is similar. However, the higher gas concentrations also appeared between 560 and 960 m,

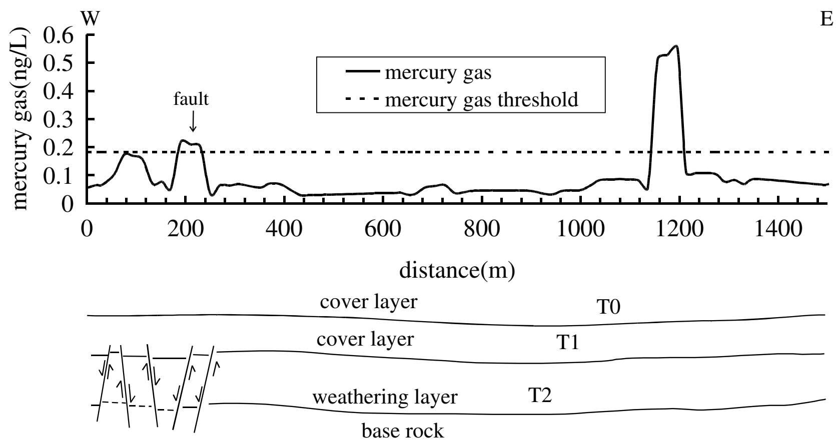


**Fig. 4** The results of mercury gas and shallow seismic detection in the traverse $A_5$ (*the arrow* over the gas concentration curve denotes the location of the fault determined by geology studies)

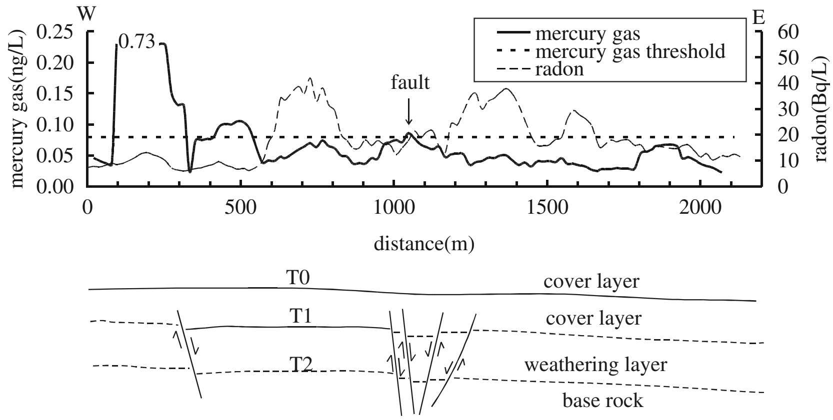


**Fig. 5** The results of gases and shallow seismic detection in the traverse $A_6$ (*the arrow* over the gas concentration curves denotes the location of the fault determined by geology studies)

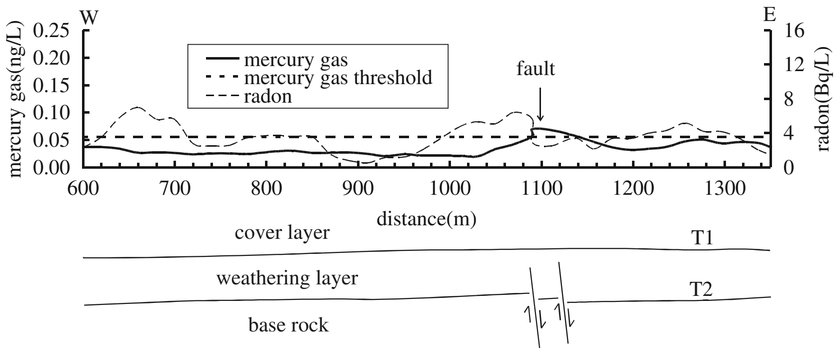


**Fig. 6** The results of gases and shallow seismic detection in the traverse $A_7$ (*the arrow* over the gas concentration curves denotes the location of fault determined by geology studies)

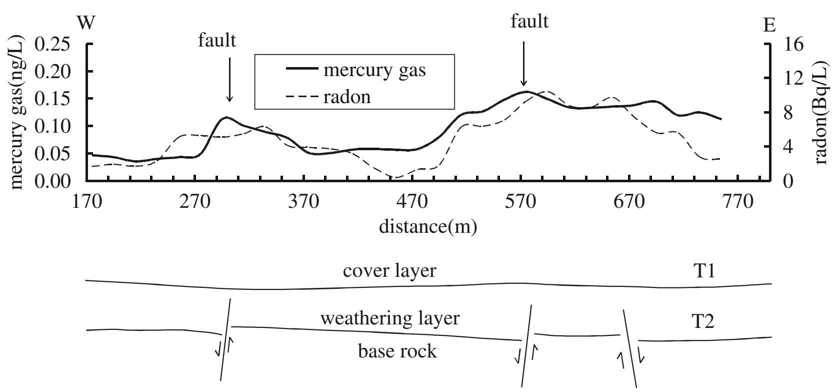


**Fig. 7** The results of gases and shallow seismic detection in the traverse $A_8$ (*the arrows* over the gas concentration curves denote the locations of faults determined by geology studies)

where the traverse passed through two abandoned construction bases (Fig. 8).

Traverse B4

The traverse is in the crop soil. The stable background concentrations and four groups of free mercury anomalies were observed in the traverse, and three of which seem to be responsible for the faults $F_{b1}$, $F_{b2}$, $F_{b3}$ and $F_{b4}$ of Tongkou-Hongshanqiao fault systems (Fig. 9; Liu et al. 2002). However, the implication of free mercury anomalies between 520 and 680 m in the traverse could not be proven by shallow seismic exploration. In combination with the locations of anomalous concentrations in neighboring traverses and the orientations, it appears that the group of anomalies is also true, and might be a geochemical signature of smaller

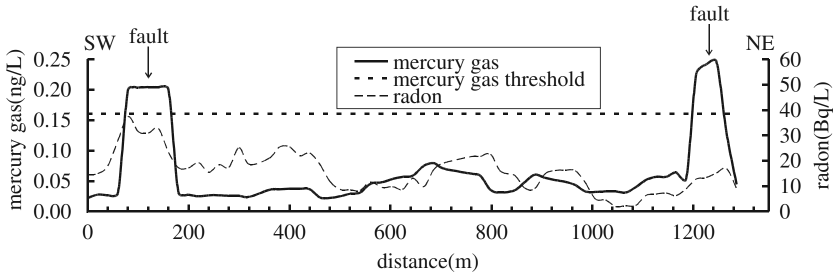


**Fig. 8** The distributions of gas concentrations in the traverse $B_1$ (*the arrow* denotes the location of fault determined by geology studies)

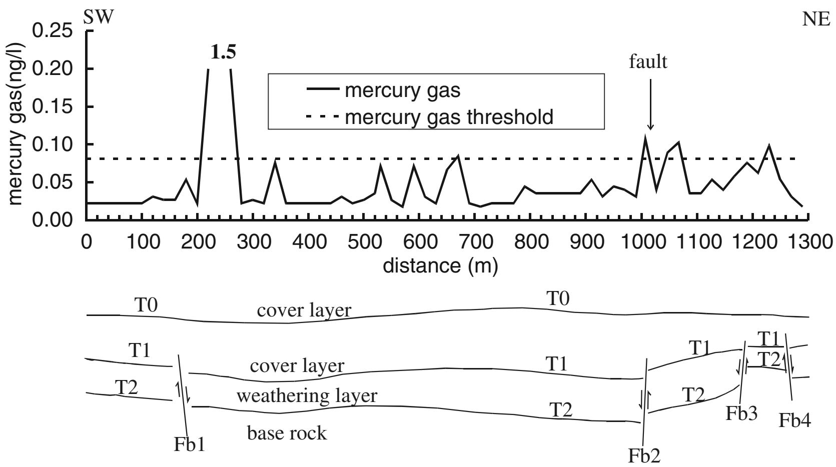


**Fig. 9** The results of mercury gas and shallow seismic detection in the traverse $B_4$ (*the arrow* over the gas concentration curve denotes the location of fault determined by geology studies)

faults and fractures. Because of shallow groundwater level, the gas bearing and migrating capacities are enhanced in those brittle deformation places, as simulated by laboratory tests (Etiope and Lombardi 1996).

The above-resulting distributions show that anomalous concentrations of the adsorbed mercury, free mercury and radon gases in soils were found in the traverses along two fault systems. Concentrations of most of those gases are two to four times higher over the fault systems than in the surrounding areas. It is noticeable that a group of joint gas anomalies may originate from the same fault. On the contrary, a wide anomaly could be a reflection of several closely distributed faults.

Geochemical surveying was one of the approaches and implemented based on the geological studies and prior to geophysical exploration in the project. As compared with the results of other methods, most of the free mercury anomalies corresponded with the faults determined by geophysics exploration and/or geology studies, it shows that geochemical surveying is a useful aid for detecting faults in urban area. Nevertheless, the additional uncertainties of the results exist in urban circumstances. The false gas anomalies may occur at the sites such as those with refilled external soil, refilled pond, abandoned construction bases and those with shallow groundwater level. Therefore, detection at those sites must be carefully conducted.

## Conclusions

A trial soil gas survey for detecting active faults was carried out in Fuzhou city, China. The traverses mainly passed through the green belts where are mostly available for gas survey in downtown area. Anomalous soil gas concentrations were found over faults. It confirms the applicability of soil gas method to detect faults in urban area. The peak locations of absorbed mercury appear to be deflective to upper side of faults, with respect to those of free mercury's, this feature can be applied to determine fault's trend. The anomalous concentrations zones of free mercury are generally narrower, and background concentrations are more stable than those of radon gas, indicating that free mercury is suitable for detection at the area, especially in those sites with shallow groundwater level. The false gas anomalies may occur at the special urban conditions, it is suggested that the types and thickness of backfill soils and the use of original sites should be investigated when conducting gas detection in urban area.

**Acknowledgements** The study was a part of Urban Active Fault Experimental Exploration Project. Field assistance from Zhao Zhiwei and Huang Jiazhi, Fujian Seismological Bureau, is gratefully acknowledged. The manuscript was considerably improved by technical reviews from two anonymous referees. This work was supported by grants from China National Development and Reform Commission (No. 2001977 and No. 20041138).

## References


Ajayi T, Adepelumi A (2002) Reconnaissance soil-gas radon survey over the faulted crystalline area of Ile-Ife, Nigeria. Environ Geol 41(10):608–613

Ciotoli G, Guerra M, Lombardi S, Vittori E (1998) Soil gas survey for tracing seismogenic faults: a case-study in the Fucino Basin (Central Italy). J Geophys Res 103(B10):23781–23794

Ciotoli G, Etiope G, Guerra M, Lombardi S (1999) Soil-gas, fracture field and photogeological survey for detecting concealed faults in the Oftanto clay busin. Tectonophysics 301(3/4):321–332

Dehandshutter B, Bobrov VA, Hus R, Astakhov NE, Androsova NV (2002) Radon anomalies as evidence for activity of the Sayan fault in northern Lake Teletskoe (Gorny Altai). Sci J Geol Geophys 43(2):120–133

Etiope G, Lombardi S (1996) Laboratory simulation of geogas microbubble flow. Environ Geol 27(3):226–232

Fujian Second Term of Hydrogeology and Engineering Geology Explorations (1985) Report of explorations of Fuzhou geothermal field (in Chinese)

Guo YX, Wu SW, Wang CM, Wang HG, Yin SL (1991) Analysis of the fracture gas survey in Shanghai City and its adjacent areas. In: Wang CM, Li XH, Wei BL (eds) Applications of fracture gases survey to seismological sciences (in Chinese). Seismological Press, Beijing, pp 67–74

King CY, King BS, Evans WC, Zhang W (1996) Spatial radon anomalies on active faults in California. Appl Geochem 11(4):497–510

Lewicki JL (2002) Soil carbon dioxide flow associated with the San Andreas and Calaveras faults, California. A thesis in geoscience, downloaded file

Liu BJ, Fang SM, Zhang XK (2002) Report of trial detecting for active faults by shallow seismic exploration in Fuzhou City (in Chinese)

McCarthy JH, Kiilsgaard TH (2001) Soil gas studies along Trans-Challis fault system near Idaho City, Boise County, Idaho, U.S. Geological Survey Bulletin 2064 LL, downloaded file

Pauwels H, Baubron JC, Freyssinet P, Chesneau M (1999) Sorption of metallic compounds on activated carbon: application to exploration for concealed deposits in southern Spain. J Geochem Explor 66:115–133

Seismological Bureau of Fujian Province (2001) Map of regional seismo-geological structures of Fujian Province and instructions (in Chinese)

Wang JH, Wang L, Sun FL (1994) A study on mercury geochemistry indicators of buried fault's characters (in Chinese). Earthq Res China 10(2):112–122

Wang GC, Wang JH, Liu CL, Liu WZ, Zhang PR (2002) A trial geochemical prospecting for buried active faults in Fuzhou City (in Chinese). Seismol Geol 24(4):593–600

Wang GC, Wang JH, Liu CL, Zhang PR (2004) Report of geochemical detecting for buried faults in Ningbo City, China (in Chinese)