A Structure-controlled Model for Hot Spring Exploration in Taiwan by Remote Sensing

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Abstract: Hot Spring Law of Taiwan was passed in legislative assembly on 3 June 2003. Hot springs would become one of the most important natural resources for recreation purposes. Both public and private sectors will invest large amount of capital in this area in the near future. The value of remote sensing technology is to give a critical tool for observing the landscape to find out mega-scaled geological structures, which may not be able to be found by conventional approaches. The occurrences of the hot springs in Taiwan are mostly in metamorphic and sedimentary rocks, other than in volcanic environments. Local geothermal anomaly or heat of springs transfer by liquid convection other than conduction or radiation. The deeply-seated fractures of hard rocks are the conduit of the convection of hot water, which could be as deep as 3000 meters in a hypothetical model of Taiwan. Clues to find outcrops of hot spring can be obtained by a structure-controlled model deduced by geological lineaments observed by satellite images and stereoscopic interpretation of aerial photographs. A case study conducted in Eastern Taiwan will be demonstrated.

Keywords: hot springs, geological model, remote sensing, photo-interpretation

1. Introduction

Hot spring is a non-renewable natural resource with characteristics of rarity, uniqueness, exhaustiveness. The Tourist Promotion Committee of Executive Yuen of Taiwan initiated a "Hot spring development program" in 1999 aiming to improve the utilities of the selected 18 hot spring areas of Taiwan and thus to invoke capital investment by private sectors. On the approval of Hot Spring Law, the Hot Spring Association of Taiwan declared that more than US$20 billions would be devoted to hot spring tourism by their members in the next two years. The synoptic and stereoscopic nature of remotely-sensed images are applied to observe geological structures which may be related to the outcropping of hot springs. And, the lineament model is subsequently applied to locate well-drilling sites, as will be discussed in this paper.

2. Genesis of Hot Springs

Two major types of occurrences of hot springs in Taiwan can be identified, e.g. volcanic type and non-volcanic type. A 20 % of the total 130 hot springs found so far are distributed in Tatun Volcano Group in Northern Taiwan. 80% of the hot springs are in areas of metamorphic and sedimentary rocks. Both volcanic and non-volcanic hot springs are strongly related to local geological structures, especially the cases for non-volcanic areas. Three elements are included in the model of hot spring genesis, e.g. the heat source, the water source and the path. Geological structures give the path for the heated water to travel from the depth to ground surface. And, thus, this is a process of convection of heat transfer, rather than conduction or radiation.

By thorium isotope dating, hot spring water is mostly with an age of more than 20000 years in the hydrological cycle from precipitation to underground water and then to the surface. This implies a deep circulation of ground water, which subsequently supports the structure-controlled model deduced by geological lineaments obtained from remotely-sensed images [1][2][3].

3. Occurrences of Hot Springs

In the study area of 65km by 55km, there are 23 natural hot springs. They are distributed in lithological types of non-metamorphism, low-grade metamorphism and high-grade metamorphism. This indicates no implications of lithological significance of the occurrences of hot springs (Fig.1), i.e. natural hot springs occur in all types of lithologies.

However, as depicted in Fig.2, a NW-SE and NE-SW tectonic trend is very obvious for the locations of these hot springs.

4. Lineaments and Tectonic Stress

It was observed that outcrops of hot springs in central Taiwan were located in places where 2 or more sets of lineaments traverse [4]. Lineaments are strain-features, which can be applied to a stress-strain ellipse model to assist the understanding of local tectonic movements [5][6][7].

With the assistence of 3D perspective view of SPOT image of the study area, lineaments were mapped as shown in Fig. 3. As shown in the rose diagram of Fig. 3, two conspicuous preferred-orientations of the lineaments are N45°E and N45°W. They are conjugate in a stress-strain ellipse model, with N45°E representing an extensional strain and N45°W a compressional strain. This finding is in agreement with the tectonic stress model developed for Taiwan Area [5][6][7].

5. Conclusions

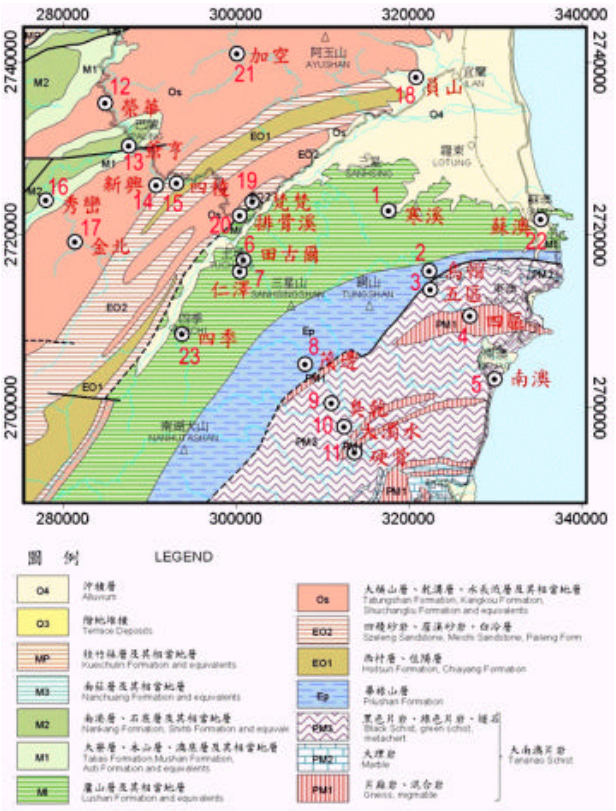

Fig. 1. 23 Hot Springs in the Study Area, distributed in sedimentary and metamorphic rock types.

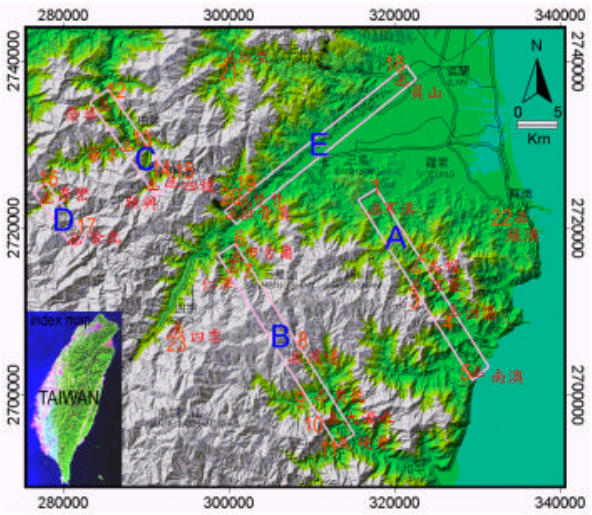

Fig. 2. 23 Hot Springs in the Study Area, distributed in 5 zonal lineaments (Zone A-Zone D).

1. Remote sensing images can be used for observing regional geological lineaments, which can be applied to a regional stress-strain ellipse model to assist the understanding of the possible path which natural hot spring could travel from deep underground to the ground surface.
2. The results of image lineaments, tectonic pattern, and field observations are in good agreement. This supports the finding of structural-control of hot spring occurrences in this study.

Fig. 3. Lineaments on SPOT images and Rose Diagram showing preferred orientations of lineaments .

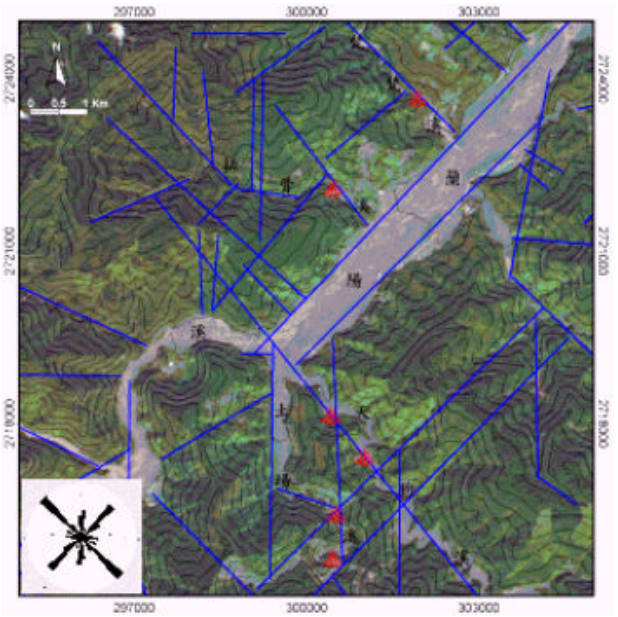

Fig. 4. Lineaments on SPOT images and Rose Diagram showing preferred orientations of lineaments.

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