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Research Article

The Origin of Fengjian — Sealing Soil to Build *lv*: Evidence from Jade Instruments Used to Monitor Earth-air

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Abstract

Fengjian (封建), a well-known, basal political system and culture in ancient China, has a long history. Similarly, jade culture also has a very long history in China and is thus an important part of Chinese cultural heritage with many significant Chinese traits. However, the use and origin of jadeware has been something of a riddle. This paper scientifically reveals how jadeware was used and also the origin of Fengjian via simulated experiments and use of unearthed archaeological jadeware to rebuild the basic method of hou-qi. The jade instruments utilized for hou-qi, through which the ancient Chinese determined seasonal temperatures by monitoring changes in earth-air pressure. They were thus used to monitor the solar terms and make so-called *lv*-calendars to guide farming times. The present author, by studying the function and use of jadeware artifacts (*cong*, *bi*, *mao*, *gui*, etc.), has determined that the Chinese Fengjian culture originated from hou-qi at least 9,200 years ago. Fengjian involved sealing soil and using jadeware to build *lv*s in palaces to monitor earth-air and thus create *lv*-calendars. Under Fengjian setting, the Eight Trigrams model was the theoretical basis of I Ching. Therefore, to begin with, Fengjian was a kind of technology and method underlying hou-qi. It was the prehistorical practice of hou-qi and Fengjian that laid the foundation of Chinese culture and pioneered Chinese civilization. They have thus had a strong influence on Chinese ideology, politics, religion, philosophy, and life-style.

Keywords

Fengjian, Feudalism, Jadeware, Hou-qi, I Ching, Eight Trigrams

1. Introduction

The Chinese civilization boasts an extensive and protracted history. In fact, it stands as the sole civilization in human history that has maintained an unbroken continuum. The main characteristics is the 'Fengjian' (封建), which is manifested in various aspects such as politics, ideology, culture, system, music, meteorology and religion. The term 'Fengjian' first appeared in *Shi Shangsong Yinwu* 《詩 商頌 殷武》: 'blessings by Fengjian' (封建厥福), and later in *Zuozhuan* 《左传》: 'feudal relatives to protect Zhou dynasty' (封建親戚, 以蕃屏周). This shows, at the very least, that the term Fengjian existed in the Western Zhou Dynasty (西周, 1122-771 bc) [1]. It is generally assumed that Fengjian means 'feudal' or 'feudalistic', i.e. dividing land to build up states (封土建國). As there were already vassal states more than 4,700 years ago in the time of the Yellow Emperor, some scholars believe that Fengjian began during the Yellow Emperor's time [2].

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However, according to the *Kangxi Dictionary* 《康熙字典》, in addition to meaning 'sealing' or 'closed', the term *feng* (封) also means 'holding *gui* (圭) to do something.' Furthermore, the term '寸' means 'measurement, rule, and method'. Similarly, *jian* (建) means 'establish *lv* (律) in palace' (立朝律) according to *Shuowenjiezi* 《說文解字》 by Xu Shen (許慎). The philologist Duan Yucai (段玉裁, ad 1735−1815) said: "It must be ancient meaning, but I cannot textually research its derivation now (此必古義，今未攷出)" [3]. Therefore, just as Ma Ruilin (馬瑞臨, *c.* ad 1280) said in a monograph on Fengjian studies, *FengjianKao* 《封建考》: "We do not know when the Fengjian begins" [4]. It is therefore apparent that determining the meaning, intention, origin, and time of origin of the term Fengjian is crucial to understanding Chinese culture and revealing the origin of the Chinese civilization.

In this context, the term *jian* (建, 'establish *lv* in a palace') gives us a clue as *lv* refers to the *length* of a tube buried in the hou-qi (候氣) method [5]. Here, hou-qi pertains to the process of monitoring earth-air, which essentially signifies awaiting the earth-air pressure within the soil to reach a threshold and subsequently break the seal film, i.e. responded by sound. As is well-known, a calendar with Chinese characteristics is called *lvli* (律曆, '*lv*-calendar' or 'meter-calendar') because it determines the months according to the lengths of tubes (pitch pipes). Concerning *lv*, Sima Qian (司馬遷) said in the *Grand Historian*《史記》: "The King establishes the regulatory framework for governance, enacts laws, and standardizes units of measurement, all grounded in the six *lvs*, which serve as the foundational principles for all aspects of the system (王者制事立法, 物度軌則, 壹稟於六律, 六律為萬事根本焉)." The 12 months within a year correspond to 12 *lvs*, which comprise 24 solar terms and 72 pentads (or *hou*s 候, the waiting time for a response of sound, 1 *hou*, corresponding to ~5 days). This monitoring was used to guide the timing of agricultural production.

The method of hou-qi is roughly outlined in the '*lvli* 律曆' part of the history book *Houhanshu* 《後漢書》 [6]. The method refers to burying 12 tubes of different length in soil. The upper ends of these tubes were to have exposed surfaces that were sealed with a membrane made from bamboo or reed. As the season progressed, at specific intervals, the earth-air pressure would attain certain critical threshold values, which would subsequently lead to the rupture of the membranes sealing the tubes [5]. When a membrane burst there would be a 'bang' and ash/charcoal (which had previously been placed in front of the tubes) would be blown out. Hence, the Chinese term *Xiangying* (響應) which means 'responded by sound' derives from this process. The breaking of specific membranes let the people know the corresponding solar term.

However, all this is just a legend that has never been really tested in modern times. Nevertheless, people believed it until the Ming dynasty when serious doubts began to arise in the validity of hou-qi. No matter how it was tested, it proved impossible to verify it. Because of this complete lack of any sound theoretical scientific basis, hou-qi was finally officially denied in the eighth year of Emperor Kangxi's reign (*c.* ad 1669) [7, 5]. Needham [8], the author of *Science and Civilisation in China*, thought of hou-qi as a pseudoscience. Even certain Chinese scholars have discredited it, believing it to be the biggest scam in the realm of science and technology in China over the past 2,000 years [9].

Meanwhile, in China, people have a long history of using jadeware, which has given rise to a unique culture — 'jade culture' [10]. Jade culture distinguishes China from other nations and boasts a wide area of distribution that extends beyond the current territorial boundaries of modern China. Regardless of whether it refers to an archaeologically-excavated material object or just the Chinese word itself, jade has made an extensive contribution to the Chinese civilization. Jade culture permeates throughout the whole of the Chinese world, be it political, religious, economic, or cultural [11, 12]. As jade is merely a stone, people are often curious as to why it has such charm in China and has become one of the most enigmatic symbols that distinguishes Chinese culture from other cultures all over the world [13].

Opinions about the origin of jadeware vary considerably. Throughout the ages, many of our predecessors have conducted numerous systematic and extensive research investigations, however, no unanimous conclusions have been drawn [14]. Jade is, in fact, a fairly scarce material and therefore precious. Regardless of whether it was used to create a ritual vessel [15, 16] or a decoration to wear [17, 18], one has to feel that in ancient times, when jade productivity was low, possessing jade and carving it into complicated jade objects would have been an extremely arduous endeavor. Thus, there seems to be something more about jade that extends beyond pure religion and aesthetic appreciation. The ancient people needed to use it for very important projects and, for whatever reasons, it had to be used.

Jade is hard and dense and can therefore be used to create tools that are impermeable and airtight when properly sealed [19]. At the same time, jade has good thermal conductivity, thermosensitivity, and can be buried in soil for thousands of years without rotting away. As jade has many good properties, its use has become personified [20, 21]. Thus, there are many jade-related words that are endowed with good meanings. In fact, according to research in the dictionary *Shuowenjiezi*, there are 142 words containing the Chinese character for jade (玉). This shows jade culture has had an extensive influence on etymology in China.

Among the various types of jadeware objects used in earth-air monitoring, the character for jade is used in, for example, *jue* (玦), *cong* (琮), *zhang* (璋), *bi* (璧), etc. Tradition records that the terms *cong* and *bi* relate to worshipping Heaven and Earth. However, there are many different recognitions of jadeware. For instance, Zang [22] believed that *bi* refers to a 'meat string' used to bribe gods. Emperor Qianlong (Qing dynasty) believed *cong* related to the jade ring of a

carriage wheel (釭頭) [23]. It seems that the use of *cong* was already becoming unknown as early as the Han dynasty. Unearthed *cong* was reused to be part of jade burial suit, specifically serving to cover the genitals [24]. At present, therefore, there are no unifying ideas and methods underlying research on the origin, purpose, and function of jadeware.

The present author has studied earth-air (地气, which is a very old Chinese commonly used word) for many years. The results of experiments show that earth-air rises and falls extensively on land [25]. There is also 'fingerprint'-like evidence to suggest that earth-air experiences a 'passive breathing' effect due to the variation of the earth's atmospheric pressure [26, 27]. Moreover, this breathing effect influences other important effects such as the rate of evaporation of phreatic water [28], occurrence of haze [29], and emission of CO_2/radon gas from land [30].

In general, the term 'earth-air' refers to the air in the vadose zone (which extends from the water table to the surface of the land). It is not surprising, therefore, that this air should be affected by changes in atmospheric pressure, there is passive breathing. However, the earth-air can also undergo 'autonomous breathing' because of the temperature variation that occurs in the soil [31]. For example, as the intensity of the solar radiation varies during the day, there will be a daily soil temperature variable zone (STVZ) set up which extends to a depth of ~60 cm in the soil [32]. Similarly, there is a yearly STVZ (corresponding to a depth of about 15-30 m) that is affected by the seasonal changes that occur in the intensity of the solar radiation throughout the year. Therefore, there are two temperature layers with *self-similar fractal structures*, i.e. there are two spatiotemporal temperature variations in natural soil, both with sinusoidal characteristics.

As a result of these studies, I have come to believe that Fuxi drew the Eight Trigrams according to the structure of the abovementioned double layers to illustrate the variation that occurs in the soil temperature and, therefore, earth-air [33]. If a closed system was to be set up for hou-qi, then the *daily* temperature variation that occurs would not be of much use to the operator. In fact, it could be viewed as a disturbance that needs to be eliminated. One way of achieving this is to build a house to provide shade from the solar radiation. The house should be large enough to exclude the lateral transmission of the effect of the daily temperature fluctuations occurring in the outdoor soil [34]. Therefore, in a large house, the daily STVZ will disappear, leaving only the more orderly temperature changes in the yearly STVZ. In ancient times, a large house ('palace') was therefore used to carry out hou-qi to establish a yearly *lv*-calendar. This is more in line with the ancient meaning of 'Fengjian'. In a closed system, the temperature will obviously be a major factor determining the air pressure [34]. According to the literature [6], the tubes initially used were made of bamboo. However, bamboo is a perishable material, so jade tubes were used later on. These tubes were called *guan* (琯) — for example, it was recorded in *Dadailiji*《大戴禮記》that '*guan* were used for hou-qi' (琯所以候氣). Therefore, it is conceivable that the large house was special place for Fengjian and hou-qi [33] and that jadewares were the official mainstream instrument. However, the civil hou-qi was used pointed bottom bottle in mall house [34]. Prehistoric jade wares have been unearthed from time to time since ancient times. Over the past century, more than 200,000 jadeware objects were unearthed in China, according to incomplete statistics [35]. In recent decades, numerous specialized archaeological excavations have been conducted, and more rigorous archaeological excavation reports have been produced. There have also been a large number of publications on jadeware research and a rich, reliable body of information is being accumulated [10, 36]. As a result, many scholars are systematically conducting research on jadeware [23].

In this paper, experiments simulating how the air pressure in a closed system responds to temperature changes are considered to reveal how representative jadeware items, e.g. the *guan*, *jue* (玦), *cong* (琮), *zhang* (璋), *bi* (璧), *gui* (圭), *xuanji* (璇玑), etc., were used in hou-qi. Based on the jadeware items found, the research of predecessors, and ancient literature, we consider the application, function, and working principles of the jadeware items. This reveals the possible methods used in hou-qi to build *lv*-calendars. The results are used to explore the origin of Fengjian and probe their roles in the genesis of the Chinese civilization and its prehistorical development.

2. Methods and Materials

Experiments were conducted on the top Gobi Desert of the world-famous Dunhuang Mogao Grottoes located at 40 ° 02′ 14″ N, 94 ° 47′ 38″ E — see Figure 1). Monitoring instruments (model HOBO-U23-001) were embedded in the soil to measure the temperature at different depths (0, 10, 20, 30, 40, 100, 200, 300, 400, 500, and 600 cm). The instruments were used to monitor the yearly temperature variation, readings being taken every 30 minutes.

1) Based on the average monthly temperature variation and self-similar fractal characteristics of the daily and yearly STVZs, we could then primarily infer the depth of the yearly STVZ [32, 33, 37] and *lv*s.
2) The monitored temperature variation and ideal gas equation ($P_1V_1/T_1 = P_2V_2/T_2$) [38] were then used to determine the influence of temperature variation on the earth-air pressure, assuming the system is closed ($V_1 = V_2$).
3) Experiments were also performed using specially-designed, flat-bottomed bottles of different size filled with different materials (Figure 2). The fillings included air (i.e. an empty bottle), activated carbon, 75% ethanol (60 mL), clay, loessial soil from the Loess Plateau (Tianshui Dadiwan), plant ash, and plant ash with 33% activated carbon added. Moreover, a paste made from loessial soil was smeared inside one bottle which was

then air-dried. This produced a layer of loessial soil on the inside of the bottle, which was used to represent the airtight soil present around excavated spaces. Some of the properties of the materials used (particle size, salt content, salt composition, and water content) are presented in Tables 1 and 2.

Figure 1. *The location of the temperature monitoring experiments in the Gobi Desert region of the Dunhuang Mogao Grottoes. On the right is a schematic diagram showing the vertical arrangement of the buried temperature sensors.*

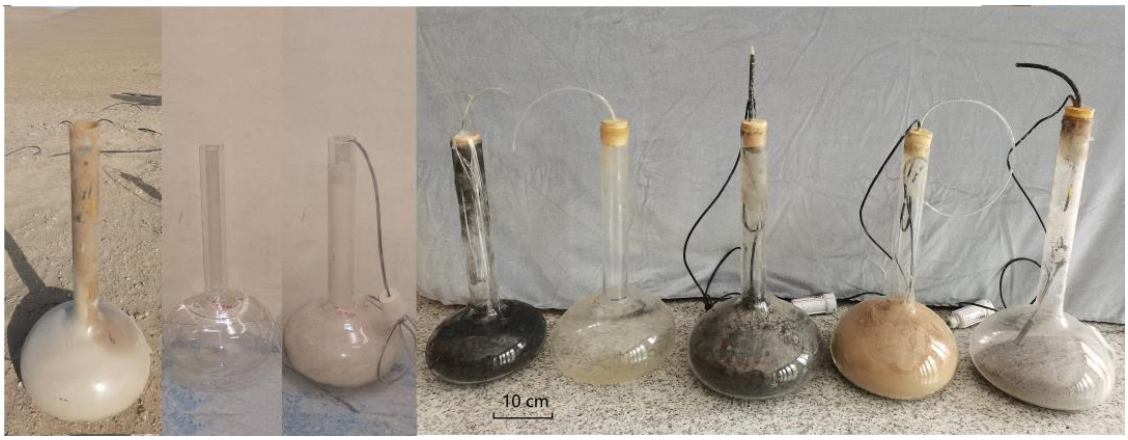

Figure 2. *Flat-bottomed bottles of different size (given in parenthesis) filled with different materials. From left to right, the materials are: an internal layer of loessial soil (2,600 mL), air (2,200 mL), clay (2,450 mL), activated carbon (760 mL), alcohol (2,200 mL), plant ash with 33% activated carbon added (2,400 mL), loessial soil (2,450 mL), and plant ash (2,600 mL).*

The materials selected were chosen because they are key components used in hou-qi or traditional Chinese sacrificial rites. It is therefore interesting to investigate how these materials respond to air pressure and temperature changes in closed conditions. In other words, we want to find the functional relationship between air pressure and temperature in the presence of these materials. This could help us decide what materials were used in ancient earth-air monitoring experiments.

To this end, miniature temperature-measuring instruments (HOBOs) were embedded in the centers of the filled bottles and the temperature recorded once every 10 minutes. The mouths of the bottles were first sealed and the bottles placed in a controlled temperature-humidity chamber (CTHC). Before sealing, hard plastic tubes were used to connect the bottles to an atmospheric pressure transmitter and paperless recorder (BT805) placed outside the CTHC. This arrangement was used to record the air pressures in the bottles every 10 minutes. The temperature in the CTHC was set to change over the range 5-40 ℃ (to cover both daily and yearly temperature changes in the soil). The temperature was increased in increments of 5 ℃, each temperature remaining constant for 4 hours. The results of the monitoring experiments were subsequently used to determine the characteristics of the pressure/temperature changes occurring in the soil under closed conditions (see Table 4).

Table 1. *Particle size distributions in the clay and loessial soil.*

Material	Particle diameter (μm)						
	1-2	2-5	5-10	10-20	20-50	50-75	75-200
Clay (%)	52.10	28.25	12.29	7.36	0	0	0
Loessial soil (%)	15.05	18.83	16.47	20.98	20.10	5.79	2.78

Table 2. *Salt and water composition of the clay, loessial soil, and plant ash.*

Material	Content (mass %)								
	Cl^-	NO^{3-}	SO_4^{2-}	Na^+	K^+	Mg^{2+}	Ca^{2+}	Total salt	Water
Clay	0.09	0.00	0.18	0.09	0.01	0.01	0.05	0.42	11.40
Loessial soil	0.01	0.00	0.00	0.18	0.02	0.04	0.18	0.42	3.70
Plant ash	0.41	0.60	0.03	0.01	0.17	0.00	0.01	1.24	—

After the experiments in the CTHC, the flat-bottomed bottles were buried in the Gobi soil to a depth of 10 cm. They were then used to record the air pressure variation as the temperature changed on a daily basis and hence determine the responses of the different materials to the temperature changes experienced. The basic monitoring methods used in hou-qi can be reconstructed using the results of the above experiments and the structures of the ancient jadeware artifacts uncovered in archaeological digs, namely, the *guan* (琯, 'tube'), *jue* (玦), *xuanji* (璇玑), *bi* (璧), *cong* (琮), *mao* (瑁), *gui* (圭), *zhang* (璋), and *yue* (钺), as pictured in Figure 3.

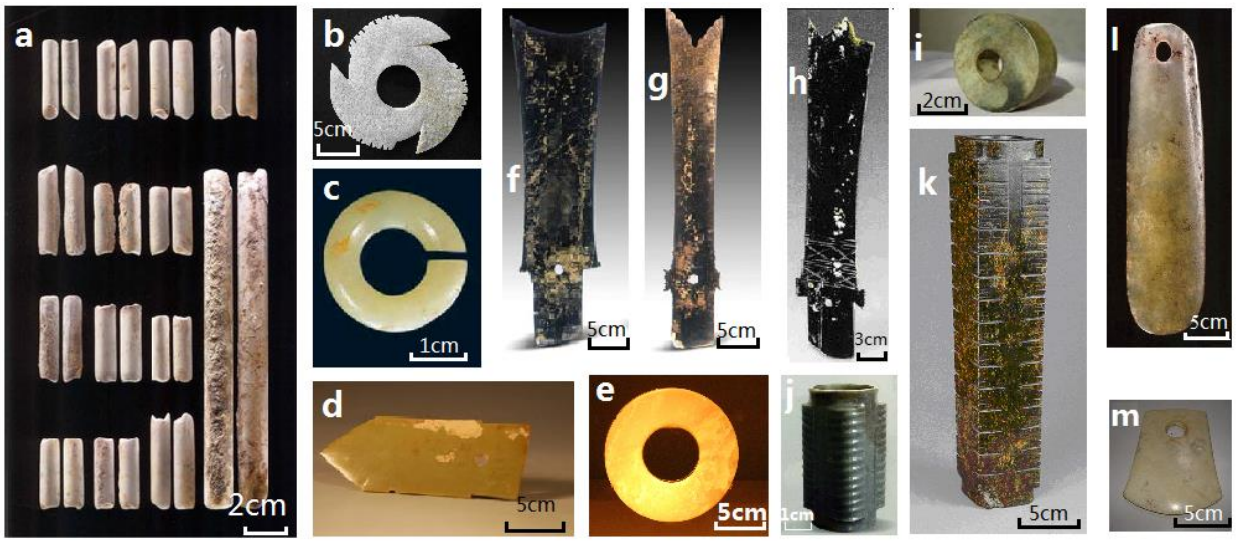

Figure 3. *The essential jadeware items used to build lv-calendars: (a) guan, (b) xuanji, (c) jue, (d) gui, (e) bi, (f,g,h) zhang, (i) mao, (j,k) cong, and (l,m) yue (Yang and Liu).* [1]

[1] Photographs a, c, f, g, h, l, and m were sourced from The Origin of Jades in East Asia: Jades of the Xinglongwa Culture (eds. H. Yang, G. X. Liu, and C. Tang), Hong Kong: Chinese art archaeological research center/ Chinese University of Hong Kong Press. The others were obtained from http://i.guancha.cn/News/2012/10/30/634871904712953301shca20051132-2-l.jpg.

3. Results and Analysis

3.1. Soil Temperature Variation and Origin of *lvs*

Under typical weather conditions (clear skies) for this region, the temperature variation in the daily STVZ follows the patterns shown in Figure 4a. By looking at the temperature peaks, one can see that the soil temperature experiences a 'hysteresis' effect. That is, a temperature peak in a shallow layer takes time to generate a peak in a deeper layer because it takes a certain amount of time for the thermal energy to be conducted downwards into that layer. Also, the amplitude of the temperature fluctuation created by the solar radiation decreases as we move deeper into the soil.

This time lag means that the temperature variation in layers that are far apart can often be in opposite directions. For example, when the temperature of the 10 cm layer is rising rapidly (~15:00), the temperature of the soil in the 30-40 cm zone is still falling. Similarly, when the deep layers are warming most rapidly, at around 1:00, the upper 10 cm layer is cooling down. After many years of monitoring, it is generally true that when the surface temperature is rising/falling, the temperature in the deeper affected layer is falling/rising.

The temperature monitoring results recorded over many days (in 2012-15) are shown in Figure 4b. The results illustrate the self-similar fractal characteristics mentioned earlier. On a yearly scale, the overall temperature variation is sinusoidal. Then, on a daily scale, the variation is also sinusoidal.

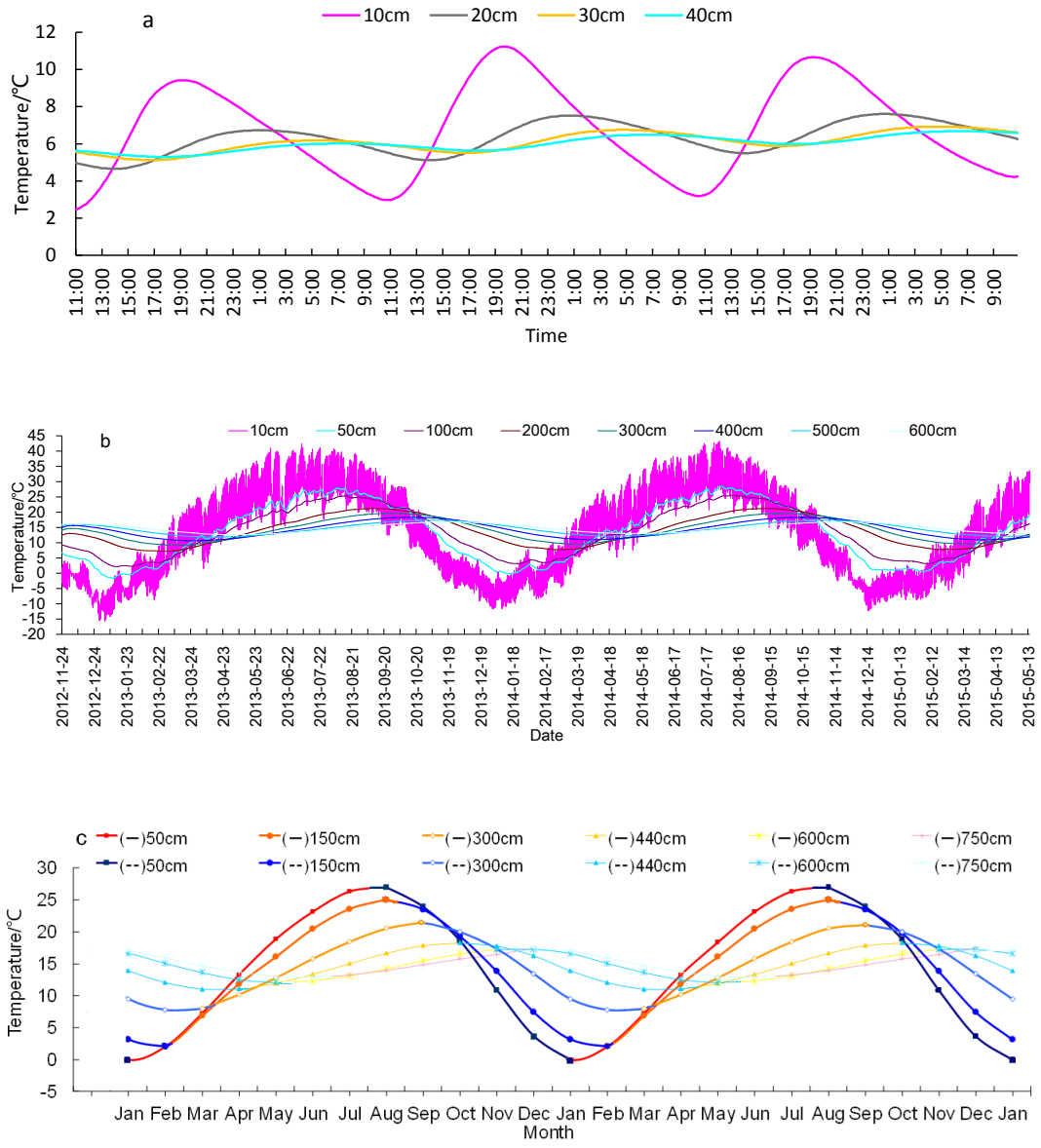

Figure 4. *Temperature variation at different depths in the soil. (a) Typical daily temperature variation. (b) Long-term (yearly) temperature variation. (c) Monthly temperature variation showing the changes in the phases of the variation.*

This time lag means that the temperature variation in layers that are far apart can often be in opposite directions. For example, when the temperature of the 10 cm layer is rising rapidly (~15:00), the temperature of the soil in the 30-40 cm zone is still falling. Similarly, when the deep layers are warming most rapidly, at around 1:00, the upper 10 cm layer is cooling down. After many years of monitoring, it is generally true that when the surface temperature is rising/falling, the temperature in the deeper affected layer is falling/rising.

The temperature monitoring results recorded over many days (in 2012-15) are shown in Figure 4b. The results illustrate the self-similar fractal characteristics mentioned earlier. On a yearly scale, the overall temperature variation exhibits a sinusoidal pattern. On a daily scale, the variation also follows a sinusoidal pattern. Figure 4b shows that the amplitudes of the *yearly* temperature fluctuations also decrease as it moves to deeper layers. In fact, based on the monitored temperatures, it can be inferred that the yearly temperature fluctuations can only be conducted to a maximum depth of ~800 cm in this geographical area [33]. This depth, of course, marks the bottom of the yearly STVZ in this region.

Based on the information in Figure 4b and the temperature-delay effect, we can deduce the times during the year when the soil in a particular layer starts to cool down (on average) and warm up (on average). This is plotted in Figure 4c. Thus, the temperatures of the 50, 150, 300, 440, 600, and 750 cm layers one by one start decreasing consecutively from ~July to ~January. (Conversely, they start increasing from ~January to ~July.) This means that the deepest layers have their highest temperatures in January and lowest temperatures in July.

The upper 50-cm layer is in a warming phase from ~January to ~July (red line in Figure 4c and denoted by ⚊) and cooling phase from ~July to ~January (black line and denoted by --). Below this, the 150-cm layer has a warming phase that starts about a month later, and a cooling phase that also starts a month later than those of 50 cm. This variation continues as we move to deeper and deeper layers. The temperature variation in the layers shown in Figure 4c therefore reflect the thermal characteristics of the soil. When the daily fluctuations are removed — as might be measured in a large room where the daily fluctuations in the solar intensity are negligible. The states of the 6 vertical layers on a monthly basis are summarized in Table 3 using the notation defined above.

Table 3. *Spatiotemporal distribution of the phases in the soil (i.e. hexagram images) during a typical year. Also shown are the corresponding lengths of the lv, lunar months named in dizhi (地支), lv-named months, and the traditional names in I Ching, if the phases were flipped vertically.*

	Month											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Phase	䷁	䷗	䷒	䷊	䷡	䷀	䷫	䷠	䷋	䷓	䷓	䷖
Traditional name	Kun 坤	Fu 復	Lin 临	Tai 泰	Dazhuang 大壮	Guai 夬	Qian 乾	Gou 姤	Dun 遯	Pi 否	Guan 觀	Bao 剥
Fuxi *Lvs* (unit)	77	81	73	65	57	51	45	42	48	54	61	69
Traditional *Lvs*	42	81	77	73	69	65	61	57	54	51	48	45
Lunar month in *dizhi*	Hai 亥	Zi 子	Chou 丑	Yin 寅	Mao 卯	Chen 辰	Si 巳	Wu 午	Wei 未	Shen 申	You 酉	Xu 戌
Lv-named month	Ying zhong 應鍾	Huang zhong 黃鍾	Dalǜ 大吕	Taicu 太簇	Jia zhong 夹鍾	Gu xian 姑洗	Zhong lǜ 仲吕	Rui bin 蕤宾	Ling zhong 林鍾	Yizai 夷則	Nan zhong 南鍾	Wuyi 無射

Therefore, if closed systems (e.g. flat-bottomed bottles or pipes) were used at depths of 50, 150, 300, 440, 600, and 750 cm, the temperature variation in the different layers could be determined by observing the concave/convex nature of thin films covering the mouths of the vessels (due to the change in pressure of the earth-air inside). The phases of the *yin* (陰) and *yang* (陽) in different layers could thus be detected as a function of time.

In ancient times, the length of the *lv* referred to the depth/length of the *cooling* (yin) part of the yearly STVZ.[2] If we subtract the minimum monthly *lv* value of 42 units from the lengths of the traditional monthly *lv*s and compare the results, then the following ratios are obtained (81 - 42):(77 - 42): (73 - 42): …: (42 - 42) = 1.00 : 0.90 : 0.79 : 0.69 : 0.59 :

[2] 《大戴禮記 曾子天圓》: '律居陰而治陽'. '*Da Dai Li ·Zengzi Tianyuan*': '*lv* inhabits in yin but controls yang.'

0.49: 0.38: 0.31: 0.23: 0.15: 0.08: 0.00. (That means there were 42 units of *lv*s exposed above ground). The ratios in boldface are about the same as those of the monitoring depths considered in Figure 4c (i.e. 750: 600: 440: 300: 150: 50 = 1.00: 0.80: 0.59: 0.40: 0.20: 0.07). We thus infer that the earliest form of the earth-air monitoring technique probably did involve observing the concave/convex nature of closed films covering the mouths of buried pipes. Pipes buried at depths of 50, 150, 300, 440, 600, and 750 cm could therefore be used to determine the temperature or *yin-yang* changes and hence the phase of the hexagram.[3] This possibly the origin of the *lv*s [4].

The people who understood the principle of the Eight Trigrams could therefore determine the spatiotemporal changes occurring in the *yin* and *yang* of the soil. The advantages of using the Eight Trigrams model would have spread throughout China and this would have played a vital role in popularizing hou-qi [34].

The phase transitions in each layer occur at the turning points of the temperature curves in Figure 4b and 4c. However, the temperatures change only slowly during the course of a year so these curves have rather gentle slopes. This makes it difficult to determine the points at which the phase changes. In addition, their times will also be affected by the external atmospheric pressure [34]. This means that determining the times of the phase transitions will inevitably involve some subjective judgment. A new method would thus have been required in order to determine the phase transition times more objectively.

It is likely that later versions of the detection method would have involved the breaking of a closed film. Additional tubes/*lv*s were also added at adjacent depths to improve the technique (e.g. between 750 and 600 cm another tube would be added at a depth of about 700 cm). In this way, slightly shorter pipes would have been buried (in order) from shallow depths to deeper depths at the latter half of the year and the mouth of the shortest pipe sealed. After about a month, the sealing film would break. At this stage, the mouth of the pipe for the second month would have been sealed, and so on. In this way, the *lvs* had the deepest winter and the shallowest summer [5], showing an inverted V-shape in the Fuxi era. The *lvs* recorded in the Zhou Dynasty may consider the odd and even concept of the month (odd months are Yang, even months are Yin), and combine the *lvs* of the months in the first and second half year according to the length to short [the first half of the depth of the Yang increase process may be called the *lv*, and the months of the second half of the Yin increase process was called the *lu* (吕), in the Fuxi era], forming a linear decline in the *traditional lvs* changes.

As the temperature changes are smaller as the depth increases, it is likely that the tubes would have remained sealed for a longer time when the months increase. Because of this, these tubes would have been sealed earlier before the current seal had broken. The slowest response time would have been encountered in December in the 750 cm layer as the earth-air at this depth is just reaching its highest temperature due to the hysteresis effect. The *lv*s all need to respond to positive (*yang*) changes, so that the lengths of the array of *lvs* decrease on the whole. That is, size-wise, they did not need to fluctuate from descending to ascending or from ascending to descending. This is because the so-called *lv*s did not respond to negative (*yin*) changes (律不書陰) [5].

Although the solar radiation intensity has a sinusoidal annual cycle, we can see from Figure 4 that the time of temperature changes that occur in the soil in the first and second half of the year are not completely symmetrical. It shows that the soil experiences warming for about 7 months and cooling for about 5 months. Overall, the increase and decrease in the soil temperature changes with depth and time being roughly sinusoidal, as shown in Figure 4b and 4c, and this must dictate the variation in the *lv*s. This lays the foundation for changing the *lv*s so that they vary approximately according to a sinusoidal pattern.

Note that burying pipes to depths of several meters and subsequently managing them is a tricky business. In addition, the temperature variations encountered with depth will vary greatly with the texture of the soil and as the topography of the land changes at the monitoring site. In particular, ground that is not sufficiently flat can have a dramatic impact on the change in temperature with depth. This means that a 'perfect' *lv* will not respond in the same way at every location. The ancient people would have soon realized this and probably looked for ways to simplify the monitoring process. After a long period of monitoring and research it seems that a unified standard ratio and *lv* were developed. According to the lengths of archaeologically excavated *cong*, *gui*, and *zhang*, the length of the *lv* was generally no longer than 50 cm (Figure 3). This is clearly much larger than the size of a standard *lv* (whose maximum size is about 20 cm, according to records). Hence, they were probably made according to the ratio (*lv* 率) mentioned above.

3.2. Air Pressure Variation in Response to Temperature Change

The results of the air pressure experiments using closed, flat-bottomed bottles are shown in Figure 5. As can be seen, the air pressure in equilibrium with the materials in the closed bottles changed in different ways as the temperature changed. That is, the different materials give rise to different pressure-temperature gradients.

Some materials responded very quickly to a change in temperature (for example, the pressure in the 'empty' bottle and bottle filled with 60 mL of ethanol can be seen to have increased in 'step-like' jumps as the temperature was increased). However, other materials responded much more slowly, generating pressure curves that are much smoother.

[3] 《說文解字》: '天垂象, 見凶吉, 所以示人也'. '*Shuowenjiezi*' say: 'Heave droops hexagrams to show concave (凶) and convex (吉) to people to be seen.'

[4] 《漢後志》曰: '伏羲作易, 紀陽氣之初, 以為律法.' '*Houhanzhi*' said: 'When Fuxi made *I Ching*, he through the way of *lv* to record the beginning of Yang air.'

This is because the soil-like materials take much longer to release air/vapor when heated. As can be seen, it generally took about 3 hours for these materials to reach equilibrium. The equilibrium pressures inside the bottles were found to vary linearly with the equilibrium temperatures inside the CTHC. That is, the air pressure, *P*, and temperature, *t*, vary according to the following simple relationship:

$$P = at + b \quad (1)$$

where *a* is a characteristic pressure coefficient for the material and *b* is a constant related to the atmospheric pressure when the bottle was initially closed. The fitting coefficients obtained using the experimental data are given in Table 4. The Pearson correlation coefficients (*R*) are all above 0.98, showing that the fits are all very good.

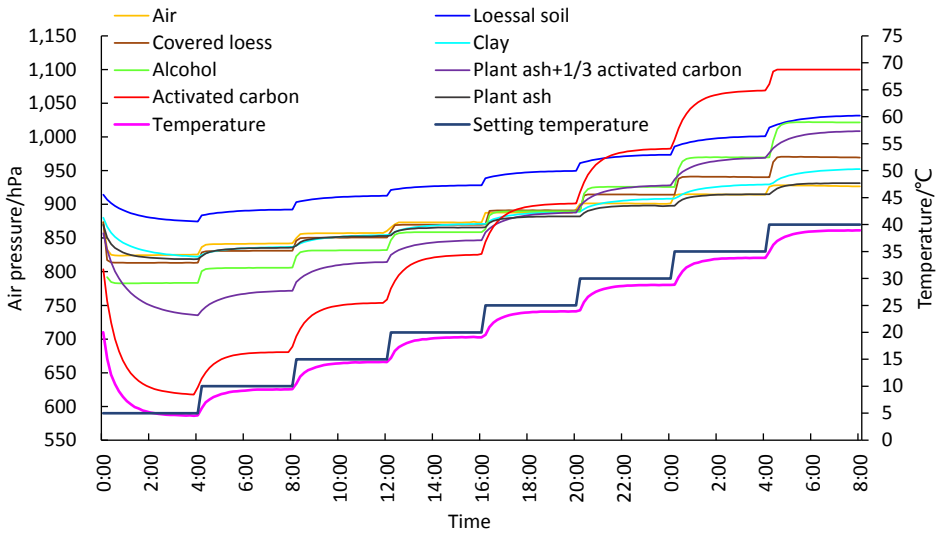

Figure 5. *Variation of the air pressure above different materials in closed systems in response to changing temperature.*

From Table 4 we can see that the coefficients of the materials increase in the order: air < plant ash < clay < covered loess < loessial soil < alcohol < plant ash plus 33% activated carbon < activated carbon. This shows that the different materials clearly have different P-t response characteristics. It is highly likely that the ancient people would have soon realized this themselves and used these characteristics to regulate and control the change in air pressure occurring in their closed systems.

Table 4. *Relationship between air pressure P (hPa) and temperature t (℃) for the different materials.*

Material in bottle	Fitting parameters*		
	a **(hPa/℃)**	***b*** **(hPa)**	R^2 **(*p* = 0.01)**
Air	2.900	813.3	0.9871
Loessial soil	4.692	840.0	0.9906
Covered loess	4.335	787.2	0.9785
Clay	3.651	802.8	0.9898
Plant ash	3.264	804.1	0.9995
Alcohol	6.589	737.3	0.9777
Activated carbon	14.28	553.5	0.9860
Plant ash + 33% activated carbon	8.210	750.2	0.9900

*Least-squares parameters obtained by fitting the data to the expression: $P = at + b$.

The variation in the air pressure and temperature recorded at a depth of 10 cm when these bottles were buried in the Gobi Desert soil is shown in Figure 6. As can be seen, the air pressures in the bottles fluctuated as the temperature varied during the day. The peaks are not completely synchronized. This is probably because of the different response times of the materials and slight differences in their circumstances, i.e. the thicknesses of the bottles and their burial depths. When the bottles are buried at different depths, the air pressure will show signs of hysteresis due to the thermal lag in the soil, as indicated in Figure 4a.

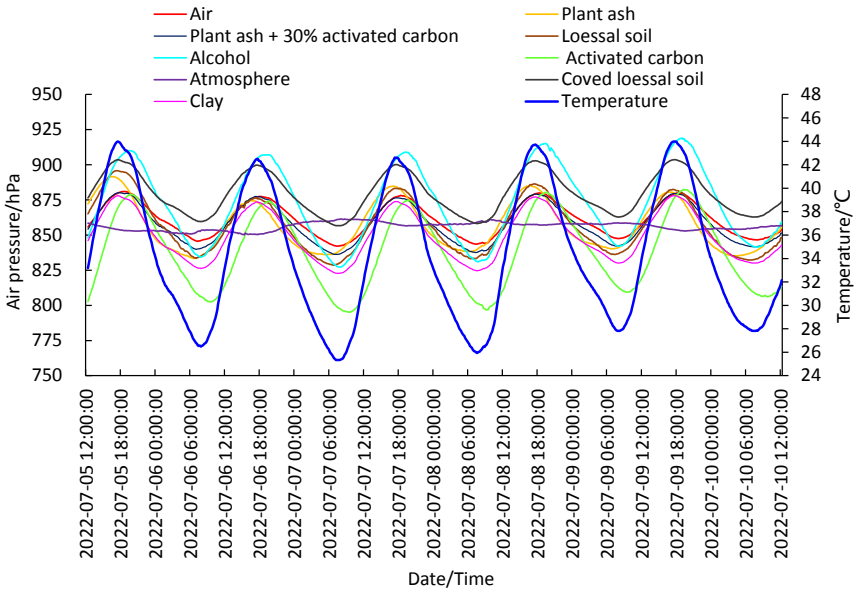

Figure 6. *The air pressure variation when the bottles were buried to a depth of 10 cm.*

These experiments show that there is a linear relationship between the air pressure and temperature inside each bottle. In ancient times, it would have thus been possible to monitor the solar terms through the response of the air pressure to the annual temperature changes. They could then formulate calendars and deduce the changes occurring in the state of the soil [34]. The fact that the earth-air pressure responds to temperature (Figure 4) is thought to be the source of the Chinese long (龍, dragon) image.

3.3. Installation Methods Used in Hou-qi

By studying the jade articles that have been excavated and consulting the ancient literature, it is possible to probe the methods that were probably used in ancient times to implement hou-qi [39].

The earliest jadeware to be archaeologically identified in China was unearthed from the Xinglongwa site and consisted of jade *guan* (Figure 3a) and *jue* (Figure 3c) [40]. Therefore, at that time, the earth-air monitoring method would have been that illustrated in Figure 7a. The ground/soil in the room was made from clay (or a mixture with blood or other materials) which was tamped down to make it air-tight [41] in advance. A hole was then excavated in the ground using a jade *yue* (Figure 3l), the depth of the hole corresponding to the *lv* required (Figure 4c). A jade *xuanji* (Figure 3b) was then used to dig a lateral cavity. A *jue* was then put in the hole to support the tube required. The space around the tube was then backfilled and a jade stick used to tamp the added material to make it air-tight. Finally, the mouth of the tube was sealed using a membrane.

After that, the surface of the membrane would have been observed. As the earth-air pressure increased, the membrane would have become convex and, when the air pressure reached a critical point, the membrane would break and there would have been a loud 'bang'. The earth-air needed to be monitored continuously, so the sound would have been a good way of monitoring the pressure while other tasks were carried out.

However, hou-qi is an ongoing monitoring. The cavity shown in Figure 7a may well have collapsed during an extended period of monitoring as it is not well supported. In later methods, therefore, the holes were made bigger so the cavity would last longer. Thus, larger *gui* (Figure 3d) or *yue* (Figure 3l and 3m) were used to excavate a larger hole into which was placed a *bi* (Figure 3e)[5]. A much larger empty cavity was thus formed under the *bi*. On top of this was placed a *cong* (Figure 3j and 3k), as shown in Figure 7b. The excavation process could also be performed using a *zhang* (Figure 3f), as shown in Figure 7c. *Zhang*s have curved bottoms and may be pointed with 2 (Figure 3g) or 3 sharp points (Figure 3h). These jade items were rotated to dig out cavities with different three-dimensional structures. Archaeological excavations have found that the *bi* and *cong* were often combined to form a complete set [24, 42-44]. This is called a *zhibibinggui* (植璧秉圭, 'holds *gui* to plant *bi*') in *Shangshu Jinteng* 《尚書 金縢》.

Jadeware thus became an instrument that could 'communicate' between Heaven and Earth through earth-air. The management of hou-qi was called *jisi* (祭祀, 'sacrifice') and the outflow of earth-air was also regarded as *shen* (神, 'god'). It is also the source of the term *Guanli* (管理, 'management of tube'). Therefore, jadeware came to be associated with ritual/sacrificial vessels.

Jade has good thermal conductivity. Placing a level jade *bi*

[5] 《周禮·地官》: '以土圭之法，測土深，正日景，以求地中.' '*Zhou Li* ·*Diguan*': 'Use Gui to demine the sun heat just conducted depth and measure the depth in soil.'

in a cavity can therefore increase the uniformity of the temperature of the air in contact with the *bi*. This can have an effective influence on the response of the earth-air to a change in temperature. The embedding depth (and width/diameter of the excavated hole) required for each solar term is fixed and cannot be changed very much. Hence, the term *fengweiguinie* (奉为圭臬) that is used in China means 'take the *gui* and *nie* (臬, a wooden handle that is tied to the *gui*) as a standard or model'.[6]

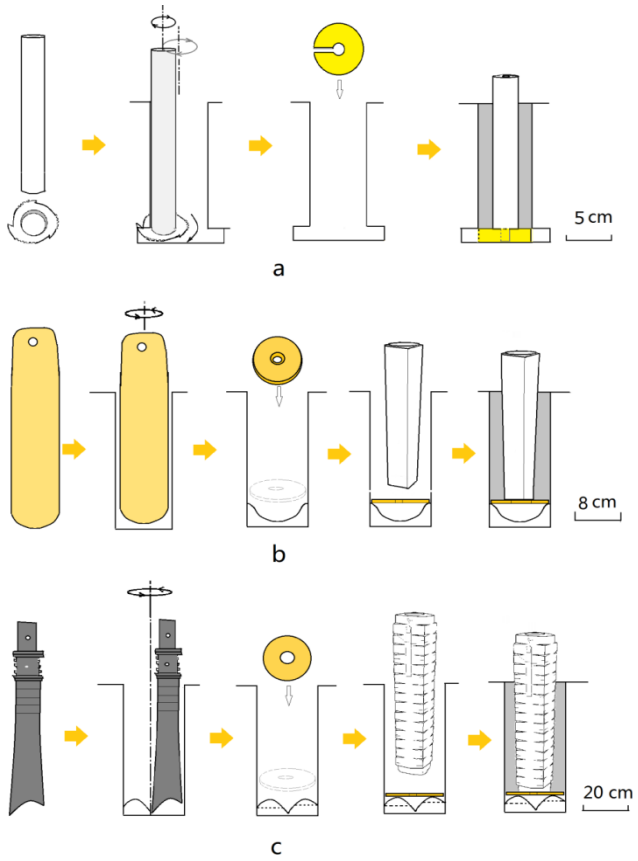

Figure 7. *Schematic diagrams showing the installation methods used in hou-qi. (a) Installation of a guan and jue with the help of a xuanji. (b) Installation of a cong and bi with the help of a gui. (c) A different installation method for a cong and bi that uses a zhang.*

According to Section 3.1, there are 42 units of the *lv*-pipes that are exposed outside the ground. This feature plays an important role in the solar term monitoring process and is also the key to why the *lv*-pipe developed into a *cong* with a larger pipe diameter. As they are larger, these tubes can be filled with appropriate response material (such as soil with activated carbon) which can be used to reverse the effect of the changing temperature of the outside ground and hence balance out the daily pressure fluctuations [34]. However, as *cong*s have larger inner diameters (~3 cm), they could not be sealed with narrow reed membranes. For monitoring purposes, therefore, a jade cap/*mao* (Figure 3i) had to be put on the mouth of the *cong*. In order to more clearly show the response of the device to the earth-air pressure, the mouth of the *mao* was filled with plant ash packaged in silk. Then, when the sealing membrane broke, the observers would hear the sound of the membrane breaking and ash would gush out from the *mao*.

Regardless of whether a jade *xuanji* is used to perform lateral excavation or a space is made under a *bi*, the basic idea is to form a cavity at a certain level in the soil. This is similar to what was achieved using the flat-bottomed bottles in the experiments described here. Of course, the air pressure is independent of the shapes and volumes of the bottles used. However, suitably sized cavities are easier to use to perform hou-qi and making the response of air pressure to temperature more accurate Moreover, if the 'ash-blowing' technique was used, the devices should have given the ancient people a clear and reasonably accurate display of the solar terms.

4. Discussion

4.1. Historical Length of I Ching Based on the Jade Items Used in Hou-qi

Archaeological excavations have shown that the earliest forms of earth-air monitoring were mainly performed using combinations of tubes, *jue*, and *xuanji* (Figures 3 and 7), as exemplified by the Xinglongwa culture. Artifacts used by the culture have been carbon dated to 6200-5200 bc [40]. This suggests that jade *jue* have been used for some 8,200 years [45]. According to the latest reports, jades have been discovered at the Xiaonanshan (小南山) archaeological site in Raohe County (饒河) which dates back 9,200 years, which means that hou-qi/Fengjian has been practiced for at least 9,200 years ago [45]. As already mentioned, later forms of hou-qi were developed that combined the use of jade *mao*, *cong*, and *bi* (Figure 3) and the earth was excavated using a jade *gui* or *zhang*. Such devices were used in Liangzhu culture (3300-2500 bc) [14, 43, 46]. The pictographs depicting the three jadeware items *mao*, *cong*, and *bi*, feature the Chinese character '王' (king). The three linked up together thus mean 'the king is the master of hou-qi and regards the monitoring as work.' In addition, the word *jue* (珏) refers to a specific combination of two jade articles in *Shuowenjiez*, which shows that jade items were universally combined in ancient times. The excavation revealed that *cong* and *bi* had been combined [46], which shows that earth-air was monitored by combining jades items to perform hou-qi.

As the hexagrams depict the variation that occurs in the earth-air activity, the 9,200-year long history of jade use must also correspond to the history of the Eight Trigrams. Therefore, *I Ching* must have a history that has lasted at least 9,200 years [34]. After hou-qi was first invented by Fuxi

[6] 《周禮·大司徒》: '凡建邦國, 以土圭正其地而制其域.' '*Zhou Li* ·*Da Situ*': 'Where a state is built, it used *gui* to determine the correct depth in the soil and make its right solar term in the territory.'

over 4,000 years ago, hou-qi became widely distributed across the vast land of China. The variety of the installation and monitoring methods developed using the same principle underlying the Eight Trigrams thus established the cultural territory of the Chinese nation [33]. As earth-air activity was regarded as god-like in ancient times, China came to be known as the 'land of god' (神州大地).

4.2. Using Lvs to Measure Time and Choice of Earth-air Monitoring Site

Earth-air activity from the surface to the deeper earth layers must have been measured in the early years of the ancient Fuxi era by monitoring the concave/convex nature of the membranes and thus used to indicate changes in the yin and yang (伏羲作易, 紀陽氣之初, 以為律法) [7]. Later, probably in the time of the Yellow Emperor or earlier, the monitoring method seems to have been simplified by only monitoring the deep layers during the Winter solstice solar term.

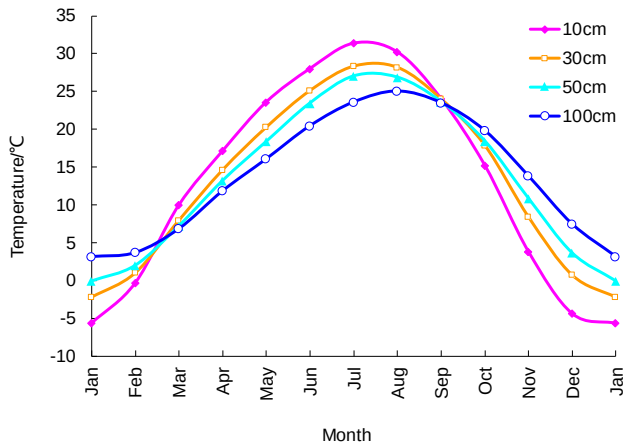

Figure 8. *Average temperature of the soil (in the range 10−100 cm) in which the lvs were traditionally buried.*

As the temperatures in the shallow layers (0-100 cm) have similar variation characteristics and fluctuation amplitudes (Figure 8), the hou-qi response could be fully realized by adjusting the type and amount of filling materials such as shown in Figure 2. Figure 4c shows that in January the temperatures of these soil layers in a large house are just starting to increase. The earth-air pressure in the January tube would therefore be increasing and the membrane would start to change from a state of shrinkage to bulging — until the earth-air pressure reached a certain critical threshold value when the membrane would break. Then, the membrane of the February tube would be starting to bulge and would ultimately break outwards. This pattern continues on until July is reached. From the end of July, the temperatures begin to decline. Therefore, each membrane will show that the earth-air pressure is decreasing and will become concave, ultimately breaking inwards into the mouth of the tube. That is, the tubes record a negative response, i.e. yin.

From the time of Fuxi to the time of the Yellow Emperor, the special places used to monitor earth-air (hou-qi) were big houses called 'Mingtang'. This initiated the famous Mingtang System (明堂制度) [47, 48]. Outside these Mingtang, the ground was bare and flat and its temperature changed during the day according to the daily STVZ cycle shown in Figure 4a. To the right side of the Mingtang was a structure called the *tan* (壇), which was dedicated to monitoring the air pressure response to the daily temperature changes. Based on the fractal structure of the soil's temperature, hou-qi experiments were performed to reveal the yearly variations occurring. The *tan* (training ground) is utilized for training students in hou-qi. This is the origin of schools in China. Later, the *tan* evolved into the *She* (社). Also to the left of the Mingtang was the ancestral temple (廟). These three institutions (Mingtang, Sheji, and ancestral temple) symbolize *the founding of the state* in ancient China. At the core of Chinese culture lies the Fengjian culture, which was patterned after the Eight Trigrams. In ancient times, the method of formulating the lengths of the *lv*s was based on 'tune of music temperament' in the following way. First, the length of the deepest *lv* of Huangzhong was determined. This length was then reduced by ⅓ to produce the *lv* of Lingzhong. Then, this length Lingzhong was increased by ⅓ to produce the *lv* of Taicu. Thus, this 'increase/decrease by ⅓ method' was used to obtain the tube lengths required for each month in turn [6]. In practice, the *lv*s should be based on the actual monitoring depth ratios and determined in combination with the musical temperament outlined above.

It should be noted that when the simple method of determining *lv* length is used, the solar terms are predicted according to the temperature fluctuations in the shallow soil (Figure 8). The large, yearly temperature variation in the shallow layer is thus beneficial to hou-qi. The rising and cooling phases can be divided into 5 sections and the solar terms monitored according to the pressure response recorded. The overall response corresponds to outflow in the first 7 months of the year and inflow in the following 5 months of the year.

Before the time of the Yellow Emperor, the creation of the *lv*s of different length would have been enacted by the separate states/tribes. In the Yao, Shun, and Yu eras, however, it became an important political mission of the Chinese nation to 'unify the date, time, *lv*, length, capacity, and weight (《尚書·堯典》: '協時月正日, 同律度量衡'). That is, it was stipulated that the *lv* used for hou-qi in all of the states had to be unified. Thus, it was set up under Huangzhong that the length of the longest *lv* was defined as 9 *Cun* (寸). Based on this, these *lv*s established the basic units of volume and weight [6].

[7] 《周易》: '爻象動乎內, 吉凶見乎外.' '*Zhouyi*': 'The images of hexagram changes inside, and the concave and convex can be seen outside.'

'*Dadailiji Zenzi tianyuan*' record that "*lv* is located in the *yin* part of the yearly STVZ depth, and controls expression of *yang*, while *li* (曆) is located in the *yang* part, and controls expression of *yin*. The *lv* and *li* are controlled by each other, there no gap of a hair's breadth between them (律居陰而治陽, 曆居陽而治陰. 律曆迭相治也, 其間不容髮)." From this point of view, *li* is a complementary concept to *lv* and should refer to the length of the temperature-increasing part in the yearly STVZ. Thus, the *li* added to the corresponding *lv* is equal to the depth of the yearly STVZ, to be more specific, the length of *lv* in the Huangzhong. This is the early, rather narrow, sense of *lv* and *li*. They later evolved into the idea of *calendar* and were more concerned with date and time. The *lv*-calendar is focused on determining the length of the 12 month's *lv*s, so the hexagrams of the months (Table 3) are only in rough correspond with the variation in time (and therefore are not rigorous, so called Liuriqifen '六日七分', six *Jia*-months is divided by seven lunar months).

In some places, the people simplified the *lv*s. For example, they used just one *lv* in a hole in the ground or a hole with different *lv*s so they could also monitor the solar terms. It was thus found possible to match the earth-air response with the solar terms using the technology. This is, after all, very important in agricultural societies as the people use the solar terms to guide their agricultural timings. The main value of hou-qi was, therefore, that it determined the conditions of the microclimate based on the actual monitoring results.

4.3. Five Movements (Wuxing, 五行) and Six Qi (Liuqi, 六氣)

By building big houses (palaces), the ancient Chinese were able to avoid the effect on the ground of the daily fluctuation in the solar radiation intensity. This made the daily STVZ become fully incorporated into the yearly STVZ, allowing the timescales to be made more uniform (resulting in the average yearly cycles shown in Figure 4c). Therefore, the layers in the hexagrams start from the *surface* and the positions of each layer are determined by time. As the thermal energy is conducted downwards, it will, after a certain amount of time reach down to a certain depth, whereupon the phase will change. In turn, the time can be determined by using the depth. The Chinese word *shi* (㬎/時, meaning 'time') was hence defined as a word in itself and reflects the depth to which the solar heat was conducted in the soil.

A specific method of division was used to introduce the idea of double trigrams [33]. The soil was divided using six lines (i.e. the lines of the hexagrams) starting from the surface and moving downwards to the last site. At the end of the sixth site, the phase changed, so the soil was divided into 5 sections or periods, as shown on the left in Figure 9a. This is the origin of the *Five Movements* (《史记》: '地有五行'). The first half of the year corresponded to the temperature-rising stage, each period corresponding to a different month. The second half of the year corresponded to the cooling stage, as shown on the right in Figure 9a. At the beginning of the Fuxi era, the concave/convex nature of the closed films applied to the mouths of five pipes were used to identify the change occurring in the yin and yang (see Section 3.1). This is the origin of the *lv*. The movement of the five sections is called the Five Movements. The ten periods (each equivalent to one month) were named *tian-gan* (天干), each period/time corresponding to a certain depth and solar term state. At that time, the concept of lunar months had not been established based on the changes occurring in the phase of the moon.

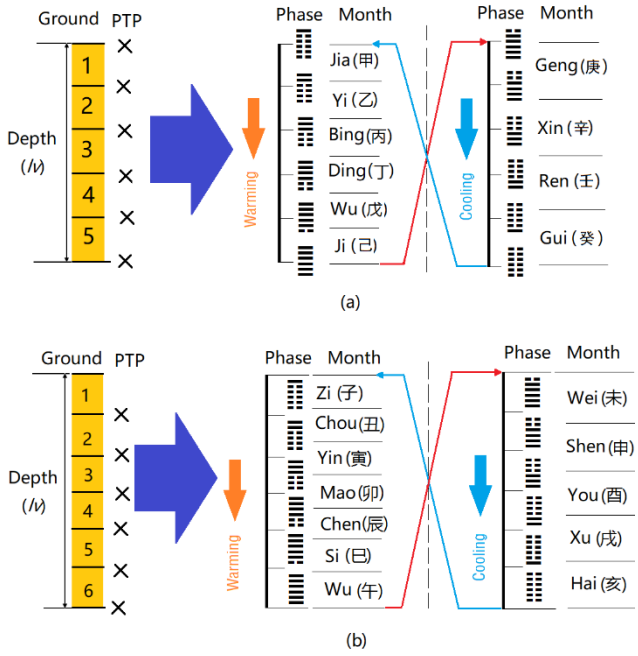

Figure 9. *Methods of interpreting the hexagrams. (a) The phase-transformation positions (PTPs) and corresponding Five Movements in a 10-month calendar. (b) The corresponding Six sections in a 12-month calendar.*

The temperature changes thus created a total of 5 segments and 6 phase-transformation positions in the soil. The hexagrams therefore reflect the temperature changes that occur on the timescale with which the Earth moves around the Sun. They thus successfully capture the most basic information about the Sun-Earth system. The lines drawn in the hexagram correspond to infinitely short lengths of time, in theory. The end site also corresponds to the greatest soil depth that can be affected by heat/temperature, i.e. the depth of the Huangzhong *lv*. Moreover, when the heat reaches the end line, the upper layer is starting a new round of temperature changes. Thus, the ䷒ hexagram stays in front of the ䷓ hexagram (and the ䷊ hexagram in front of the ䷋ hexagram). Similar relationships hold between the other lines. In essence, these 5 segments and 6 PTPs reflect the fact that the ancient Chinese at that point had no concept of '0'.

So, according to the changes occurring in the yin-yang, the

year is divided into two parts: the first half of the year is the time in which the yang changes; the latter half is when the yin changes. Together, the changes add up to form a 10-part calendar known as the *Jia*-calendar (甲曆) with each 'month' (Ri,日) lasting 36 days (Figure 9a). The so-called 'seven-Ri (日) recovery (䷗ 復)' There are 15 solar terms in a year and each has 24 days [49, 50]. The remaining 5 days (6 days in a leap year) were used for sacrifice and harvest celebrations. This is the famous 10-month calendar that was used from the time of Fuxi (around the early Dadiwan period) to the time of Shennong (神农) (around the Yangshao period) [51]. The calendar only needed 10 pipes to monitor the rise in temperature/pressure and was focused on the rise of earth-air and increase in soil temperature that occurred in the 10 sections. At this time, there may have already existed a method of using '10 *lv*s' in shallow soil to perform hou-qi. Today, the 10-month calendar is still employed by the Yi (彝), Bai (白), Hani (哈尼), and Lisu (傈僳), as well as other ethnic minorities [51, 50].

In the Five Movements system, the amount of time between ䷁ (Kun, 坤) and ䷀ (Qian, 乾) (when yang changed to yin) is 216 days; from ䷀ to ䷁ is 144 days. '*Zhouyi*': 'Qian has 216 days, and Kun has 144 days, in all 360, it is the period of undergo time.' (《周易》: '乾之策二百一十有六，坤之策百四十有四，凡三百有六十，*當期之日*). This is exactly consistent with the warming and cooling periods in Figure 4c. Therefore, exactly 6 months of the 10-month calendar (216 days; ~7 months in the Gregorian calendar or lunar calendar.) account for 9 of the 15 'solar terms' ($9 \times 24 = 216$ days) when heating occurred. Cooling took place during the other 4 months or 6 'solar terms' ($6 \times 24 = 144$ days) in Figure 9a (~5 months in the lunar/Gregorian calendar). This is the origin of the Qian hexagram 'using nine' and the Kun hexagram 'using six' in I Ching. In this way, time and space can be completely unified. That is, using space we can express time and using time we can express space. The annual period of the 10-month calendar is very stable, so the solar terms and dates could be fixed correspondingly.

At the core of the Five Movements theory was the need to determine the depths of the five sections. This was necessary to ascertain the transformation between yin and yang and hence comply with the Eight Trigrams model. In musical theory, the Five Movements correspond to the 'Five Tones' (五音: *jiao* 角, *shang* 商, *gong* 宫, *yu* 羽, and *zhi* 徵). In *Guanzi Diyuan* 《管子 地员》, it is recorded that: "Digging to 35 feet (about 7 m) will reach to the spring; the tone is *jiao*." In fact, there is a linear relationship between the Five Tones and depth. More explicitly, the ratios jiao:shang:gong:yu:zhi correspond to 35:28:21:14:7 or 1:0.8:0.6:0.4:0.2. These numbers are very close to the depth ratios determined in the Mogao Gobi soil, as mentioned above Table 3. This correspondence meant that the depth of the deepest *lv* in the yearly STVZ scale could be measured in ancient times.

In about the Yellow Emperor's time, the 10-month calendar was reformed to a 12-month calendar — the Chinese lunar calendar — called *dizhi* (Figure 9b). In this case, the temperature-increasing process was divided into six sections, known as the 'Six Qi' in *Huangdineijing*《黄帝内經》. In this reformed calendar, the depth reached at the beginning of the month was still regarded as the depth of this month. The monthly *lv* in the 12-month calendar refers to the distance from the surface to the depth of the line which *yang* changes to *yin*. Furthermore, the month's hexagram image refers to *this varying line phase at the beginning of this month*. In addition, the dates in the 12-month calendar are disturbed by leap months (there are 7 leap months in 19 years). Therefore, the response date does not exactly correspond to the month's hexagram (but the hexagrams can match perfectly with the period of monthly solar radiation intensity changes). This results in the Chinese 12-month lunar calendar being generally later than the Gregorian calendar by ~2 months, as shown in Figure 4 and Table 3. The *lv*s from long to short correspond to the lunar months from *Zi* (子) to *Hai* (亥) in the traditional document.

Based on the two experiments outlined in Section 2, we infer that by controlling the hou-qi of the materials used and regulating the burial depth of the *cong*, just *one* jade *cong* would have been needed to monitor the 12 months and 24 solar terms. Most jade *congs* are engraved with scales which would have been used to regulate their burial depth. In this way, they were able to make 72 times measurements in a year, each corresponding to one *hou* (~5 days).

We also infer that this monitoring process was, at first, carried out in the ground like the *lv*s were generally monitored. Later, however, in order to increase the sensitivity of the monitoring process, it was carried out in a *lingtai* (靈台) in a big house. The height of a *lingtai* is about 50 cm and its diameter is about 2.6 m [52]. This means that the *cong* would have been protected by a roughly 1-m-thick layer of soil, and this would have eliminated the effect of daily temperature changes and small weather events. However, the overall temperature variation would have been consistent with the annual air temperature variation. Thus, the temperature fluctuation range would have been large and facilitated the accurate monitoring of the earth-air. Using a *lingtai*, it would probably have been just possible to measure a solar term (15 days). To monitor the 72 *hou*s, however, they must have used activated carbon in the *cong*.

4.4. Historic Evolution of Hou-qi and Fengjian

It was that Fuxi who invented hou-qi, formulated the *Jia*-calendar, and used the Eight Trigrams model to reveal the rising and falling of the earth-air. To the ancient people, this would have marked the mastering of a law of Nature. Because of the regularity of the *lv* activity, the term w*enming* (文明, which is generally translated as *civilization*) was defined in I Ching. The original meaning of *wenming* in Chinese refers to the intersection (*wen* 文) of the *heat* with the soil and relates

to the downward conduction of heat produced by the solar radiation (Figure 4). As the heat is formed by the sunlight (*ming* 明), the terms *ming* and *youming* (幽明, 'secluded bright') also appear in the I Ching. Using a *gui* to dig to the 'bright' intersections was thus called 'dig earth to open bright' (闢地開天). Therefore, 'civilization' refers to the people understanding the principles underlying the regular activity of the *lv*s (文明以健[8]). By using this knowledge, the ancient people were able to survive through their labor and successful agricultural production. They could therefore live peacefully and develop in a sustainable way, having rid themselves of the constraints that Nature used to impose on them. This is the sociological meaning of *civilization* in I Ching.

Therefore, it could be considered that the Chinese people started to form a civilized society from the time of Fuxi. At that time, the hou-qi, Eight Trigrams, and calendar concepts spread completely spontaneously. The tribes elected Fuxi as 'the King of the kings (百王之先) and took the initiative to accept this civilization process as a way of benefiting the people, thus laying the roadmap for the development of Chinese culture.

Hou-qi was conducted in palaces to monitor the regional microclimate and thus guide the farming activity of the around people. This is the original meaning of the word of 國 ('state'). This is a compound word with parts that mean 'use *ge* to dig land', 'buried pipe', and '*bi*'. It therefore refers to using hou-qi to guide the agricultural production in the area, and so it also means 'territory'. Therefore, the predecessor of Fengjian was *building hou-qi* (建候), which meant looking for a suitable place to establish an institution (palace), laying an airtight foundation to seal the soil to establish a hou-qi system, producing jade instruments, installing the equipment, and managing the facility. The focus was on establishing the solar terms, a calendar, and state in order to benefit the people, i.e. the people would obtain wealth by closing the soil and building *lv* (封建厥福). This illustrates that scientific discovery and technology can have a profound impact on social institutions.

Up to the Shennong period, the main purpose of sealing the soil (in addition to performing hou-qi in shallow soil and monitoring solar terms) was to build the Five Tones using the Five Movements. Based on the Eight Trigrams theory, many different methods and numerous jade instruments were invented to facilitate hou-qi. At the same time, religious ideas and sentiments were starting to emerge. However, it was still the case that different kingdoms preferred to use different methods and, as a result, had different units of time, *lv*, length, capacity, and weight, etc.

In the Yellow Emperor's time, more sensitive monitoring methods may have been discovered that allowed the ancient people to detect the influence of the moon on the earth-air [30]. This could have sparked the change from the Five Movements to the Six Qi, and from the 10-month calendar to the 12-month Chinese lunar calendar (an epoch-making transition). The core of hou-qi was shifted to enact the *lv*s. After a unified country was established, unifying the *lv*s became the focus in hou-qi and this led to its unification with musical temperament as music was an important part of the rites performed by the people. At that time, 'Fengjian' had a special political meaning: *feudalism* (i.e. dividing land to build up states). However, the establishment of a vassal state required the approval of the emperor and the state had to adopt the methods used in the unified hou-qi system.

At some point during the period from the time of Zhuanxu (顓頊) to the Xia Dynasty (夏), earth-air monitoring (i.e. sacrifice to Heaven and Earth) became the Emperor's privilege. The feudal princes did not have the right to perform hou-qi and promulgate a calendar and private hou-qi was completely prohibited. Because of the this, at certain sites in China — Sanxingdui (三星堆) [53], Shimao (石峁) [54], and Taosi (陶寺) [55, 56] — hou-qi jadeware and other ritual vessels have been unearthed that were rudely damaged and then buried. At the Shimao site, it appears that the authorities were so afraid the jadeware would be dug out and reused (the special name for this is *fubi* 復辟, meaning 'restoration') that the items were pressed into the city walls [57]. Due to the precipitous terrain surrounding the Sichuan (四川) Basin, the destruction of the Sanxingdui site was postponed for about 1,000 years. Eventually, however, the ancestral temple and *Sheji* were destroyed in Sanxingdui and Jinsha (金沙) and jadeware relics and other bronze ritual objects were buried in pits [58, 59]. In remote Guangdong, hou-qi was continued up to the Zhou period (1000 bc) and was then completely prohibited [60].

However, making hou-qi a privilege created an awkward situation: the solar terms were monitored in the capital which was subject to a certain kind of microclimate. The results were therefore not very representative for whole country. As a result, the monitoring results even no better than the expected theoretical stipulation (15 days in a solar term, the solar terms being used to guide the farming activity across the whole of the unified country). Therefore, due to the imposition of its exclusive usage rights and lack of universal application, the down-to-earth practice of hou-qi may have gradually been lost during the Xia and Shang dynasties (becoming a legend of the Mingtang System).

In the Western Zhou dynasty, based on the principle of the Eight Trigrams, hou-qi then developed into a systematic culture called *Zhouyi*《周易》, changing at its core from natural science to social science. The feudal political system continued until the Eastern Zhou dynasty. From the Qin dynasty (秦朝), a system of prefectures and counties was formed centered on the central imperial power and the feudal political system died out. However, the Fengjian culture [such as *Zhouyi*, *Zhouli* (周禮)] was still at the core of society. This continued to be the case over the subsequent 2,000 years or so. It wasn't until the eighth year of Emperor Kangxi's rule (ad 1669) that

[8] The root of the words '健'and '建' is '聿', which means '律'.

hou-qi was officially denied. However, the traditional Fengjian culture still has strong vitality today [7].

Chinese culture therefore started out as Fengjian culture, which came from the practice of hou-qi. Based on the Eight Trigrams model from beginning to end, its initial aim being to create *lv*-calendars to ascertain agricultural times. Its political meaning, methods, and focus were different at different stages, but the core ideas of I Ching remained unchanged. The concepts of hou-qi, Five Movements, Six Qi, sealing soil to establish *lv*s, dividing land to build up states, etc. have been inherited and developed in a continuous way and can undoubtedly be called Fengjian in the widest sense of the word. The Chinese civilization originated from a prescientific system. In contrast, the early earth-air experiments were conducted in a systematic scientific manner and thus constitute a high starting point in China's scientific endeavors. It must have been very profound for the people to realize they could measure something that varied on the scale of the Sun and Earth! It is, perhaps, an early example of a scientific discovery having a profound impact on the superstructure of society. However, when the practice of hou-qi was lost, the people started to speculate wildly about the meaning of the Eight Trigrams, then draw wrong conclusions by false analogy, make a strained interpretation. This led Liang Qichao (梁啟超) to say: "The I Ching is a stronghold of feudal superstition." It seems that this is undoubtedly true.

Hou-qi would have been of inestimable value in ancient times, as it enabled the creation of *lv*-calendars that could be utilized to guide agricultural production. Nowadays, the same sort of guidance could be achieved by simply using a thermometer to monitor the soil temperature in real-time. Therefore, hou-qi is essentially an 'old-fashioned' earth-air monitoring technique and the associated jadeware items are some of the earliest scientific monitoring instruments. In fact, hou-qi may be the earliest meteorological monitoring technique devised by man. It certainly seems to be the one with the longest history of continuous use (over 4,000 years). The Eight Trigrams themselves are some of the earliest characters created. For humans they represent the notion that the laws of Nature may be complicated but they are governed by rules that can be rationalized and understood. It is possible that the ancient Chinese had an understanding of earth-air that was far deeper than our current level of comprehension. The comprehensive achievements they made based on their earth-air monitoring experiments show that mankind started to become civilized at least 9,200 years ago. However, in the hou-qi sense, China has only experienced a completely 'Fengjian society'.

In short, Fengjian is a kind of science and technology — sealing soil to build *lv*. Agricultural production based on Fengjian can obtain wealth stably, with a stable sense of control and satisfaction, the so-called blessings by Fengjian. Therefore, the Chinese civilization originated from the scientific monitoring of earth-air. It was Fuxi who have created the Chinese completed agricultural system and made Chinses people independent of Nature system, give up the law of the jungle, thus he thus plotted a civilization path for the world. The rediscovery of Fenjian has great significance, its scientific spirit could still be at the core of civilization in the future.

5. Conclusions

Based on the results of experiments monitoring the yearly variation in the temperature of soil, closed-system experiments, and archaeological jade artifacts that have been discovered (*jue*, *xuanji*, *bi*, *cong*, *zhang*, and *mao*), the present author has reconstructed the earth-air monitoring method (hou-qi) that was used in ancient China. The scientific recovery of the method used in hou-qi reveals the Fengjian nature and origin of the Chinese jadeware.

Jade was used to fabricate the earliest monitoring instruments and these were then used by the ancient Chinese people to scientifically monitor the earth-air and build *lv*-calendars. By carbon dating the jadeware artifacts, it has been proved that the Chinese civilization originated at least 9,200 years ago, making it one of the oldest civilizations in the world. At this time, humans already had a profound understanding of solar radiation and annual temperature changes. They must have also realized that the spatial variation in temperature could be used to indicate the variation of time. The roots of Fengjian can be found in the practice of hou-qi and by determining the response of the earth-air to temperature variation they found they could establish an *lv*-calendar. Therefore, the main purpose of Fengjian was to look for the laws that govern Natureand guide the people to harness these laws. Through their own labor, they were able to conduct agriculture in a timely and sustainable manner. In this way, they solved the problem of survival and entered the realm of civilized society.

Abbreviations

STVZ	Soil Temperature Variable Zone
CTHC	Controlled Temperature-Humidity Chamber

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Author Contributions

Hongshou Li is the sole author. The author read and approved the final manuscript.

Data Availability Statement

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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