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ON FRACTAL MECHANISM OF COASTLINE —A Case Study of China

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ABSTRACT: MANDELBROT enunciated the uncertainty of the length of a coastline in his paper "How long is the coastline of Britain?" published in "Science" in 1967. The fractal concept was presented for the first time in that paper and has been applied to many fields ever since. According to the fractal theory and conditions of fractal research of coastline, the controls of faults and biologic function on the fractal character of coastline are preliminarily discussed on the basis of GIS in this paper. Finally, some significant conclusions are drawn: 1) the faults control the basic trends of coastlines of two study areas; 2) the fractal dimension of coastline of Taiwan is smaller than that of Changle – Lufeng, because the faults of Taiwan more intensely control the trend and fractal dimension of the coastline; 3) the larger the fractal dimension of the faults or the major faults, the more the controlling effect of them on the trend and fractal dimension of coastline; 4) the larger fractal dimension of the coastline of Changle – Lufeng indicates that the biologic function intensely shapes the coastline. In a word, the controls of faults and biologic function on the fractal character of coastline are discussed with a case study of China in this paper, it can be seen that faults and biologic function both have influence over the trend and fractal dimension of coastline, the fractal mechanism of coastline of two study areas may be so.

KEY WORDS: fractal; fractal dimension; GIS; faults; biologic function; coastline

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1 INTRODUCTION

MANDELBROT (1967) enunciated the uncertainty of the length of a coastline in his paper "How long is the coastline of Britain?" published in "Science" in 1967. The fractal concept was presented for the first time in that paper and has been applied to many fields ever since. The fractal dimensions of different coastlines have been calculated by many researchers of MANDELBROT (1967), GOODCHILD (1980), PHILLIPS (1986), QIU (1988), TURCOTTE (1992), PHILIP (1994), ANDRLE (1996), JAY and XIA (1996), PAAR *et al.* (1997), JIANG and PLOTNICK. (1998), STOMCZYNSKI (1999), ZHU *et al.* (2000). Till now, related references and further researches on the fractal mechanism of coastline are seldom seen. The controls of faults and biologic function on the fractal character of coastline are preliminarily discussed in this paper with a case study of China. It may be useful to deepen the related study.

2 METHOD AND DATA SOURCES

2.1 Method

There are two methods to calculate the fractal dimension of coastline: one is the divider method (MANDELBROT, 1982), and the other is the box-counting method (GRASSBERGER, 1983). The former is never used in practice because of its main limitation: the object being measured must be connected, but the latter has no restrictions on the shape of the object. The box-counting method is used in this paper.

To calculate the fractal dimension of coastline, one covers the coastline with the square grid with variable length. Supposing the length of side of the square grid is ε_k, and the number of grids including the coastline is $N(\varepsilon_k)$, according to the fractal theory, then

$$N(\varepsilon_k) \propto \varepsilon_k^{-D}$$

The corresponding lengths of sides of square grids

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are $\varepsilon_1, \varepsilon_2, \varepsilon_3, \ldots, \varepsilon_k$, and the numbers of grids covering the coastline are $N(\varepsilon_1)$, $N(\varepsilon_2)$, $N(\varepsilon_3)$, ..., $N(\varepsilon_k)$ correspondingly. The equivalent equation is

$$\lg N(\varepsilon_k) = -D\lg\varepsilon_k + A$$

where A is a constant, and D is the fractal dimension of coastline. D is given by the absolute value of the line slope.

MapInfo 5.0 and ArcView GIS 3.2a are used in the grid analysis, then the extracted data are analyzed in Excel 2000. It is self-evident that this data processing method on the basis of GIS is more precise than manual operation. The technological flow for fractal analysis of coastline is shown in Fig. 1.

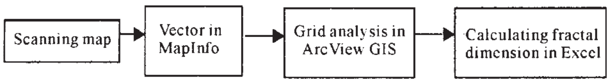

Fig. 1 Map of technological flow for fractal analysis of coastline

2.2 The Principles for the Coastline Selection

The coastline under study in China is selected according to the rules similar to that drawn by Jiangsu Survey Bureau when the coastline was demarcated in the investigation of land resources of China in 1990.

(1) Principle for demarcating the boundary between land and sea on river mouth.

The harbor character of the large river mouth is retained, the landforms of sand-spit, shoal and lagoon are reflected and the horn shape of the river mouth is displayed. If the river mouth is unsymmetrical, the boundary is marked where the river becomes narrow or the curvature of promontory is the largest.

(2) Principle for demarcating the islands.

The islands off the bedrock coast and silt coast are not counted. The land of silt beach, which is protrusive during high tide, is considered as an island. The shoreline is not counted either.

2.3 Data Sources

Two study areas are selected in this paper: One is the region of Changle – Lufeng, it extends from Changle in Fujian Province to Lufeng in Guangdong Province (Fig. 2), and the other is Taiwan Island (Fig. 3). The maps used are from the Atlas of Landsat Imagery of Main Active Faults in China (Institute of Seismology of State Seismological Bureau, 1989) and the Atlas of Geo-Science Analyses of Landsat Imagery in China (Department of Research and Development of National Remote Sensing Center *et al.*, 1984). Their scales are 1∶2 000 000.

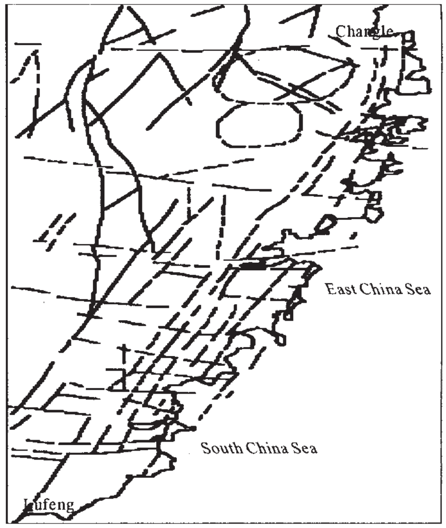

Fig. 2 Map showing faults and coastline in the region of Changle – Lufeng

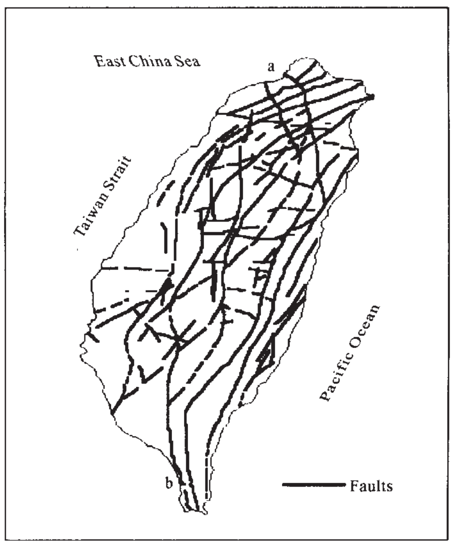

Fig. 3 Map showing Taiwan coastline and faults

3 CONCLUSIONS

(1) The fractal dimensions of faults and coastlines of two study areas are listed in Table 1. The fractal dimensions of faults in Fig. 2 and Fig. 3 are D_{f1} and D_{f2} respectively, the fractal dimension of coastline in Fig. 2 is D_{c1}, that of coastline of bedrock coast in the eastern Taiwan Island extending from point a to b in Fig. 3 is D_{c2}, that of the whole coastline of Taiwan Island in Fig. 3 is D_{c3}.

Table 1 Fractal dimensions of faults and coastlines in Fig. 2 and Fig. 3

	D_{f1}	D_{c1}	D_{f2}	D_{c2}	D_{c3}
Fractal dimension	1.042	1.0291	1.0961	1.0017	1.0024
Correlation coefficient	0.9946	0.9992	0.9904	1	1

Table 1 shows that the correlation coefficients of fractal dimensions of faults and coastlines approach to 1.00, indicating that statistical fractal character exists in them, and their fractal dimensions are constant. From Table 1, it can be seen that the values of D_{f1} and D_{c1} are 1.042 and 1.0291 respectively, the values of D_{f2} , D_{c2} and D_{c3} are 1.0961, 1.0017 and 1.0024 respectively.

(2) As shown in Table 1, the value of D_{f1} is smaller than that of D_{f2}, it can be seen that the complexity of spatial distribution of faults in Fig. 3 is clearly more than that in Fig. 2. Thus, the fractal dimension of faults is an useful parameter depicting the complexity of spatial distribution of faults.

(3) The faults in Fig. 2 develop in the mesozoic granite and terrane, and consist of four approximately parallel major faults whose trend is to northeast. They are interweaved with some faults of small scale whose trends are to northwest and east-west. Then the tectonic pattern of grid is formed, but the fault cliffs completely develop in the clearly linear regions. The activities of major faults are associated with faults whose trends are to northwest and north, and the faults control not only the development of small quaternary fault basins, but also the development of shoal and deep-sea trough. As shown in Fig. 2, the faults whose trend is to north-northwest form the basically geomorphic pattern of Taiwan Island. The eastern Taiwan is intensely influenced by the faults, its crag stands and its coastline is smooth and straight. A comparison between Fig. 2 and Fig. 3 shows that the faults control the basic trends of the coastlines as a whole. The coastline of Changle – Lufeng in Fig. 2 looks like curly, but its basic trend is to northwest by and large. The trend of the whole coastline of Taiwan Island is also controlled by the faults whose trend is to north-northwest. It is more obvious to the coastline of bedrock coast in the eastern Taiwan.

(4) Though the faults control the basic trends of the coastlines of the two study areas, the differences of the fractal dimensions of coastlines exist. The bedrock coast is intensely controlled by the faults in the eastern Taiwan, its crag stands and its coastline is comparatively smooth and straight, its fractal dimension (D_{c2}) is only 1.0017, and smaller than that of the coastline of Changle – Lufeng (D_{c1}). According to the comparison between D_{c1} and D_{c2}, on one hand, it can be seen that the faults in the eastern Taiwan more intensely control the trend and fractal dimension of the coastline, on the other hand, it is revealed that the biologic function also plays an important role in the development of the coastline of Changle – Lufeng. There are bedrock coast and biologic coast in that area. Though the region where the biologic coast lies is very calm, the fractal dimension of the coastline in Fig. 2 is much larger, because its coastline is intensely shaped by the biologic function.

(5) There is bedrock coast in the eastern Taiwan, whereas the plain coast in the western Taiwan. A comparison between D_{c2} and D_{c3} shows that the fractal dimension of the whole coastline of Taiwan Island is larger than that of bedrock coast in the eastern Taiwan, because the coastline in eastern Taiwan is more intensely controlled by the faults.

(6) The major faults control the basic trends of the corresponding coastlines in Fig. 2 and Fig. 3, in addition, the value of D_{f2} is larger than that of D_{f1}. The fractal dimensions of major faults are further calculated. They are listed in Table 2.

Table 2 Fractal dimensions of major faults in Fig. 2 and Fig. 3

	D_{z1}	D_{z2}
Fractal dimension	1.016	1.0348
Correlation coefficient	0.9979	0.9989

D_{Z1} is the fractal dimension of major faults whose trend is to northeast in Fig. 2, D_{Z2} is that of major faults whose trend is to north-northeast in Fig. 3. The value of D_{Z2} is larger than that of D_{Z1}, and the value of D_{f2} is larger than that of D_{f1}, indicating that the fractal dimension of faults or major faults in Fig. 3 is larger than that in Fig. 2. At the same time, the fractal dimension of coastline of bedrock coast in the eastern Taiwan is smaller than that of Changle – Lufeng, because the faults of Taiwan more intensely control the trends and the fractal dimensions of coastlines (D_{c2}, D_{c3}). The larger the fractal dimension of the faults or the major faults, the more the controlling effect of them on the trend and fractal dimension of coastline. The larger fractal dimension of the coastline of Changle – Lufeng indicates that the biologic function intensely shapes the coastline. In short, the factors controlling the trend and fractal dimension of coastline are various. In two study areas, the faults control the basic trends of the two coastlines, and the variable fractal dimensions of coastlines result from the effect of faults and biologic function.

4 DISCUSSION

In this paper, the controls of faults and biologic function on the fractal character of coastline are discussed with a case study of China, it can be seen that faults and biologic function both have influence over the trend and fractal dimension of coastline, the fractal mechanism of coastline of two study areas may be so.

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