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Research Article

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Evolution of the radial sand ridges off Subei Coast

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ABSTRACT

In order to understand the evolution of modern tidal sand ridges, this paper studied the development of radial sand ridges and the movement of suspended sediments around sand ridges in northern Jiangsu (Subei) Coast, China, by use of multi-temporal satellite images, bathymetric maps and field data. The results showed that the total number of radial sand ridges off Subei coast especially the number of small sand ridges (no more than 10km² in area) increased significantly while total area and average area of sand ridges decreased sharply. High content of suspended sediments frequently existed in the center of the radial sand ridges, and the suspended sediments moving towards there resulted in the accumulation of sand there and erosion of outer sand ridges. Radial sand ridges are in the stage of breaking-down and shrinking on the whole. The distribution and diffusion of suspended sediments plays an important role in the evolution and stability of sand ridges. The increase or decrease in net sand transport indicates accumulation or erosion of sand ridges.

Key words: Radial sand ridges, Off Subei Coast, Satellite images and bathymetric maps, Suspended sediments, Evolution

INTRODUCTION

Tidal sand ridge is an important landform unit in coastal zone and continental shelf area, which is widely distributed in the estuary, harbor, etc. [1]. Since the 1960s, scholars have conducted the detailed studies on the formation and evolution of tidal sand ridges [2], sedimentary model and classification of sand ridges [3] as well as internal structural and sedimentological characteristics of sand ridges [1]. Radial sand ridges off Subei Coast are special tidal sand ridges, which were discovered in the 1950s and carefully studied in the 1980s [4]. Since the 1990s, the researchers have conducted the in-depth studies on the formation mechanism, dynamic environment, evolution [5-7] and sediment supply [8] of radial sand ridges. Nevertheless, scholars have attached less importance to modern stability and evolution of sand ridges. This paper studied the development trend of radial sand ridges by use of remote sensing and GIS techniques with the filed observations.

STUDY AREA

Located in Jiangsu coast between Yangtze River Delta and abandoned Yellow River Delta, radial sand ridge off Subei Coast is about 200 km long and 90 km wide, with a total area of 20,000 km² (including an area of 1696.41 km² above sea level), which is the largest sand ridge in China. Radial sand ridge off Subei Coast is famous for its special pattern, complex landform and varied hydrodynamic conditions. The entire sand ridge, taking Qionggang as the summit, comprises more than 10 large submarine sand ridges like Dongsha sand ridge which extend in the north, east and southeast directions (Fig. 1). The total number of large and small sand ridges there exceeds 70, with respective length of 10-100 km and width of 10-15 km. The water depth in tidal creek between sand ridges is 10-30 m, even up to 48 m. The flood currents in the study area gather radially to the center of sand ridges, while ebb currents diffuse to the sea [9].

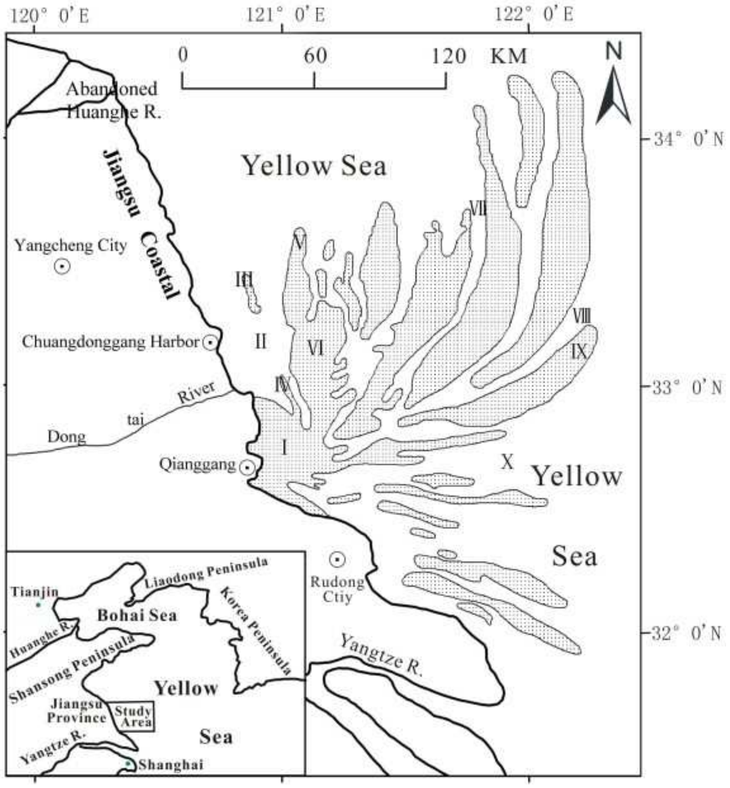

Fig. 1. Distributions of tidal sand ridge

Ⅰ= Tiaozini Ridge; Ⅱ= Xiyang Trough; Ⅲ= Sanyazi Ridge; Ⅳ= Beijianzi Ridge; Ⅴ= Liangruesha Ridge; Ⅵ = Dongsha Ridge; Ⅶ = Chenjiawucao Trough; Ⅷ = Kushuiyang Trough; Ⅸ = Jiangjiasha Ridge; Ⅹ= Huangshayang Trough.

EXPERIMENTAL SECTION

Landsat TM and NOAA satellite images in 1987-2000 were used to monitor the diffusion of suspended sediments; bathymetric maps in 1966 and 1979 were used to compare the vertical change of sand ridges; the measured data of large area of suspended sediments in sand ridge region were used as the supplement to verification data. ENVE 4.5 software was used to process the satellite images. The distribution of suspended sediment concentration(SSC) in radial sand ridge region were obtained by density slicing of TM (4, 3, 1 combined band) and NOAA (channel 1) images. We selected 9 training samples from typical sand ridge region and sea area to analyze their spectral features for the supervised classification. Bathymetric data were digitalized and processed by software Mapinfo.9.0.

RESULTS

Distribution of suspended sediments

Field measurement of SSC: In spring (April), the surface SSC in sand ridge rises above 100 mg/L (Fig. 2a) from less than 10 mg/L, the measured maximum value (184 mg/L) appeared at the summit of sand ridge. The level curve of SSC extends to outer part of sand ridge from the center of radial sand ridge from high to low. The distribution of bottom SSC in sand ridge in spring is basically similar to that in the surface layer (Fig. 2b), but its concentration (the measured maximum value was 523 mg/L) is generally 2-4 times of that in the surface layer. In autumn (September), the distribution characteristics of surface and bottom SSC (Fig. 2c and 2d) are basically similar to those in spring, but the SSC generally decreases, which is one-fifth of spring value in the surface layer and half of spring value in the bottom layer.

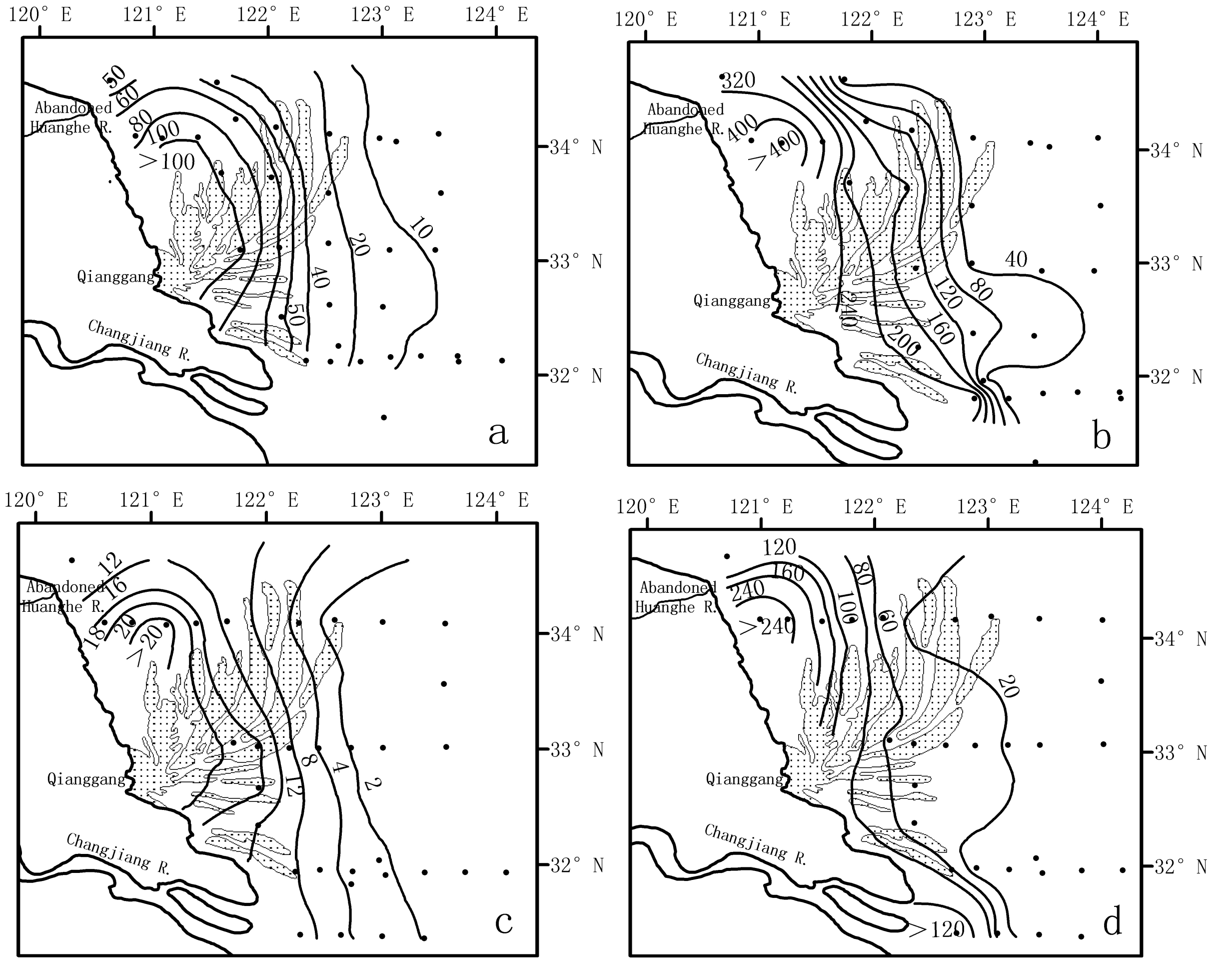

Fig. 2. SSC in mg l -1 at (a) sea suface and (b) near bottom during April 2003; (c) sea surface and (d) near bottom during September 2003

Satellite images of SSC: Landsat TM (1987) and NOAA (1988) images were used to monitor the distribution and diffusion of suspension sediments in the study area.

Seen from NOAA satellite ch1-band images (imaging time: 13:00 on April 16, 1987) processed by density slicing, the suspended sediments in radial sand ridge region, basically centered on the sea area between Yancheng and Rudong, diffuse in the form of three water flows to the north, northeast and southeast, of which the muddy water flows to the north and the northeast are more intense (Fig. 3). These two muddy water flows extend to the entire abandoned Yellow River Delta in the north. Muddy water flow to the southeast forms a band and connects to muddy water flow with high content of suspended sediments near the Yangtze River estuary. Muddy water flow close to the coast in the southeast direction has low content of suspended sediments and small flow range.

Fig. 4 shows the distribution of suspended sediments by Landsat TM satellite image (imaging time: April 9, 1988), with base map scale of 1: 200000. At the time of imaging, this region was at low tide, muddy water flow extended to outer sea along tidal creek under the influence of ebb current, accordingly clear seawater intruded into sand ridge region. On the west bank of Xiyang, except that the river estuaries had high content of suspended sediments, the rest was the intrusion area of clear seawater; the east bank had high content of suspended sediments. In the shallow water around some small sand ridges and in the surroundings of submarine sand ridges, there were high content of suspended sediments, suggesting that the waves disturbed and re-suspended the surrounding shoal sediments [10].

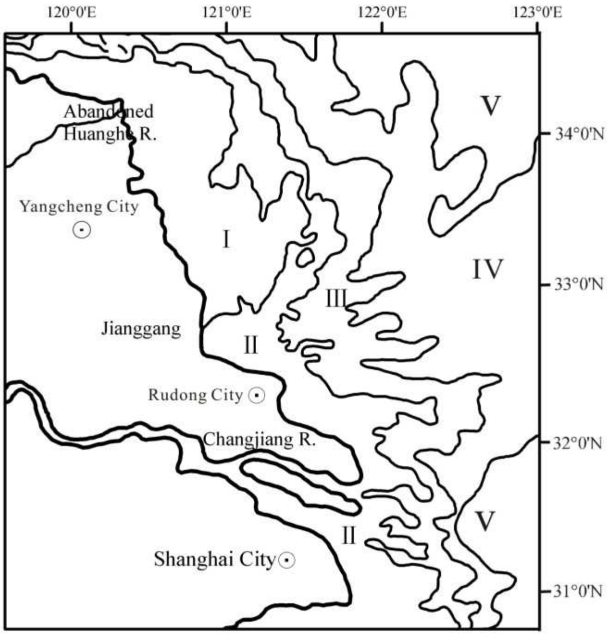

Fig. 3. Interpretation map from density slicing NOAA image Channel 1 (Apr. 16, 1987). Ⅰ－Ⅴ: contend of suspended sediment from high to low

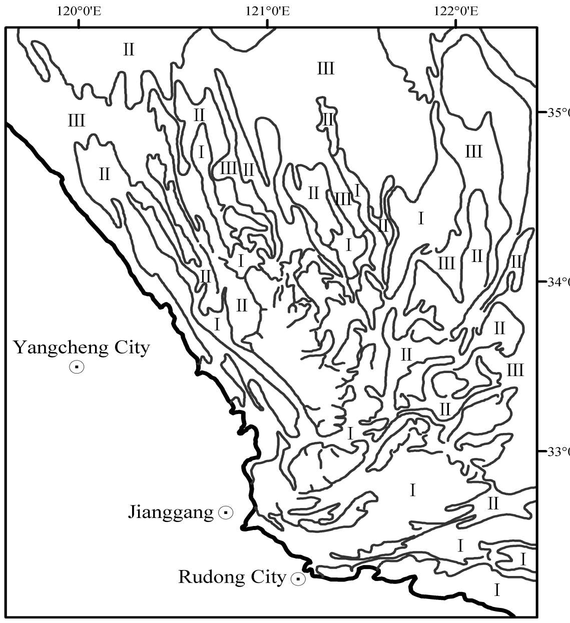

Fig.4. Interpretation map from Landsat TM image (Apr. 9, 1988). Ⅰ－Ⅲ: contend of suspended sediment from high to low

GIS statistical analysis of quantity and area of sand ridges

The bathymetric maps in 1966 and 1979 were digitized and compared in Mapinfor 9.0, which gave the quantity of sand ridges, area of each sand ridge and total area of radial sand ridges. The analysis results showed that on the bathymetric map of 1966, there were 17 sand ridges with respective area of no more than 10km² (above zero meter line, the same below), while the average area of sand ridges was 5.8 km². On the bathymetric map of 1979, the quantity of such sand ridges increased to 21, while the average area of sand ridges was 5.77 km². Some small sand ridges have disappeared or decreased in area. For example, Liangyuesha in the north of sand ridge covered an area of 60.04 km² in 1966, which decreased to 43.92 km² in 1979. However, some sand ridges increased in area. For example, Sanyazi covered an area of 6.4 km² in 1966, which increased to 15.93 km² in 1979. The elevation of radial sand ridges was also calculated. The average elevation was -7.5 m (elevation range of -32-5.8 m) in 1966 and reached -5.6 m (elevation range of-34-7.8 m) in 1979, indicating that radial sand ridge has been elevated by 1.9 m in the past 13 years.

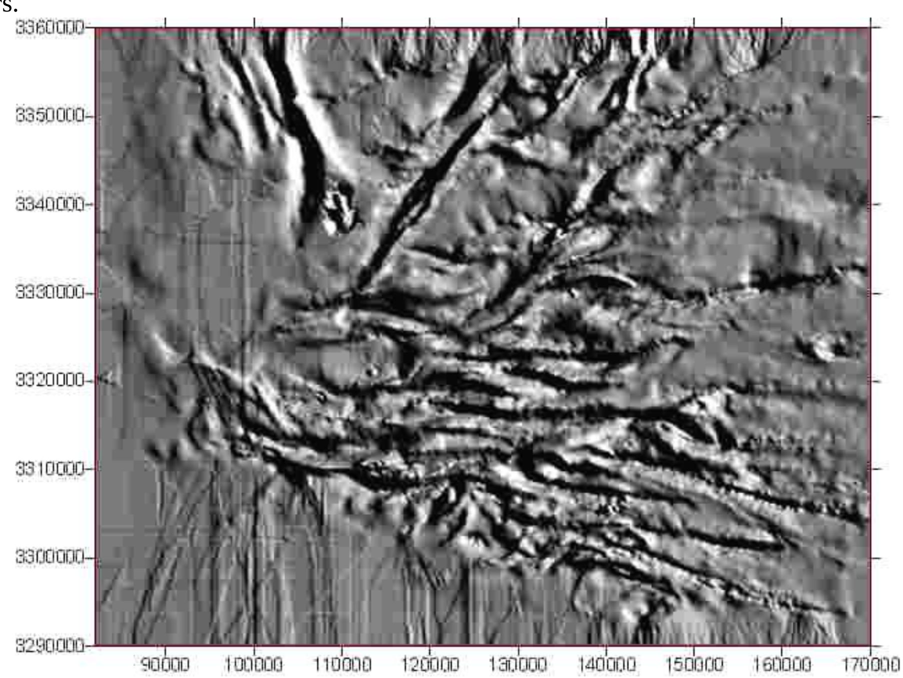

Fig.5. Space diagram of the central area of the radial sand ridges between 1960' and 1970'

The areas of 60km in east-west and north-west directions in the center of radial sand ridge were respectively taken as the contrast areas to study the erosion change inside radial sand ridge, with computational grid of 50m. The calculation results showed that the center of sand ridge in 1966 had an elevation change of -31.5-5.8 m, with average elevation of -0.97 m (including sea ridge area of 2,242 km² above sea level with average elevation of 1.7 m; sea ridge area of 1,358 km² below sea level with average elevation of -5.3 m). In 1979, the elevation change was -31.5-5.8 m, with average elevation of -0.97 m (including sea ridge area of 2, 293 km² above sea level with average elevation of 3.9 m; sea ridge area of 1, 307 km² below sea level with average elevation of -5.4 m). Seen from this, the center of sand ridge has been elevated by 1.46 m in the past 13 years (elevated by an average of 2.2 m above sea level), but the tidal creek zone has been in a state of erosion (Fig. 5).

DISCUSSION

Distribution characteristics of suspended sediments

The distribution of suspended sediments in the study area has seasonal and regional differences, but the concentration of suspended sediments in the middle of radial sand ridges are generally higher (with measured maximum value of 523 mg/l) (Fig. 2a, b, c and d), and the SSC distributes in the form of fan from the middle to outer part of sand ridge under different tide conditions. The measured data indicate that surface and bottom concentrations of suspended sediments in spring are both higher than that in autumn due to the impact of waves.

The distribution of SSC in the study area is closely related to the substances in abandoned Yellow River in the north and modern Yangtze River in the south. The concentrations of suspended sediments in these two areas are both higher (Fig. 2 and Fig. 3). Abandoned Yellow River Delta and submarine sea area in the north were subject to intense erosion, about 40 billion tons of substances returned into the sea [11], of which a large part entered into the sand ridge region and led to rapid silting in some area, even up to 100 m/a [12]. According to the comparative study of remote sensing images for sand ridge region, the sand ridges in northern sea area moved frequently, and the movement speed of small sand ridge was up to 350 m/a [13], resulting in re-suspension of more sediments.

The distribution of suspended sediments in sea area around sand ridges is obviously related to submarine tidal creek. The concentration of suspended sediments in tidal creek was the lowest, the concentration on both sides of tidal creek was at the middle level, and the concentration at the summit of sand ridge was the highest (Fig. 4). Satellite image of April 9, 1988 showed that the diffusion shape of muddy water flow of suspended sediments was very similar to the landform there.

Evolution trend of sand ridges

The sand ridges changed with fluctuations, but on the whole they were in the breaking-down stage with increase in quantity and decrease in average area. From the early 20th century to the 1970s, radial sand ridges were in a state of shrinking, for example, the north side and east side of sand ridge region shrank nearly 20 km. Meanwhile, Xiyang tidal creek increased in width, main line of tidal creek constantly moved eastward, head of tidal creek extended southward; Dongsha sand ridge decreased in area, it shrank in east, west and north sides, moved outward in south side only; Tiaozini and other sand ridges tended to be broken due to the extension of tidal creek head (Fig. 5).

Seen from the comparison between bathymetric maps in 1966 and 1979, the total number of sand ridges especially the number of small sand ridges (no more than 10 km² in area) increased significantly while total area and average area of sand ridges decreased sharply. For example, the number of sand ridges with respective area of no more than 10 km² increased to 21 in 1979 from original 17 in 1966 (above zero meter line, the same below); the total number of sand ridges increased to 61 from 41 in 1966, while total area of sand ridges decreased by 352km², and the annual average decrease in the area of sand ridges above sea level was about 27km². The total volume of sediments in the center of sand ridges increased by 5.23×10^9 m³, of which the silting area accounted for 71.2% of total area while the erosion area accounted for 28.8% of total area. The sediments in radial sand ridges obviously gathered to the centre (Fig. 5).

Field observations indicate that the edge of Dongsha sand ridge appears to be broken due to being cut by new tidal creeks in recent years, and tidal creeks swing quickly. The artificial buildings built to the west of Dongsha in early 1980s and originally located at the ridge of sand ridge (near Xiyang) are currently in sub-tidal creeks of Xiyang, with the foundation eroded by nearly 4 m (Fig. 6A) in the past 20 years. The ridge of sand ridge has been also eroded; new tidal creeks move quickly in Dongsha sand ridge and tend to continually extend to the center of sand ridge (Fig. 6B).

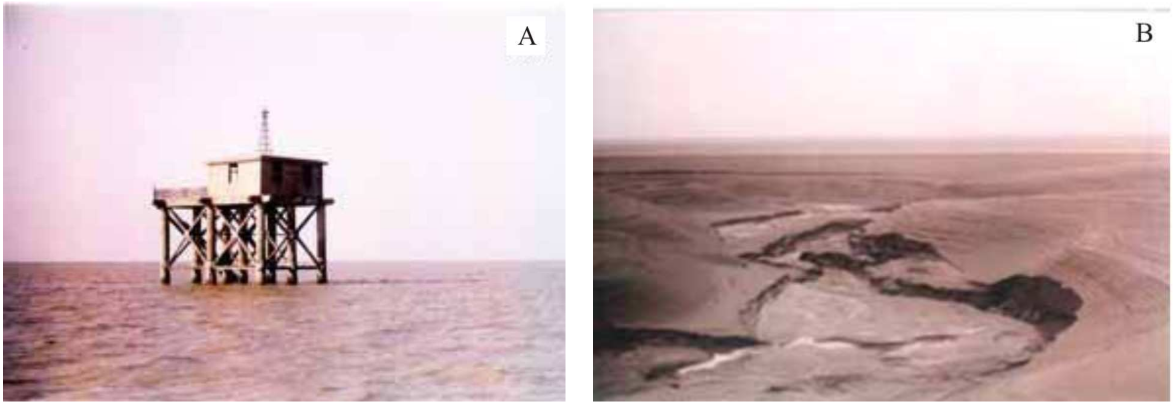

Fig. 6. (A) Tidal channel eroded the floor of a human structure (it was on the top of Dongsha ridge previously, and now it is in the tidal channel). (B) Growth of tidal channel in the sand ridge

CONCLUSION

Seen from the comparison of bathymetric maps for sand ridge region, the total quantity of sand ridges especially the quantity of small sand ridges (no more than 10 km^2 in area) increased significantly while total area and average area of sand ridges decreased obviously. On the whole, sand ridges are in the breaking-down stage with increase in quantity and decrease in average area. The distribution and diffusion of suspended sediments is a very important factor affecting the evolution and stability of sand ridges. The increase or decrease in net sand transport is an obvious indicator for accumulation or erosion of sand ridges. The frequent existence of high content of suspended sediments in the center of sand ridges and the movement of suspended sediments towards there caused the accumulation of sand there, and erosion of outer sand ridges. Meanwhile, the submarine sand ridges in the northeast were greatly developed because of the abundant suspended sediment. As a result, the average pattern of suspended sediment showed some evolution information of submarine sand ridges.

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