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BASIC CHARACTERISTICS AND CONTROLLING FACTORS OF ANASTOMSING FLUVIAL SYSTEMS

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ABSTRACT: Although anastomosing fluvial rivers are given much attention recently by some research workers because the result channel sandstone of which is one typical primary reservoirs of petroleum and natural gas, of which the flood plains and the interchannel wetlands are pay zones where coals had formed, the comprehension of anastomosing river is some extent limited at present. Some researchers regard that the anastomosing river river and the anabranched river are the same kind of rivers. In this paper, the sedimentary, geomorphic and hydraulic characteristics and the main controlling factors of anastomosing fluvial system are summarized systematically. Some of the characteristics are compared with others fluvial rivers. Humid climate is suitable to form anastomosing channel systems, in arid-semiarid regions anastomosing river maybe develop if many befitting factors combine together. The authors of the paper think that anastomosing river is one typical channel pattern and is dissimilar to anabranched channel pattern.

KEY WORDS: anastomosing rivers; geomorphic characteristics; sedimentary characteristics; controlling factors

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1 INTRODUCTION

The term "anastomosing river" was first applied by SCHUMM (1968), referred to stable, low bed-load, multiple channel system with low gradient, high sinuosity and separated vegetated islands. This specific meaning on "anastomosis" which was first used by Jackson in 1834 ended the synonymous history of anastomosing and braided river. In the latest three decades, series of modern and ancient anastomosing fluvial depositional systems were studied. Some typical anastomosing rivers have been developing in modern sedimentary environments, such as the lower reaches of the Saskachewen River, the anasto mosing reach of the Alexandra River (SMITH *et al.*, 1980) in Canada; the upper reaches of the Columbia River (SMITH, 1983) and the Cooper's Creek in Australia (RUST, 1981); the Magdalena River, the Mistaya River and the Wakool River in Colombia, South America (SMITH, 1986), and the anastomosing fluvial in Rhine-Meuse Delta of Netherlands (TORNGVIST, 1993), etc. Some ancient anastomosing fluvial depositional systems were discovered in the Lloydminster of Canada (PUTNAM, 1983) and in the Cutter Formation in New Mexico (EBERTH *et al.*, 1991), etc.

Modern anastomosing rivers are also discovered in China, for examples, the Jingjiang tributaries of the Changjiang (Yangtze) River, the Tongjiang O reach of the Heilong River and rivers at Zhujiang

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(Pearl) River Delta are all typical anastomosing rivers. Though some examples of anastomosing fluvial systems are reported in China (ZHANG, 1994; ZHANG and WANG, 1997; CHEN, 1998), the studies on which are still insufficient or even misunderstanding. For example, the Mayangzhou anabranched reach of the Changjiang River was improperly referred to an anastomosing channel pattern by ZHANG (1988), the braided reach of the Luanhe River in the Qian' an Basin was wrongly regarded as an anastomosing channel pattern by ZHANG and LIU (1994) *et al*.

The differences between the anastomosing and the anabranched rivers have gradually caught more attention of research workers. Knighton and Nanson (1993) showed that the interchannel lands of anastomosing rivers were usually excised from the continuous floodplain and were greatly related to the size of the channels. NANSON and KNIGHTON (1996) classified the anastomosing rivers as a fine-grained, low-energy subset of the broader category of anabranching systems (GIBLING *et al*., 1998). It is a pity that up to now, many water engineers and geomorphologists have not realized the importance of anastomosing river yet, still regarded it as one of channel patterns related to anabranched rivers.

The above brief review shows that the understandings of anastomosing river still have not reached an agreement. The paper here elaborates the basic characteristics and controlling factors of anastomosing fluvial systems and gives its comparison with other fluvial systems.

2 THE BASIC CHARACTERISTICS OF ANASTOMOSING RIVER

2.1 Stable Multiple Channels, Muddy Interchannel Wetlands and Floodplains

Anastomosing river shows a complex of multiple channels, interchannel wetlands and broad floodplains. It differs from braided river that has higher flow energy and discontinuous floodplains composed of silt-sand sediments, the interchannel sand bars of which continually migrate laterally and downstream, the locations of braided channels change frequently. Comparing with braided river, channels of anastomosing river are very stable because the interchannel wetlands and floodplains are composed of mud-silt sediments and usually are covered by dense vegetation. Although some bank sediments were eroded by water flow, the channels migrate inappreciably. Anastomosing river also differs from anabranched river. Anabranched fluvial system has duality of floodplain that is composed of upper thin mud-silt beds and lower thick sand bodies. The lower thick sand bodies connect with active channel sand body as a whole and both of them forming accompany with the migration of old channel. The interchannel wetlands and floodplains of anastomosing river are composed of fine grain sediments only without sand bodies in which (Fig. 1).

2.2 Fine Grain, Cohesive Sediments and Dense Vegetation

The banks of anastomosing river are composed of muddy and silty sediments with high coherence. They are the natural barriers of wetlands and floodplains. The flow is confined in channels at normal water level period; while at flood period, the flood water may overflow the banks, the wetlands and the floodplains and deposited the fine grain suspended sediments there. By this way not only are the wetlands and the floodplains aggraded but also the banks are consolidated. It differs from braided rivers of which the banks are hardly developed. It also differs from anabranched and meandering rivers of which the banks are developed moderately. In the meantime, the dense vegetation covered the banks, the wetlands and the floodplains of anastomosing rivers, these arbors, shrubs and herbage plants also consolidate the banks with their roots thus increase the ability of banks to resist flow scouring. All these are the main reasons why anastomosing channels are very stable.

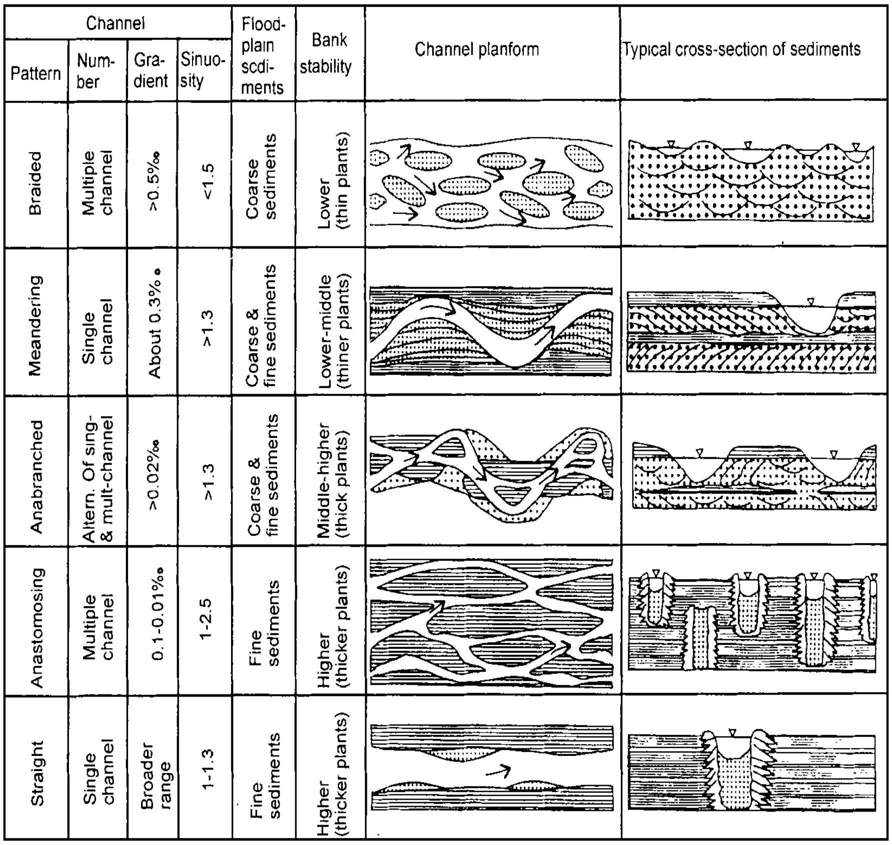

Fig. 1 Comparison of anastomosing and other fluvial systems

2.3 Low Channel Gradient and Low Flow Energy

Comparing with braided, anabranched and meandering rivers, anastomosing rivers have the lowest mean gradient commonly (Table 1). Most of them in Table 1 are between 0.2‰ and 0.02‰. Only a few anastomosing rivers have relative high gradient. For example, the gradient of the Mistaya River is 3.9‰ (Table 1), this is rare in anastomosing river systems. The controlling factors of the Mistaya River are cohesive fine sediments, dense plants on the banks and constant runoff, the influence on the channel pattern by gradient is rather limited. Ordinarily, low gradient causes the low channel flow energy, and flows with lower energy certainly will do less to the stability of channel banks. In multiple channel system the discharge variation and flood peak steep of anastomosing river are far smaller than that of braided rivers. These characteristics dominate that the scouring undergone to anastomosing river banks is smaller than that do to braided river banks. It is similar to meandering or anabranched rivers. So the low gradient is also one main cause why anastomosing channels are very stable.

2.4 Depositional Micro-Environments

Anastomosing rivers develop under specific geomorphic, tectonic and climatic background. Their depositional micro-environments commonly involve the following elements: anastomosing channels, abandoned channels, avulsion channels, natural levees, crevasse splays, confined meander belts, interchannel wetlands, floodplain wetlands, numerous shallow lakes and peat bogs, etc. The formation of these environments is closely related to the channel geometry such as gradient, sinuosity and flow hydraulic condition such as discharge variation and flow energy etc. In Table 2 the geometry, micro-geomorphic characteristics and depositional micro-environments are compared among three rivers which are typical examples respectively for anastomosing, braided and meander- ing river systems.

Table 1 The sinuosity and channel gradient of some anastomosing rivers

Time	River names	Mean sinuosity	Channel gradient (‰)	Width/Depth ratio of chan.	References
Modern	Lower Saskatchewan River (Canada)	1.4	0.123		SMITH (1983)
	Upper Columbia River (Canada)	1.16	0.096		SMITH (1983)
	Wakool River (Canada)	1.65			SCHUMM (1968)
	Alexandra River (Canada)	1.51	0.6	8–23	SMITH *et al*. (1980)
	Mistaya River (Canada)		3.9	8–41	SMITH *et al*. (1980)
	N. Saskatchewan River (Canada)		1.0	9–35	SMITH *et al*. (1980)
	Cooper's Creek (Australia)	1.61–1.75			RUST (1981)
	The River in Rhine-Meuse Delta (Holland)		0.025	< 30	TORNQVIST (1993)
	Zhujiang River (Xijiang Channel) (China)	1.03–1.23	0.023	> 13.6	WANG (1998) *
	Ana. Chan. Reach of Heilong R. (China)	1.3–4.5	0.063	54	WANG (1998) *
Ancient	The anas. fluvial system of sparky Formation in Lloydminster (Canada)	1.56	1.9	8.6	PUTNAM (1983)
	Cutter Formation (USA)			< 15	EBERTH *et al*. (1991)
	Magdalena River (Colombia)		0.082–0.124	20	SMITH (1986)
	The Pliocene anastomosing channels of Qaidam Basin (China)	1.12–1.21		< 70	WANG (1998) *

* WANG Sui-ji, 1998, Comparative study on fluvial sedimentary characteristics of different fluvial styles, the Dr. thesis of Peking University.

Table 2 Comparison of depositional micro-environments among anastomosing, braided and meandering rivers

Comparative items	Lower Saskachewen River* (Anastomosing river)	Luanhe River (Braided river)	Beatton River* (Meandering river)
Planform	Anastomosing multiple channel, interchannel muddy wetland, dense vegetation	Braided multiple channels, interchannel sand bars, thin vegetation in banks	Meandering single channel, developed vegetation in banks
Sinuosity	1.62	1.23	2.1
Channel width/depth ratio	9–35	42.5–91	–
Gradient (‰)	0.122	1.25–1.45	0.3
Sediment of floodplain and/or wetlands	Mud and silt	Sand and gravel, thin and discontinuous mud bed	Double bed of Lower Sand and upper mud
Suspend/bed load ratio	Highest	Lowest	Middle
Aggradation way	Vertical accretion	Vertical and lateral accr.	Lateral accretion
Aggradation rate	5–30cm/100a.	–	±5cm/100 a.
Levees	Prominent	Rare	Common
Scroll bars	Few	Rare	Common
Oxbows	Common	Rare	Common
Abandoned channels	Common	Common	Absent
Avulsions	Common	Never	Never
Crevasse splays	Few	Rare	Absent
Meander belt	Confined	Never	Wide
Shallow lakes	Common	Never	Rare
Peat bogs	Common	Never	Rare
Dunes of banks	Never	Common	Rare

* Some data are from SMITH (1983).

Obviously, as illustrated in Table 2, the channel geometry and micro-geomorphic characteristics and depositional micro-environments among the three types of channel patterns are different completely. The anastomosing channels, interchannel wetlands, developed natural levees, avulsion channels, numerous shallow lakes and peat bogs are the typical micro-geomorphic elements and depositional micro-environments of anastomosing rivers. These depositional micro-environments are rare in the other fluvial river systems such as braided, meandering, anabranched and straight river systems.

3 THE GEOMORPHIC CONDITION AND CLIMATIC BACKGROUND

3.1 Geomorphic Condition

Anastomosing rivers appear commonly in alluvial plains and some delta plains, some develop in the intermountainous basins. The regions where the anastomosing river develops usually have low ground gradients. Low ground gradient lead to the formation of low channel gradient, and finally to the formation of anastomosing rivers. The formation and development of anastomosing rivers require suitable subsidence of basin floor. It makes the channel gradients vary little while the sediment experience rapid aggradation in anastomosing channels. There exists the condition in the alluvial plains, delta plains and intermountainous basins.

If the subsidence rate of basin floor is inappreciable, the rising of sea level is another main controlling factor of anastomosing formation and development. The sea level rising is similar to the subsidence of basin floor and both influence the channel geometry and sedimentary rates. Among the three geomorphic elements above, the delta plains correspond to the sea level rising most obviously, so anastomosing rivers develop frequently in delta plains.

3.2 Climatic Background

As stated above, the dense vegetation covered over the banks, interchannel wetlands and floodplains, which is one factor that maintains the stability of banks and channels. In fact, the dense vegetation is strongly influenced by the climate, besides, small discharge variations of anastomosing rivers are also closely related to climate.

Anastomosing rivers develop popularly in tropical, subtropical and temperate zones, most of them appear in humid regions. For examples, the lower reaches of the Saskachewen River, the Jingjiang tributaries of the Changjiang River, the Tongjiang reach of the Heilong River and rivers at the Zhujiang River Delta are typical anastomosing rivers in humid regions. This channel pattern also develops in arid-semiarid regions, but this is not common. The Cooper's Creek of Australia (RUST, 1981) and Red Creek of U.S.A (SCHUMANN, 1989) are two examples in aridregions. However, anastomosing rivers appear in humid regions more than in arid regions. It is obvious that the humid climate is suitable to form anastomosing channel systems. In arid or semiarid regions, if many befitting factors combine together, anastomosing rivers maybe develop there.

Some characteristics of the anastomosing rivers in humid and in arid-semiarid regions are compared at Table 3. The densities of anastomosing channels are about 20% in humid regions (SMITH *et al.*, 1980) and lower than 3% in arid-semiarid regions (RUST, 1981), respectively. At arid-semiarid regions, the vegetation and levees of the rivers did not develop well and new channels may be formed by crevasse at the low-lying or unsubstantial locations of levees, the interchannel areas are very broad. At humid regions, the vegetation and levees of anastomosing river develop well, new channels were formed by avulsion. Desiccation crack and calcareous crust are more common and vertical aggradation rate is less in arid-semiarid regions than that are in humid regions. The channel stability is higher and the average thickness of channel sand bodies is thicker in humid areas than is in arid-semiarid regions. So the width/depth ratios of anastomosing channels in arid-subarid regions are higher than that in humid regions, but they are far smaller than that of braided, meandering or anabranched channels.

Table 3 Comparison of anastomosing fluvial depositional systems in humid and arid-semiarid climate regions

Comparative items	Humid climate region	Arid climate region
Channel	Stable multiple channel systems	Stable multiple channel systems
Density of channels	About 20% (Smith & Putnam, 1980)	Lower than 3% (Rust, 1981)
Suspend mud / bed sand ratio	Higher	Lower
Vertical aggradation rates in floodplain	Higher	Lower (for the interchannel areas are broader)
Frequency of crevasse	Lower	Higher
Width/depth ratio of channel	Lower	Higher
The characteristics of over bank mud	Desiccation crack is fewer, absent continuous calcareous crust	Desiccation crack is common, exist continuous calcareous crust
Vegetation density	Higher	Lower
Main controlling factors of channel stability	Rising of sea level, fine sediments and dense vegetation	Eolian accumulation, tectonic subsidence, cohesive mud and calcareous crust
New channel formation	Avulsion	Crevasse or avulsion
Aggradation rates	Channel aggradation rate is equal to that in floodplain	Channel aggradation rate higher than that in floodplain
Organism sedimentation	Plants exist in organism	Plants exist in rhizoid nodule

4 THE CAUSES OF ANASTOMOSING RIVER FORMATION

The formation of anastomosing rivers is influenced by many controlling factors. These factors involve rapid downstream subsidence of basin floor, sea level rising, dense vegetation of bank belts, low gradient geomorphic location and cohesive sediments of levees and floodplains etc. The rapid downstream subsidence or, sealevel rising and high depositional rates in channels make the channel gradient keep varying little, thus the energy of the unit discharge and flow scouring ability to the banks changes little too. The cohesive muddy and silty sediments and dense vegetation above banks, floodplains and inter-channel wetlands increase the stability of channel banks and levees, all these lead to the formation of the low gradient and low flow energy, multiple inter-connected, suspended or mixed-loaded anastomosing channels separated by stable, vegetated floodplain.

Some main controlling factors that influence fluvial rivers are illustrated in Fig. 2. Although the main influencing factors for different fluvial patterns are similar, but their actions to each fluvial pattern are different. These associated influencing factors may form five basic fluvial patterns and can be transformed to each other. As a low energy channel pattern, the position and characteristics of anastomosing river are very clear.

Influencing factors above are concluded from field geomorphologic observation and depositional system studying. Their operation mechanisms, especially the avulsion mechanism of a new anastomosing channel, need simulating by experiment. So far the hydrodynamic simulations are mainly related to the braided, meandering rivers which are common in nature, and rare to straight and anabranched rivers. The comprehension to the concept and position of anabranched rivers still has controversy. One point of view is that the anabranched channel is a variation of meandering river (NI *et al.*, 1998). The anastomosing river as a fine-grained, low-energy subset of broader category of anabranching systems (NANSON *et al.*, 1996) is another representative viewpoint. The authors of the paper think that the anastomosing is one typical channel pattern and is dissimilar to

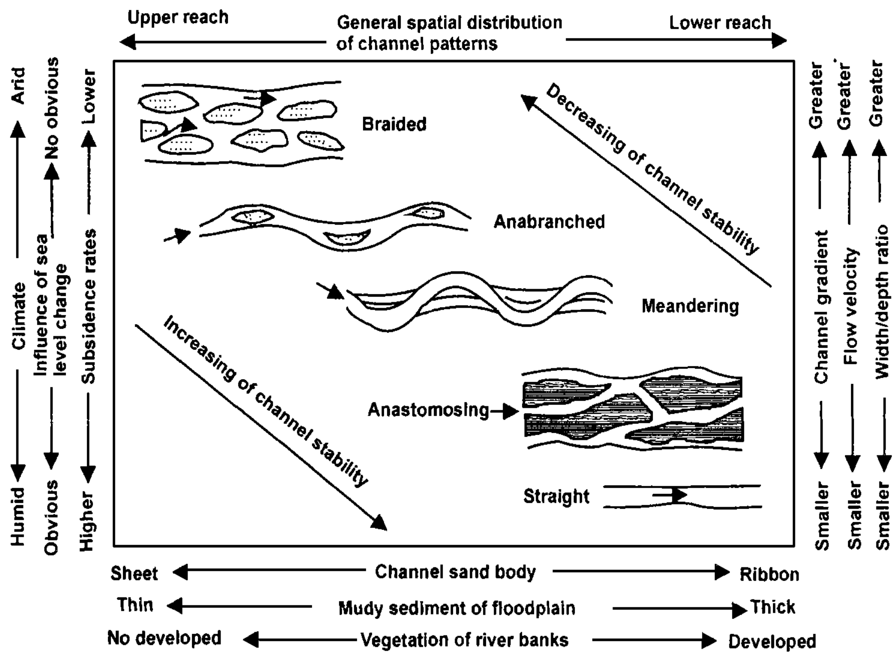

Fig. 2 Comparison of influencing factors between anastomosing and other fluvial rivers

anabranching channel pattern. It is a revolution that the anastomosing channel pattern will divide from anabranched patterns as the braided was divided from anabranched channel patterns. However, the study of geomorphic and depositional characteristics and cause of formation of anastomosing rivers need further hard work.

5 SUMMARY

Anastomosing river is one typical fluvial channel pattern, stable and multiple channel system, which has floodplains and interchannel wetlands composed of muddy and silty sediments. The cohesive muddy-silty sediments of levees, dense vegetation over bank belts, low channel gradient and flow energy may increase the channel stability. Its cross sections of channel sand bodies have very small width/thickness ratios. This kind of rivers develops commonly in alluvial plains, delta plains and intermountainous basins that have low land gradient. Humid climate is appropriate to form these rivers, but in arid-semiarid regions anastomosing rivers also appear accidentally. Anastomosing channels, interchannel wetlands, levees, avulsion channels, numerous shallow lakes and peat bogs are the typical micro-geomorphic elements and depositional micro-environments. The downstream tectonic subsidence or the sea level rising is main outer influencing factor of the formation and development of anastomosing rivers.

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