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한반도 남동부에 분포하는 해안단구의 지형층서 및 연대자료를 이용한 융기율 평가

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Estimation of Uplift Rate Based on Morphostratigraphy and Chronology of Coastal Terraces in the SE Part of Korean Peninsula

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요약: 동해안의 봉길리에서 정자지역에 분포하는 해안단구 퇴적물에 대한 지질조사와 새로운 연대측정 자료를 이용하여 우리나라 동해안 남부지역의 해안단구 층서를 재조명하였다. 동해안 해안단구는 해발고도에 따라 uHT (90~130m), HT (63~86m), MT (36~55m), 그리고 LT (8~25m) 등으로 구분된다. Lower Terrace I은 MIS 5c시기의 Aso-4 및 MIS 5d 혹은 5e시기의 Ata 테프라를 포함하고 있다. 이러한 테프라와 OSL 연대자료로 미루어 Lower Terrace I은 MIS 5e동안 형성된 것으로 해석된다. Lower Terrace II의 연대도 역시 테프라와 OSL 연대자료로 미루어 MIS 5a인 것으로 생각된다. Lower Terrace가 형성되었던 MIS 5동안의 한반도 남동부의 융기율은 0.08~0.25 mm이며, 평균 0.15 mm인 것으로 계산되었다. 이러한 융기율은 일본과 대만으로 비롯한 조구조운동이 활발한 다른 지역의 융기율에 비해서 매우 작은 값이다.

주요어: 단구층서, 하부 단구, 연대학, 테프라, 융기율

Abstract: Terrace stratigraphy of the southeastern coastal areas of Korea is reappraised on the basis of terrace mapping and geochronology. Coastal terraces are divided into uHT (90~130 m), HT (63~86 m), MT (36~55 m), and LT (8~25 m) according to altitude. Among these, the Lower Terrace I is interpreted to have formed during MIS 5e based on Tephras Aso-4 (MIS 5c), Ata(MIS 5d or 5e) and OSL data. The age of Lower Terrace II is thought to be MIS 5a based on tephras and OSL data. The uplift rate in the SE part of Korea during the formation of the Lower Terrace (i.e. the MIS 5) ranges from 0.08 to 0.25 mm/yr and averages as 0.15 mm/yr. Such value is quite small in comparison to that of Japan, Taiwan or many other tectonically active areas in the world.

Key Words: terrace stratigraphy, Lower Terrace, chronology, tephra, uplift rate

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1. Introduction

The development of Quaternary stratigraphy has led to establishment of several correlation schemes, which are based on traditional paleotemperature curve (Emiliani, 1966), generalized curve of oxygen stable isotope (Shackleton and Opdyke, 1973; Aguirre and Pasini, 1985), or terrestrial loess-paleosol sequence (Kukla, 1977; Ding et al., 1991). Coastal terraces are characterized by spherical and rounded beach pebbles along the coastline. They commonly show step-like distribution, because they are formed in response to coastal base level changes. Because the development of coastal terraces is directly linked to coastal base level change, their longitudinal and transverse distribution can provide valuable information in interpretation of uplift history of coastal landscapes. In Korea, terrace stratigraphy has been used as a very important tool in estimation of uplift rate, which is essential in safeguarding nuclear power plant or major infrastucture facilities against neotectonic movement and disaster (KIGAM, 1998; Lee et al., 2004).

Coastal terraces are conspicuously well-developed along the southeastern part of Korea (Kim, 1973; Oh, 1977, 1981; Jo, 1976, 1980; Lee, 1985, 1987; Kim, 1990; Kim et al., 1990; Lee and Kim, 1992a, 1992b; Kim, 2001; Kim et al., 2004a, 2004b; Choi W.H., 2004; Choi et al., 2004). Coastal terraces are be divided into 5 units, including beach and coastal alluvial plain (AP, 4~5m), Low Terrace (LT, 8~25 m), Middle Terrace (MT, 36~55 m), High Terrace (HT, 63~86 m) and upper High Terrace (uHT, 90~130 m). Successive coastal terrace steps can be mapped by altitudinal height, landscape dissection features (back and seaward edges) and lateral continuity. The aim of this study is to establish the stratigrahic distribution of coastal terraces, to reveal the age of Lower Terrace with the help of key tephra markers (Kim et al., 2004a) and finally to reevaluate of the uplift rate during the formation of the Lower Terrace. In this study, we focus on the Lower Terrace, which is distributed along the coast from Bonggil to Jeongja.

2. Terrace stratigraphy and chronology

The Holocene coastal alluvial plain (AP) represents a lowermost unit at about 4 to 5 m above modern sea level (a.s.l.). The AP is assumed to have formed during the Holocene Climatic Optimum (HCO) or Transgression-I (Holocene transgression, ca 7,000~6,000 yrs BP). The Lower Terrace occurs at the altitude of about 8 to 25 m a.s.l. (Kim et al., 2004a). The Lower Terrace II (lower) is distributed as low as 8~13 m, and frequently shows a sharp gradient change at its seaward edge. The Lower Terrace I (upper) is distributed between 18 and 25 m a.s.l.. The depositional age of Lower Terrace I and II can be dated both by tephrochronology and OSL datings.

The study of tephras may provide valuable information on the depositional age of terrace deposits. Tephras of Aso-4 (ca 90 ka) and Ata (100~120 ka) are found in the Lower Terrace I at the Yonghan site. The Aso-4 tephras are also found near Weolseong nuclear power plant site, while the Ata tephras occur at many sites, such as Sanhadong (Weolseong), Yonghanri (Pohang) and Shinchanri (Janggi), Jeongja (Gangdong)(Kim et al., 2004a). These tephras are distinguished by unique refraction index and the chemical composition of glass and pyroxene. The amount of glass in tephras is usually very small, probably indicative of considerable reworking. Based on the OSL ages and the tephra evidence, the formation of the LT I correlates with the MIS 5e (Kim et al., 2004a; cf. Shackleton and Opdyke, 1973). The age of Lower Terrace II can be also inferred from characteristic tephras. AT tephras (ca 25 ka) are found in the uppermost part of the Lower Terrace II as well as in the Lower Terrace I. However, they do not mark any separate stratigraphic horizon, but are present as scattered fragments, particularly in latest Pleistocene paleosol layer, or as reworked materials in the pedo−sedimentary layer. In case of the Lower Terrace II, tephra−bearing sediments are overlain by slope deposits, or old sands and gravels with some intercalations of muds as old as 30 to 40 ka. In the latter case, the top of sands and gravels is frequently covered with patterned ground formed under a cold climate regime during the last glacial maximum period (Kim et al., 2004b).

A number of OSL ages have been reported in the last several years by Korean and Japanese researchers. However, amongst these, Hataya's result from the Yonghan site in the northern part of Pohang City is promising in terms of both morpho−stratigraphical meaning and numerical dating (Hataya, 2003; Sasaki et al., 2003), because his attempt is to relate terrace stratigraphy to numerical ages. He showed that OSL ages of the Lower Terrace II, distributed at the level of about 10~12 m at the Yonghan site, are in the range of 58~63 ka. Hence, it is reasonable that the age of the basal beach gravels and wave−cut platforms is interpreted as the MIS 5a (Kim et al., 2004a).

3. Estimation of Uplift Rate

Using the evidence from the coastal terraces, an uplift rate for the SE block of the Korean peninsula was estimated by Choi S.G. (2001). He estimated the uplift rate as 0.10 mm/yr on the basis of the disposition of the last interglacial shoreline. In particular, he regarded some interval (12~18m a.s.l.) of the Lower Terrace as evidence for the last interglacial(5e, 125 ka).

In this study, the uplift rate for each terrace is recalculated on the basis of the height of paleoshorelines mapped in detail (Kim et al., 2004a, 2004b). The uplift rate is defined as a function of $Y=B+AX$, where A is terrace formation age (yr), B is a global average sea level (m), X is uplift rate (m/year), and Y is an average height of paleoshoreline in coastal terraces. The global average sea level is applied based on marine isotope stage (Hanson et al., 2002). Using the above equation, the uplift ratios of three coastal terraces (AP, LT and MT) are recalculated as follows. The Holocene AP (4~5 m a.s.l.)can be assumed to have formed during the Holocene Climatic Optimum and marine transgression, ca 6,000−7,000 yrs B.P. If we assumed that middle late Holocene global average sea level was about 0± 2 m, and that all

Table 1. Uplift rates of SE part of Korean Peninsula based on coastal terrace during the last half million years.

Coastal Terrace	Altitude (m)	Uplift Rate (mm/yr)	Remark
Mid. Holocene Alluvial Plain	3 ~ 4	0.14 (~ 1.00)	maximum rate exaggerated
Lower Terrace	8 ~ 25	0.08 ~ 0.25	LT II : 0.14~0.25mm/yr LT I : 0.08~0.17mm/yr
Middle Terrace	32 ~ 55	0.10 ~ 0.17	MT III : 0.15~0.17mm/yr MT II : 0.14~0.16mm/yr MT I : 0.10~0.15mm/yr

coastal plains in SE Korea were tectonic surfaces at that time, it comes out that uplift rate of Holocene AP is 0.14~1.00 mm/yr. But the maximum rate(1.00 mm/yr) is thought to be overestimated because there are some discrepancies in the temporal shoreline estimation during the Holocene. Some of the discrepancies are caused by the high wave regime of the eastern coastal area, storm washing processes during the typhoon season, and so on. The LT II (8~13 m a.s.l.) is interpreted to have formed during the MIS 5a, from which the uplift rate of Lower terrace II is estimated as 0.15 - 0.19 mm/yr (Y: ca 8~13 m, A: 80 ka(5a), B: -5± 2 m (assumed)). The LT I (18~25 m a.s.l.) is interpreted to have formed during the MIS 5e, hence the uplift rate is estimated to be 0.08~0.17 mm/year (Y: 18~25 m, A: 125 ka, B = +6± 2 m). Lastly, the MT III, II and I (32, 45 and 55 m, respectively) are assumed to correlate with the MIS 7e, the MIS 9, and the MIS 11, respectively, so that the uplift rates of MT III, II, and I are calculated as 0.15~0.17 mm/yr (Y: ca 32 m, A: 210 ka (MIS 7), B: -3± 4 m (assumed)), 0.14~0.16 mm/yr (Y: ca 45 m, A: 330 ka (MIS 9), B: -4± 4 m (assumed)), and 0.10~0.15mm/yr (Y: ca 55 m, A: 430 ka (MIS 11), B: 0± 10 m (assumed)), respectively. In summary, estimated uplift rates of the Lower Terrace (LT II and I, 8~25 m a.s.l.) vary between 0.08 and 0.25 mm/yr, while those of the MT (MT III, II and I, 32~55 m a.s.l.) range from 0.10 to 0.17 mm/yr (Table 1).

The lowest uplift rate is found in the LT I (0.08 mm/yr at 18 m level a.s.1.), while the highest one is observed in the LT II (0.25 mm at 13 m level a.s.l.). The average uplift rate of the LT is 0.165 mm/yr, and that of the MT is 0.135 mm/yr. Our uplift rate is greater than that of Choi S.G.(2001), but smaller than that of Choi S.J.(2004) (Table 2). Finally, it is concluded that the uplift rate of 0.15 mm/yr can be feasibly estimated as mean value in the SE part of the Korean Peninsular during the last half million years. This value is rather small compared to that of East Asian regions including Japan and Taiwan or Western Pacific regions during the same time interval (Chappel and Shackleton, 1986; Pillans et al., 1998).

Table 2. Comparison of uplift rates of coastal terraces based on different references.

Choi S.G. (2001), Choi S.G. et al.(2004),		Choi S. J. (2004)		Kim J.Y. et al (2004) and this study	
SE Coastal Area		Daebo−Guryongpo−Gampo Area		Jeonchon−Gangdong, Gampo Area	
Marine Terrace	paleoshore line(m)	Marine Terrace	paleoshore line(m)	Coastal Terrace	paleoshore line(m)
MT	30−50			MT	55
					45
		3a Tr*	30−33		36
		3b Tr	17−22	LT	25~18*
LT1 *	18				
LT2	10	2nd Tr	8−10		13~8
		1st Tr	< 1	Coast Plain	< 4
uplift rate: 0.10 mm/yr		uplift rate: 0.19 mm/yr		uplift rate: 0.15 mm/yr	

* MIS 5e is differently allocated according to references

4. Conclusion

Terrace morphology is conspicuous in the south eastern coastal areas of Korea and terrace formations are interpreted as responses to base level fluctuations. The LT I (8~13 m a.s.l.) and the LT II (18~25 m a.s.l.), were formed during the MIS 5e and the MIS 5a, respectively, based on the presence of the Aso−4 tephras (MIS 5c), the Ata tephras (MIS 5d or 5e), and much younger AT tephras (about 25ka) in the terrace deposits. The highest uplift rate is found in the recent coastal alluvial plains, but it is considered that coastal wave regimes or storm surges on the pebble beaches may bring about disposition of anomalous paleoshorelines due to coastal processes during typhoon season, rather than shoreline changes caused by Holocene uplifts. In addition, the Lower Terrace (LT I and LT II) show the uplift rate between 0.08 and 0.25 mm/yr, while the uplift rate of the MT ranges from 0.10 to 0.17 mm/yr. In conclusion, the average uplift rate of SE Korea is about 0.15 mm/yr, and this rate is rather small in comparison to that of other East Asian regions during the last half million years.

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