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# SPATIAL AND TEMPORAL VARIATIONS IN THE GEOCHEMISTRY OF CRETACEOUS HIGH-Sr/Y ROCKS IN CENTRAL TIBET

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**ABSTRACT. Recent studies based on low-temperature chronology and sedimentology have proposed the existence of a proto-Tibetan Plateau (p-TP); however, the timing and mechanisms of its formation and evolution remain ambiguous. High-Sr/Y rocks are an important petrological indicator of thickening. Here, we compile geochemical data of Cretaceous rocks to interpret their petrogenesis and to constrain deep geodynamic processes. Geochemical characteristics, in combination with zircon Hf isotopic compositions, indicate that the high-Sr/Y rocks were derived from the partial melting of thickened juvenile lower crust, with or without contamination by mantle peridotite. Comparing geochronological and geochemical data, we observe a correlation between magma migration and the composition of high-Sr/Y rocks. Based on these observations, we propose a revised tectonomagmatic evolution model for central Tibet, involving crustal thickening, retreating delamination, and breakoff. Our research suggests that the rapid uplift of the p-TP was a consequence of the removal of isostatic load during the Mesozoic.**

Keywords: Proto-Tibetan Plateau, high-Sr/Y rocks, crustal thickening, retreating delamination, breakoff, rapid surface uplift

## INTRODUCTION

Based on studies of the eastern Hoh Xil basin in north Tibet (fig. 1B), Wang and others (2008, 2014a) determined that the uplift of the Tibetan Plateau was progressive, and the authors proposed the existence of a proto-Tibetan Plateau (p-TP) prior to India–Asia collision. Previous numerical modeling and structural geology studies have suggested that the elevation of central Tibet was already above 4 km during the Cretaceous as a result of collision between the Lhasa and Qiangtang terranes (England and Housemann, 1986; Murphy and others, 1997; Kapp and others, 2003, 2007). Further evidence of this crustal uplift event is provided by the occurrence of molasse deposits (Li and others, 2016a; Sun and Hu, 2017) and the rapid cooling rates determined from granites (Guynn and others, 2006; Wang and others, 2007; Ren and others, 2015; Zhao and others, 2017). However, the timing and mechanism of formation of the p-TP remain ambiguous because of the limited study of coeval magmatic rocks.

The Bangong–Nujiang suture zone (BNSZ) separates the Lhasa terrane to the south from the Qiangtang terrane to the north (fig. 1), and represents remnants of the Bangong–Nujiang Ocean. Large-scale Cretaceous magmatism has been identified on the flanks of the BNSZ and is regarded as a key aspect to understanding the tectonic evolution of central Tibet (fig. 2). The significant compositional diversity of this magmatism has led to various geodynamic models being proposed, and these are still debated (for example, Zhu and others, 2011, 2016; Wu and others, 2015a, 2015b; Xu and others, 2017). For example, previous studies have demonstrated the presence of two arcuate E–W trending zones of magmatic rocks that parallel the BNSZ. The Early Cretaceous zone (125–110 Ma) is characterized by normal calc-alkaline magmatic

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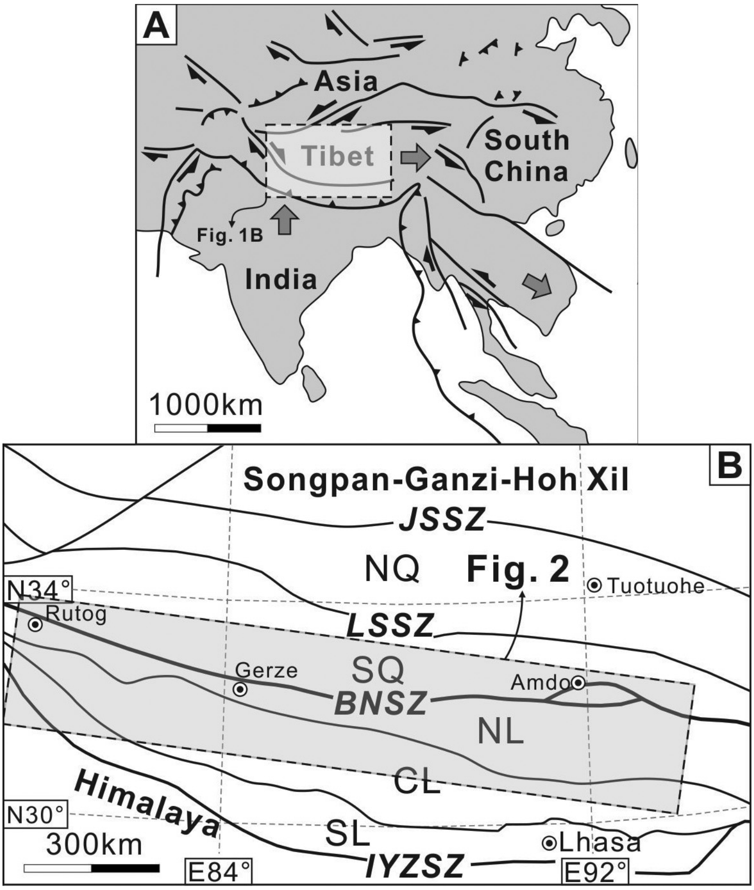

Fig. 1. (A) Generalized map of the Tethyan realm and (B) simplified geological map of the Tibetan Plateau showing the major blocks. Abbreviations: JSSZ = Jinsha Suture Zone; LSSZ = Longmuco-Shuanghu Suture Zone; BNSZ = Bangong–Nujiang Suture Zone; IYZSZ = Indus–Yarlung Zangbo Suture Zone; NQ = Northern Qiangtang terrane; SQ = Southern Qiangtang terrane; NL = Northern Lhasa terrane; CL = Central Lhasa terrane; SL = Southern Lhasa terrane.

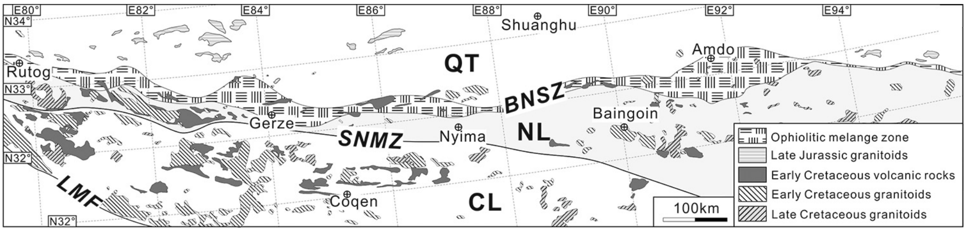

Fig. 2. Simplified geological map showing Mesozoic magmatic rocks within the Bangong–Nujiang Suture Zone of central Tibet. Abbreviations: BNSZ = Bangong–Nujiang Suture Zone; SNMZ = Shiquan River–Nam Tso Melange Zone; LMF = Luobadui–Milashan Fault; QT = Qiangtang terrane; NL = Northern Lhasa terrane; CL = Central Lhasa terrane.

rocks, whereas the Late Cretaceous zone (100–75 Ma) is characterized by rocks with calc-alkaline high Sr/Y ratios and an adakitic affinity (for example, Yu and others, 2011; Wang and others, 2014b; Lei and others, 2015; Sun and others, 2015). Recent research has demonstrated that Sr/Y ratios of magmatic rocks can be used to track temporal variations in crustal thickness (for example, Zeng and others, 2011; Chapman and others, 2015; Chiaradia, 2015; Wu and others, 2016, 2018b). Recent studies in the area have shown that some Early Cretaceous magmatic rocks have high Sr/Y ratios (for example, Li and others, 2008, 2017a; Wu and others, 2015a, 2015b). Furthermore, we have identified systematic spatial and temporal variations relating to the high-Sr/Y magmatism during the Cretaceous. Hence, it is necessary to reconsider the existing tectonic evolution model of central Tibet.

In this study, we have collated and reviewed the geochronological, geochemical, and Hf isotopic data reported in the literature for high-Sr/Y rocks in central Tibet to elucidate the mechanisms by which spatially and temporally related geodynamic processes resulted in the evolution and expansion of the p-TP during the Cretaceous.

## GEOLOGICAL BACKGROUND AND TECTONIC SETTING

The Tibetan Plateau, from north to south, consists of the Kunlun–Qaidam, Songpan–Ganze–Hoh Xil, Qiangtang, Lhasa, and Himalaya terranes, with central Tibet comprising mainly the Qiangtang and Lhasa terranes (Yin and Harrison, 2000). Recent studies have established a close relationship between the BNSZ and the Mesozoic tectonic evolution of central Tibet (for example, Yin and Harrison, 2000; Pan and others, 2012). Studies of ophiolites, sedimentary strata, and subduction-related magmatic rocks from within the BNSZ have suggested that the Bangong–Nujiang Ocean existed before the Triassic (Zhu and others, 2011; Pan and others, 2012), with oceanic subduction during the Jurassic (Du and others, 2011; Wu and others, 2016, 2018b; Zhu and others, 2016) and closure of the ocean during the earliest Cretaceous (Xu and others, 1985; Dewey and others, 1988; Yin and Harrison, 2000; Leier and others, 2007; Zhu and others, 2011).

In central Tibet, the continental collision between the Lhasa and Qiangtang terranes was followed by the production of large volumes of magmatic rocks (fig. 2) (Yin and Harrison, 2000; Kapp and others, 2007; Zhu and others, 2011, 2016). The recent identification of bimodal volcanic suites and coeval A2-type granites (Qu and others, 2006, 2012; Sui and others, 2013; Chen and others, 2014; Fan and others, 2015; Hu and others, 2017; Wu and others, 2018a), which are generally formed during post-collisional stages of orogenesis (Whalen and others, 1987; Eby, 1992), has led to the proposition that the Cretaceous magmatic 'flare-up' event in central Tibet occurred in a post-collision extensional environment (for example, Zhu and others, 2011, 2016; Wu and others, 2018a).

Numerous studies have examined the high-Sr/Y rocks, revealing that such rocks are exposed mainly in the northern Lhasa terrane and formed over a period of ~50 Myr (*ca.* 125–75 Ma) (fig. 3) (for example, Li and others, 2008; Zhang and others, 2014a; Wu and others, 2015a, 2015b; Hao and others, 2016). High-Sr/Y rocks typically occur as porphyry intrusions (monzonite, diorite, granodiorite, and granite) or rare eruptive rocks (andesite and dacite) in central Tibet. The mineral assemblages of these rocks consist primarily of plagioclase, biotite, quartz, and amphibole. They are dominantly medium- to high-K calc-alkaline intermediate–felsic rocks, but with high Na/K ratios (fig. 4).

## PETROGENESIS OF CRETACEOUS HIGH-Sr/Y ROCKS

In this study, we have collected geochemical data (N = 301) from the literature for rock samples characterized by high Sr contents (>300 ppm) and high Sr/Y ratios (>20), typical of adakites (fig. 5; Defant and Drummond, 1990; Castillo, 2006). Data

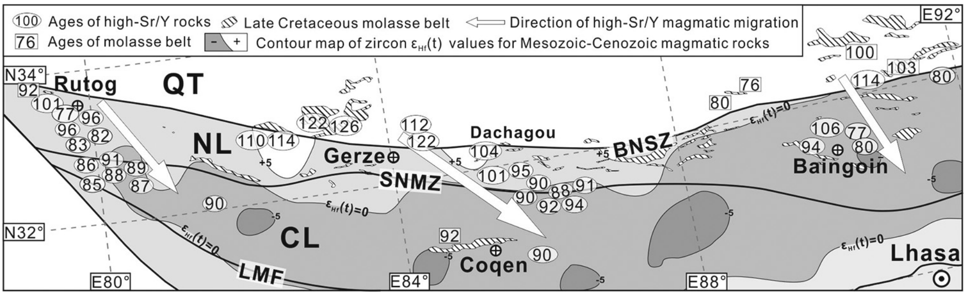

Fig. 3. Spatial and temporal distribution of Cretaceous high-Sr/Y rocks and a molasse belt in central Tibet. Abbreviations: QT = Qiangtang terrane; NL = Northern Lhasa terrane; CL = Central Lhasa terrane. Sources of age data: Bai and others, 2009; Chang, ms, 2012; Guan and others, 2014; Fu and others, 2014, 2015; Hao and others, 2016; Hu and others, 2017; Jiang and others, 2011; Lei and others, 2015; Li and others, 2008, 2011, 2013a, 2013b, 2014a, 2014b, 2015, 2016b, 2017a, 2017b; Liu and others, 2012, 2014, 2015; Lv and others, 2011; Ma and Yue, 2010; Qin and others, 2015; Qu and others, 2006, 2012; She and others, 2009; Sui and others, 2013; Sun and others, 2015, 2017; Wang and others, 2013, 2014b; Wu and others, 2014, 2015a, 2015b, 2016; Zhang and others, 2014a,b, 2015; Zhao and others, 2008, and references therein.

for coeval low-Sr/Y rocks were also collected for comparison. The origin of high Sr/Y ratios in granitoid magmas is debated because these signatures can occur via several different processes (Moyen, 2009 and references therein): (1) melting of a high-Sr/Y

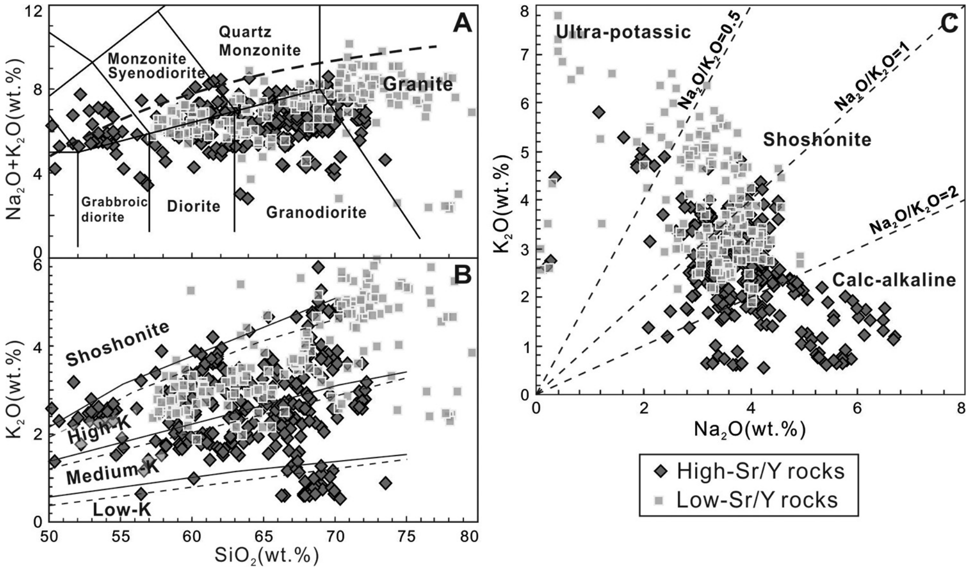

Fig. 4. (A) Total alkali vs. silica diagram (Middlemost, 1994), (B) $K_2O$ vs. $SiO_2$ diagram (Le Maitre and others, 1989; Rickwood, 1989), and (C) $K_2O$ vs. $Na_2O$ diagram (Foley and others, 1987) for Cretaceous magmatic rocks in central Tibet. Geochemical data sources for high-Sr/Y rocks: Bai and others, 2009; Chang, ms, 2012; Fu and others, 2014; Guan and others, 2014; Hao and others, 2016; He and others, 2018; Hu and others, 2017; Jiang and others, 2011; Lei and others, 2015; Li and others, 2008, 2013a, 2013b, 2014b, 2015, 2016b, 2017a, 2017b; Liu and others, 2012, 2014, 2015, 2018; Lv and others, 2011; Ma and Yue, 2010; Qin and others, 2015; Qu and others, 2006, 2012; She and others, 2009; Sui and others, 2013; Sun and others, 2015, 2017; Wang and others, 2014b; Wei and others, 2017; Wu and others, 2013, 2015a, 2015b; Yu and others, 2011; Zhang and others, 2014a, 2014b, 2015; Zhao and others, 2008, and references therein. Geochemical data sources for low-Sr/Y rocks: Ding and others, 2012; Gao and others, 2011a, 2011b, 2016; Hu and others, 2017; Li and others, 2013b, 2017c; Liu and others, 2018; Wang and others, 2012, 2018; Wei and others, 2017; Zhang and others, 2017.

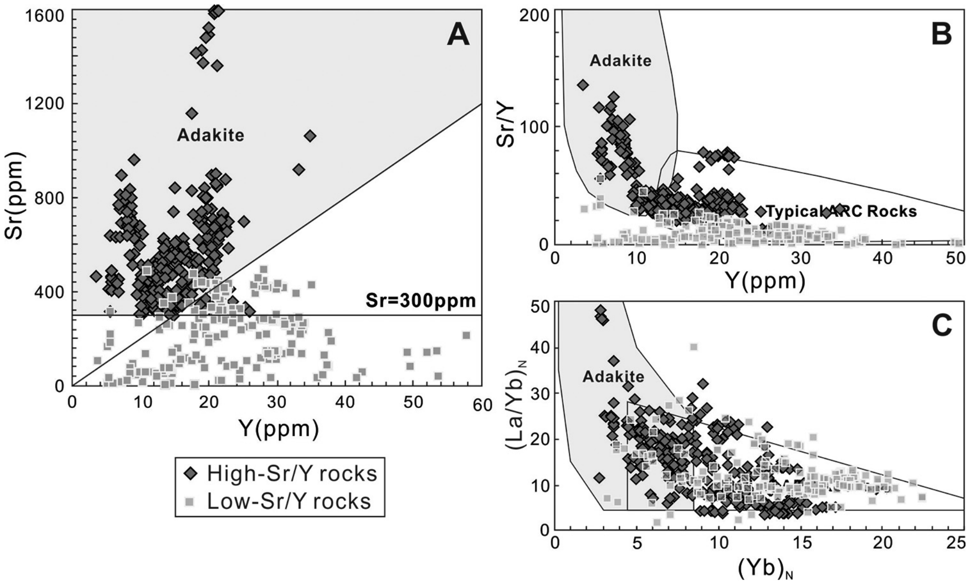

Fig. 5. (A) Sr vs. Y diagram, (B) Sr/Y vs. Y diagram, and (C) $(La/Yb)_N$ vs. $(Yb)_N$ diagram (Defant and Drummond, 1990) for Cretaceous magmatic rocks in central Tibet. Geochemical data sources are as in figure 4.

source; (2) deep melting of thickened mafic crust with abundant residual garnet; (3) low-pressure fractional crystallization of amphibole; or (4) magma mixing between felsic melt and the mantle.

Hafnium isotopic compositions of zircons from magmatic rocks have been used to infer that the northern Lhasa terrane consists of juvenile crust that was recently accreted in response to subduction of the Bangong–Nujiang oceanic crust during the Mesozoic (Zhu and others, 2011; Hou and others, 2015). Furthermore, the Sr/Y and $(La/Yb)_N$ [where the subscript N denotes that the ratios are normalized to the chondrite values of Sun and McDonough (1989)] ratios of high-Sr/Y rocks have changed over time (fig. 6). Based on these variations, we conclude that the juvenile crustal source of the northern Lhasa terrane did not have high Sr/Y ratios. On the other hand, the relatively high $SiO_2$ contents and the general lack of mafic enclaves in these high-Sr/Y rocks suggest that magma mixing did not contribute to their formation.

Previous studies have shown that fractional crystallization of amphibole and garnet may produce granitoids with high Sr/Y ratios (Davidson and others, 2007; Alonso-Perez and others, 2009; Smith, 2014). Amphibole preferentially incorporates middle REEs, whereas heavy REEs are incorporated into garnet. As a result, fractionation of amphibole and garnet will increase the $(La/Yb)_N$ ratio of evolved melts, and garnet fractionation will simultaneously increase $(Dy/Yb)_N$ ratios (Macpherson and others, 2006; Davidson and others, 2007). The high-Sr/Y rocks display increasing $(La/Yb)_N$ and $(Dy/Yb)_N$ ratios with increasing $SiO_2$, suggesting that fractionation of amphibole was not a significant process for most of these rocks from central Tibet (figs. 7A–7C).

In contrast to the above, the geochemical and isotopic features of high-Sr/Y rocks indicate that they were derived from deep melting of thickened mafic lower crust. Co-variations in Sr/Y, $(La/Yb)_N$, and $(Dy/Yb)_N$ ratios indicate that garnet was the major residual mineral. This result indicates that during the emplacement of

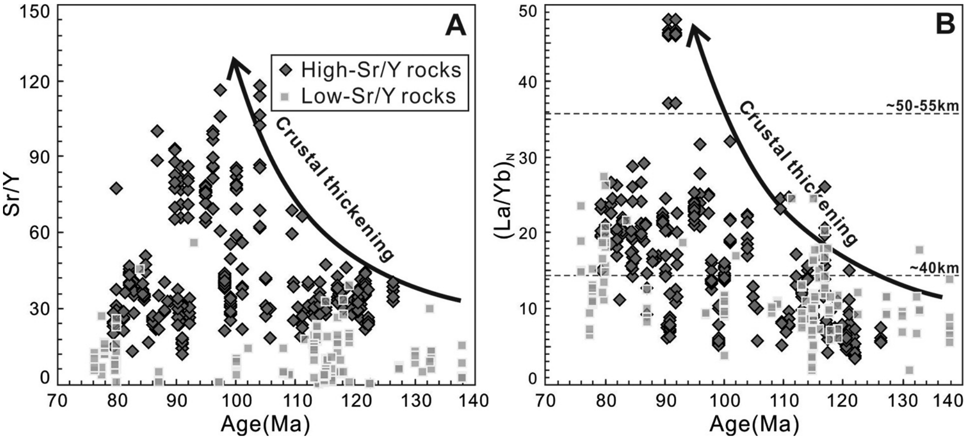

Fig. 6. (A) Sr/Y vs. age diagram (B) and $(La/Yb)_N$ vs. age diagram for Cretaceous magmatic rocks in central Tibet. The crustal thickness correlation is inferred after Chung and others (2009). Geochemical data sources are as in figure 4.

high-Sr/Y rocks, the depth of crust was >50 km (*ca.* 1.5 GPa; Sen and Dunn, 1994; Rapp and Watson, 1995). Furthermore, as garnet is Na-depleted relative to plagioclase (for example, Sen and Dunn, 1994), melting of mafic rocks at elevated pressures can also produce Na-rich melts (Defant and Drummond, 1990; Sen and Dunn, 1994; Rapp and Watson, 1995; Patiño Douce and Harris, 1998). High-Sr/Y rocks are also characterized by positive $\varepsilon_{Hf}(t)$ values (fig. 8), indicating a juvenile magma source. We therefore suggest that the geochemical systematics of high-Sr/Y rocks reflect the partial melting of juvenile mafic material at relatively high pressures.

It has been shown experimentally that mantle-rich element (for example, Mg, Cr, and Ni) increase when melts interact with mantle peridotite (Rapp and others, 1999; Gao and others, 2004). High-Sr/Y rocks from central Tibet are generally enriched in MgO, Cr and Ni, indicative of a mantle signature (for example, Wang and others, 2014b; Lei and others, 2015; Sun and others, 2015). Most high-Sr/Y rocks plot in the area of thickened lower crust-derived adakites (with or without delamination) in figures 7D–7I. This rock group is considered to have been generated by interaction between the mantle and melts derived from lower-crustal materials.

We conclude that Cretaceous high-Sr/Y rocks from central Tibet were derived from the deep (>50 km) melting of thickened juvenile lower crust, with varying degrees of contamination by mantle peridotite.

## SPATIAL AND TEMPORAL VARIATIONS IN THE GEOCHEMISTRY OF HIGH-Sr/Y ROCKS

Crustal thickness determines the pressure of magma sources and affects the locations and probability of stagnation levels and differentiation, thereby influencing the degree of mantle contamination when thickened lower-crustal materials are delaminated into the mantle (for example, Haschke and Günther, 2003; Chung and others, 2005; Mamani and others, 2010). Mantle-rich element contents can thus be interpreted in terms of the timing and processes of high-Sr/Y melt contamination by mantle peridotite during delamination. Therefore, knowledge of the geochemistry and evolution of high-Sr/Y magmas provides an indirect but useful framework for understanding the timing and processes of crustal thickening and lithospheric delamination.

The compiled data on zircon U–Pb ages of Cretaceous high-Sr/Y rocks are plotted on a geological map of Tibet in figure 3. Mantle-rich element abundances (Mg, Cr, and

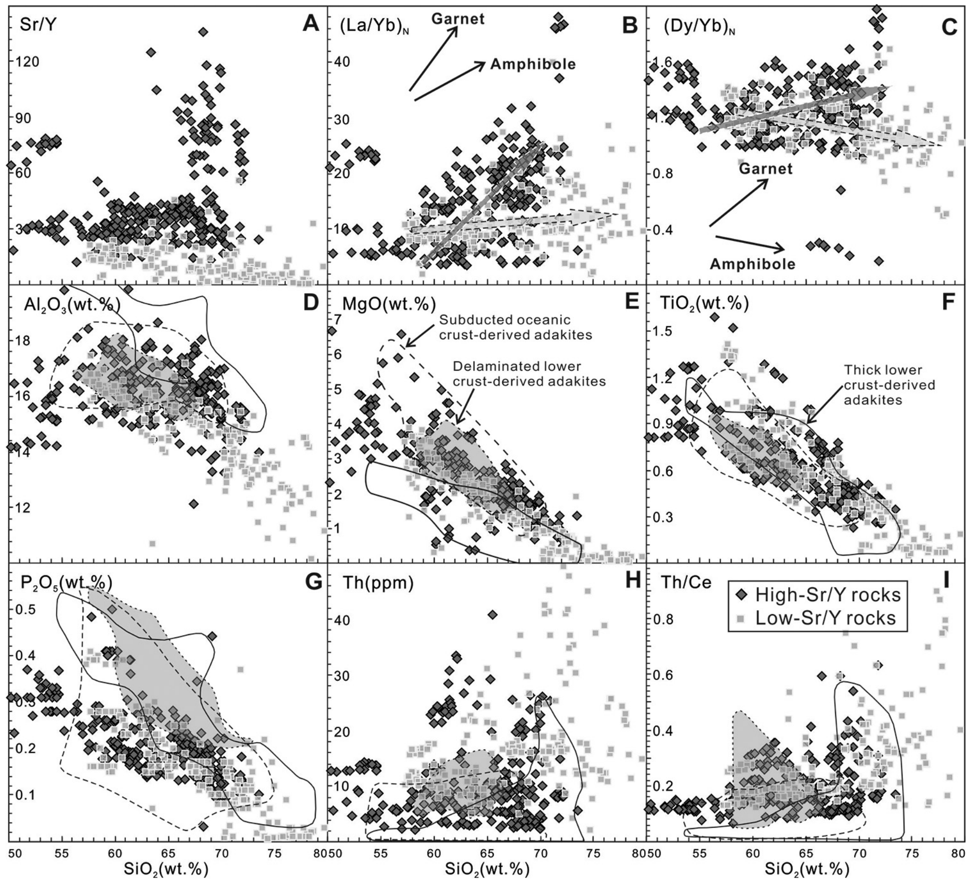

Fig. 7. Selected major and trace elements, and element ratios, plotted against $SiO_2$ for Cretaceous magmatic rocks in central Tibet. The differentiation trends of garnet and amphibole are from Davidson and others (2007). The subducted oceanic crust-derived, delaminated lower crust-derived, and thickened lower crust-derived adakite fields are after Wang and others (2006). Normalizing values are from Sun and McDonough (1989). Geochemical data sources are as in figure 4.

Ni) show significant temporal and spatial variations (fig. 9). Based on these data, the following observations can be made: (1) high-Sr/Y magmas show diachronism, as magmatism progressed from the north part of the high-Sr/Y magma domain toward the south (fig. 3); (2) given that mantle-rich elements (Mg, Cr, and Ni) indicate mantle contamination, two peaks occurr at 125 to 110 Ma and 105 to 75 Ma, respectively (fig. 9). Furthermore, we observe that a sudden increase in those elements occurred at *ca.* 105 Ma [high abnormal values of Cr were not considered (fig. 9C)]; (3) at *ca.* 85 Ma, the high-Sr/Y magmatism ceased to migrate southwards; however, the younger rocks (85–75 Ma) are also characterized by relatively high contents of Mg, Cr, Ni and are found over the entire domain of high-Sr/Y magmatism; (4) we identify a coeval E–W trending belt of molasse (100–75 Ma) that overlaps with the high-Sr/Y belt paralleling the BNSZ in central Tibet (fig. 3).

The observed spatial and temporal variations in the geochemistry of Cretaceous high-Sr/Y rocks show that the evolution of the thermal structure of the central Tibet deep lithosphere warrants further investigation.

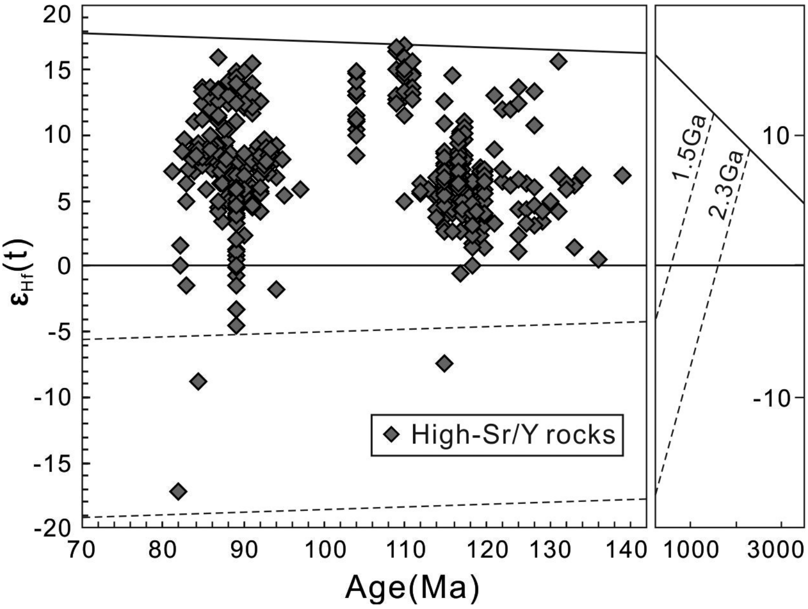

Fig. 8. Zircon $\varepsilon_{Hf}$(t) values vs. age for Cretaceous high-Sr/Y rocks in central Tibet. Sources of hafnium isotopic data: Hu and others, 2017; Li and others, 2015, 2016b; Liu and others, 2018; Sui and others, 2013; Sun and others, 2015, 2017; Wang and others, 2014b.

## INTEGRATED TECTONIC MODEL

### *Crustal Thickening and Formation of the p-TP Before ca. 106 Ma*

Previous studies suggested that central Tibet was already elevated during the Cretaceous (for example, Murphy and others, 1997; Kapp and others, 2007). The presence of high-Sr/Y rocks further supports the existence of thickened crust (>50 km) in central Tibet at this time. However, the mechanism and timing of p-TP uplift remain unknown. Tectonic shortening and magmatism are generally considered to be key mechanisms of crustal thickening (Gill, 1981; Sheffels, 1990).

Recently, multiple stages of tectonic compression and magma underplating during the evolution of the BNSZ have been proposed (for example, Kapp and others, 2005, 2007; Zhu and others, 2011, 2016; Wu and others, 2016). In the Late Jurassic, the subducted oceanic crust resulted in underplating of mantle-derived basaltic magma and tectonic shortening of the overlying continental crust (fig. 10A). The low-temperature chronology and high-Sr/Y rocks provide direct petrological evidence for Late Jurassic crust thickening prior to continental collision between the Lhasa and Qiangtang terranes (Wang and others, 2007; Song and others, 2014; Hao and others, 2016; Wu and others, 2016; Zhao and others, 2017). During the Early Cretaceous, tectonic compression in a syn-collisional setting and subsequent magma underplating in a post-collisional extension setting led to further crustal thickening in central Tibet (fig. 10B) (Murphy and others, 1997; Xiong and Liu, 1997; Haines and others, 2003; Kapp and others, 2005, 2007; Volkmer and others, 2007). Accordingly, we suggest that both tectonic compression and magmatism during the Mesozoic evolution of the BNSZ had a significant impact on crustal thickening in central Tibet.

In summary, high-Sr/Y rocks indicate that multiple stages of crustal growth and thickening occurred during the evolution of the BNSZ, resulting in the establishment of the p-TP during the Cretaceous.

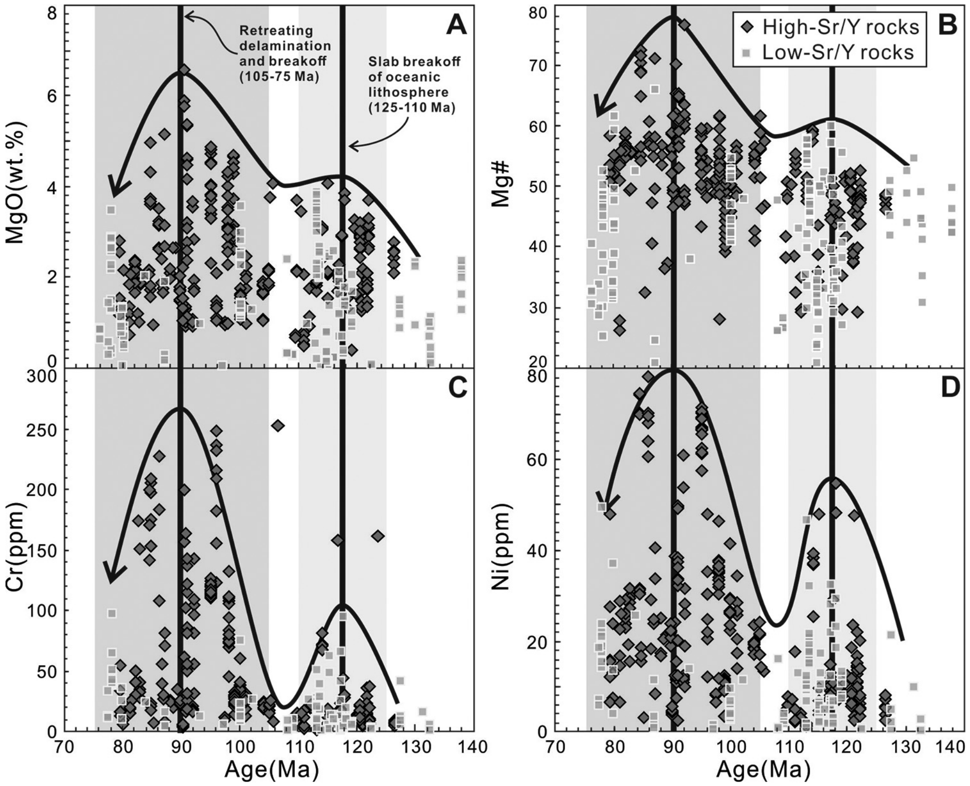

Fig. 9. (A) MgO content vs. age, (B) Mg# values vs. age, (C) Cr content vs. age, and (D) Ni content vs. age diagrams for Cretaceous magmatic rocks in central Tibet. The solid lines indicate the sudden increased contribution of a mantle component. The mantle upwelling during 125–110 Ma is from Zhu and others (2011). Geochemical data sources are as in figure 4.

### *Retreating Delamination and Rapid Surface Uplift at 105 to 86 Ma*

Thickened eclogitic lower crust has a density greater than that of the mantle. Therefore, to maintain isostatic equilibrium, thick crustal roots beneath mountain belts must be removed during orogen development. Recent research has demonstrated that delamination of over-thickened crust is the most effective mechanism of lithospheric thinning, due to its negative buoyancy (for example, Ueda and others, 2012; Krystopowicz and Currie, 2013; Li and others, 2016c). The detached crust ultimately descends into the underlying asthenosphere, inducing mantle convection (Houseman and others, 1981; Lustrino, 2005; Dilek and Altunkaynak, 2007; Krystopowicz and Currie, 2013).

Thermo-mechanical numerical models have shown that two styles of delamination can occur during orogen development: retreating and stationary delamination (Krystopowicz and Currie, 2013). In the retreating delamination model, the detaching slab undergoes bending and rollback because of its negative buoyancy. The initial detachment event would open a gap in the slab that fills with upwelling hot asthenosphere. Such mantle flow would cause the retreat of the hinge, finally resulting in the migration of surface uplift and magmatism across the orogen (fig. 3 in Krystopowicz and Currie, 2013; Gray and Pysklywec, 2013). Delamination-related high-Sr/Y melts generally contain significant proportions of mantle-rich elements because of

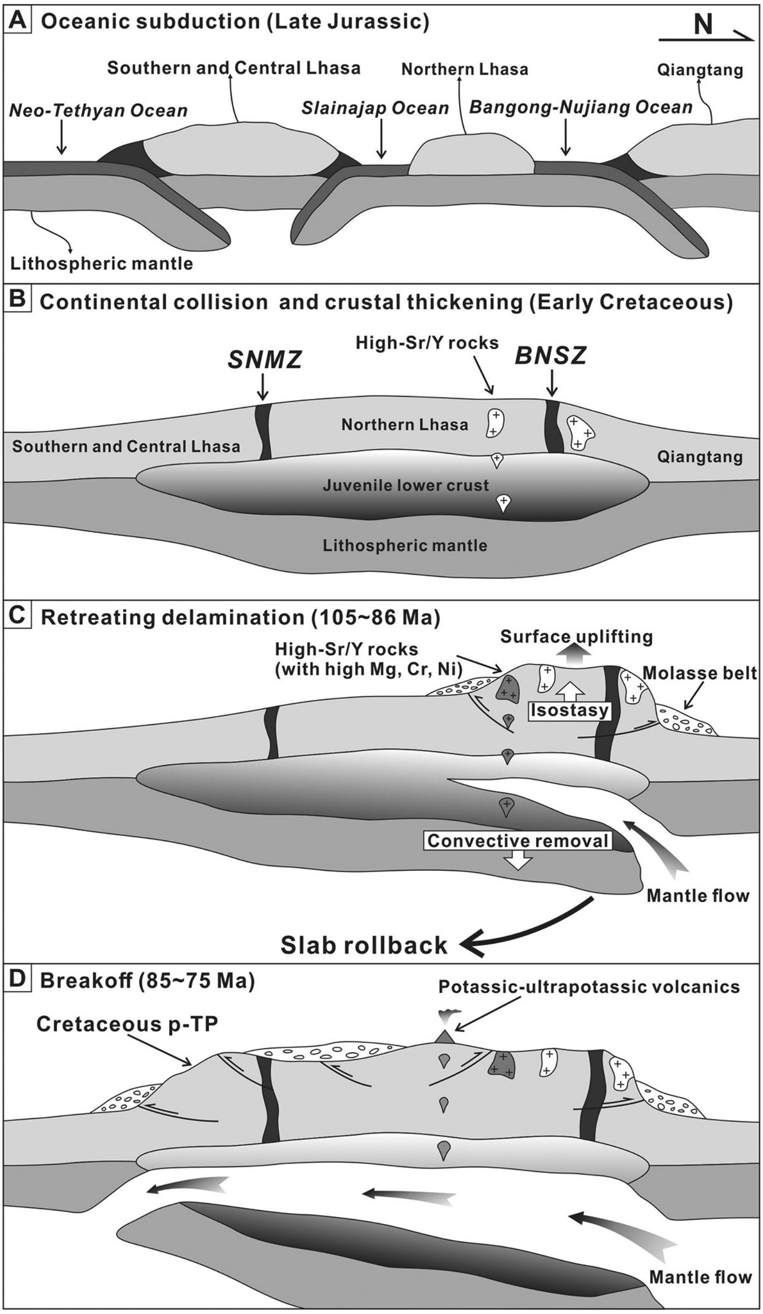

Fig. 10. Integrated geodynamic evolution of central Tibet from Late Jurassic to Late Cretaceous. (A) Oceanic subduction during Late Jurassic. (B) Crustal thickening during Early Cretaceous. (C) Retreating delamination during 105–86 Ma. (D) Breakoff during 85–75 Ma. Abbreviations: SNMZ = Shiquan River–Nam Tso Melange Zone; BNSZ = Bangong–Nujiang Suture Zone.

interaction with mantle peridotite (for example, MgO, Mg#, Cr, and Ni) (Rapp and others, 1999; Gao and others, 2004). Thus, the increase in the content of these elements in central Tibet between 105 to 86 Ma, and related southward migration of high-Sr/Y rocks, provide further support for the hypothesis that the region underwent retreating delamination during that period. Furthermore, the presence of coeval OIB-type mafic rocks and potassic rocks (Qu and others, 2006; Bai and others, 2009; Chen and others, 2017; Liu and others, 2018), which could originate from upwelling asthenosphere and thinning lithosphere (Turner and others, 1996; Ferrari, 2004), provides petrological evidence for delamination (for example, Bonin, 1988, 1990; England and Houseman, 1989). The occurrence of high-Sr/Y rocks (with high contents of compatible elements) on the northern margin of the northern Lhasa terrane, and young high-Sr/Y rocks on the southern margin of the northern and central Lhasa terrane, indicates that the initial detachment event occurred first in the north and then migrated southwards toward the central Lhasa terrane during a period of retreating delamination from 105 to 86 Ma (fig. 10C).

### *Breakoff at 85 to 75 Ma*

Our model of slab breakoff that followed delamination is as follows. Over time, the length of the delaminated slab would have increased, resulting in greater negative buoyancy. The slab length needed for breakoff decreases with decreasing mantle lithosphere strength and increasing eclogite density; thus, when the slab strength was finally exceeded, the slab broke, possibly through viscous necking (for example, Duretz and others, 2011, 2012). Age data for central Tibet indicate that the southward migration of high-Sr/Y magmatism ceased at *ca.* 85 Ma, and younger rocks (85–75 Ma) are located over the entire region. Based on these observations, we propose that breakoff occurred at *ca.* 85 Ma, opening a slab window and triggering the upwelling of hot asthenospheric mantle. Such a window would promote the circulation of hot asthenosphere and the melting of sinking delaminated lower crust.

Bird (1979) suggested that rapid surface uplift may be tied to delamination as the dense lithosphere is replaced by lower-density asthenosphere. This wholesale uplift model was used to interpret the rapid increase in surface height (1500–3000 m) of the Tibetan Plateau during the Cenozoic as a result of isostatic rebound in response to the removal of lithospheric mantle (England and Houseman, 1989). In central Tibet, the widespread Late Cretaceous molasse deposits (Li and others, 2016a; Sun and Hu, 2017), combined with the timing of cooling inferred from apatite and zircon fission track data (Rohrmann and others, 2012; Song and others, 2014; Ren and others, 2015), suggest that the p-TP also underwent significant rapid uplift-related mechanical erosion and a cooling event coeval with delamination (fig. 10D).

In summary, the above mechanical and thermal consequences, including the delamination-related magmatism, uplift-related erosion, and cooling event, suggest that retreating delamination and subsequent breakoff beneath thickened crust provide the best explanation for the spatio-temporal distribution of Cretaceous high-Sr/Y rocks in central Tibet.

## CONCLUSIONS

The distribution of Cretaceous high-Sr/Y rocks suggests that the crust beneath central Tibet thickened in response to the evolution of the Bangong–Nujiang Ocean, resulting in the development of the p-TP prior to the India–Asia collision. Spatial and temporal variations in geochronological and geochemical data of high-Sr/Y magmas can be explained by retreating delamination (105–86 Ma) and breakoff (85–75 Ma) of thickened crust. Rapid surface uplift of the p-TP was accomplished by isostatic rebound in response to these deep delamination processes during the Mesozoic.

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