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Mantle upwelling during Permian to Triassic in the northern margin of the North China Craton: Constraints from southern Inner Mongolia

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ABSTRACT

The nothern margin of the North China Craton (NCC) preseves the tectonic imprints of early Paleozoic to Triassic tectonic processes. Here we investigate the geochronology, geochemistry, zircon hafnium and whole rock Nd isotope data on a suite of magmatic rocks from the Ningcheng pyroxenite–gabbro–diorite complex and the Jiwangyingzi Formation in the Inner Mongolia region of the northern NCC. The zircon U–Pb dating identifies multiple stages of mafic to intermediate magmatism from Early Permian (298 ± 4 Ma) to Middle Triassic (219 ± 1 Ma) in this area and their hafnium isotopes display diverse mantle sources. An integration of field observations, geochronology and elemental and isotopic geochemistry indicates a complex petrogenetic history for the magmatic suite. The Ningcheng pyroxenite–gabbro–diorite complex is a product of multiple pulses of magmas with crystal fractionation, hybridization and assimilation, with the involvement of melts derived from lithospheric mantle and even the asthenosphere. Our data reveal an increasing involvement of mantle component from Late Permian to Triassic. The features of progressive mantle upwelling correlate with tectonic processes associated with the closure of Paleo-Asian Ocean and subsequent post collisional extension, resulting in active magmatism from Carboniferous to Triassic in this region.

1. Introduction

The North China Craton (NCC) is one of the oldest cratons in the world, with crustal rocks as old as 3.8 Ga (Liu et al., 1992; Zhai and Santosh, 2011 and references therein). The NCC is distinguished from other global cratons by its intense remobilization and decratonization since the Early Mesozoic, accompanied by widespread magmatism, intraplate deformation and metallogeny (Menzies et al., 1993; Griffin et al., 1998; Menzies et al., 2007; Yang et al., 2008, 2013; Zhang et al., 2002, 2011; Tang et al., 2012; Zhang, 2012; Zhai and Santosh, 2013).

The northern part of NCC traces a complex tectonic evolution and stabilization in Precambrian (Zhao et al., 2010; Santosh et al., 2010; Santosh, 2010; Zhang et al., 2011). From early Paleozoic to Triassic, the NCC was strongly influenced by southward subduction and closure of the Paleo-Asian Ocean and its subsequent post-collisional extension, as indicated by tectonics and magmatism (Yan et al., 1999; Davis et al., 2001; Xiao et al., 2003; Zhang et al., 2003, 2009a,b,c, 2012, 2010, 2011; Ying et al., 2011).

With a view to characterize the tectonic evolution of the northern margin of the NCC, we present new geochronological, geochemical and zircon Hf data on a suite of Early Permian to Late Triassic intrusions from the southern Inner Mongolia region, at the northern margin of the craton. The main objectives of this contribution are: (1) to report U–Pb isotopic ages of the Ningcheng complex, the magmatic intrusion in Jiwangyingzi Formation; (2) to evaluate the petrogenesis and source characteristics of these intrusions; and (3) to provide constraints on the tectonic evolution of the northern domain of the NCC using these data.

2. Geological background

The NCC consists of an Archean-Paleoproterozoic metamorphic basement and an overlying Mesoproterozoic to Phanerozoic unmetamorphosed sedimentary cover (Lu et al., 2008; Zhai and Santosh, 2011; Zheng et al., 2013) (Fig. 1a). The NCC has been traditionally divided into the Eastern Block, the Western Block, and the intervening Trans-North China Orogen/Central Orogenic Belt based on ages and lithological assemblages (Zhao et al., 2001, 2005; Kröner et al., 2005; Wilde et al., 2005; Kusky, 2011).

The northern margin of the NCC is bound by the Central Asia Orogenic Belt (CAOB) on the north (Xiao et al., 2010), which

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Table 1
Major (wt%) and trace (ppm) elements for the igneous rocks from the Ningcheng complex and Jiwangyingzi Formation.

Sampling location	Ningcheng complex										Jiwangyingzi Formation	
Sample (wt%)	Quartz Diorite Dy09-09	Quartz Diorite Dy09-10-2	Gabbro Diorite Dy09-03	Gabbro Diorite Dy09-05	Pyroxenite Dy09-08	Pyroxenite Dy09-10	Pyroxenite Dy09-13	Pyroxenite Dy09-14	Gabbro Dy09-01	Gabbro Dy09-02	Gneissic Granite Dy09-11	Diorite Dy09-12
SiO_2	62.0	62.0	51.7	51.3	53.1	51.3	53.4	50.2	44.8	47.6	69.5	51.3
TiO_2	0.9	0.8	1.6	1.6	0.4	0.3	0.4	0.6	2.6	1.8	0.4	1.3
Al_2O_3	15.9	15.8	18.5	19.3	3.7	3.5	4.7	6.3	18.2	17.1	15.5	18.2
TFe_2O_3	5.1	4.9	9.2	8.9	10.3	10.9	10.1	10.8	12.1	8.4	3.0	10.3
MnO	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2
MgO	3.3	3.3	4.3	3.9	29.0	30.4	26.6	20.7	6.7	8.6	0.9	3.8
CaO	4.3	4.2	8.1	7.2	2.1	2.5	3.3	8.8	10.4	10.6	2.8	7.6
Na_2O	4.0	4.1	3.7	4.1	0.4	0.4	0.7	0.9	2.7	2.0	4.2	3.8
K_2O	3.7	3.7	1.2	1.2	0.8	0.6	0.7	0.7	1.4	2.8	3.1	2.2
P_2O_5	0.3	0.3	0.6	0.6	0.1	0.1	0.1	0.1	0.5	0.3	0.1	0.7
LOI	0.3	0.4	0.3	1.2	0.1	0.0	0.1	0.7	0.6	0.9	0.5	0.8
TOTAL	99.8	99.6	99.4	99.5	100.1	100.1	100.1	100.0	100.0	100.1	100.0	100.2
FeO	3.3	2.9	5.2	5.1	8.2	8.3	8.0	7.8	6.3	5.0	1.6	6.1
$Mg^{\#}$	64	67	59	58	86	87	86	83	66	76	51	53
Trace elements (ppm)												
Li	15	28	8.9	11	4.1	3.6	7.2	3.3	4.1	5.8	26	38
V	94	84	180	228	76	65	83	124	362	196	34	140
Cr	82	88	61	77	2189	2316	2132	1162	35	50	4.4	1.4
Co	19	19	31	36	101	115	102	97	57	50	5.5	26
Ni	53	53	35	43	1227	1405	1156	572	60	91	2.1	3.5
Cu	47	14	35	33	35	48	49	105	121	82	5.4	22
Zn	61	63	100	109	85	86	93	82	82	58	47	122
Ga	19	18	21	22	6.2	5.9	7.1	8.5	20	15	19	22
Rb	133	149	26	28	28	22	25	23	25	85	110	63
Sr	617	604	1207	775	43	47	112	307	1257	1062	557	1281
Y	17	17	12	22	5.3	5.6	7.3	13	25	14	12	21
Nb	13	13	6.9	17	3.5	2.6	3.2	3.2	9.0	6.3	13	8.5
Cs	6.9	7.9	1.0	2.8	1.2	0.9	1.0	1.1	0.5	1.4	3.4	2.6
Ba	1015	944	468	520	287	186	202	325	786	1188	1352	1071
La	42	44	25	28	9.5	7.4	12	14	19	11	51	43
Ce	78	81	51	55	18	15	22	30	44	24	92	89
Pr	8.9	9.3	6.0	7.1	2.1	1.8	2.6	4.1	6.5	3.4	9.1	11
Nd	35	36	25	31	8.5	7.7	10	18	31	16	32	51
Sm	5.9	6.1	4.8	6.4	1.5	1.6	1.9	4.0	7.4	3.5	4.6	9.1
Eu	1.7	1.6	1.9	2.1	0.4	0.4	0.6	1.2	2.5	1.5	1.4	3.1
Gd	4.8	4.5	3.9	5.4	1.3	1.2	1.8	3.4	6.5	3.5	3.2	7.1
Tb	0.7	0.7	0.6	0.9	0.2	0.2	0.3	0.6	1.1	0.6	0.4	1.0
Dy	3.7	3.6	2.9	4.6	1.0	1.1	1.5	3.0	5.4	3.1	2.0	4.9
Ho	0.7	0.7	0.5	0.8	0.2	0.2	0.3	0.6	1.0	0.6	0.4	0.8
Er	1.9	1.9	1.2	2.2	0.6	0.6	0.8	1.5	2.6	1.5	1.1	2.2
Tm	0.3	0.3	0.2	0.3	0.1	0.1	0.1	0.2	0.4	0.2	0.2	0.4
Yb	1.7	1.7	1.0	2.0	0.6	0.6	0.8	1.3	2.2	1.4	1.4	1.8
Lu	0.3	0.2	0.2	0.3	0.1	0.1	0.1	0.2	0.3	0.2	0.2	0.2
Ta	0.9	0.9	0.5	1.4	0.3	0.2	0.3	0.2	0.5	0.3	1.0	0.4
Pb	23	24	9.3	11.0	5.5	4.7	5.0	4.4	4.6	4.0	24	9.2
Th	16	26	3.5	1.8	3.7	2.7	3.0	3.5	0.8	0.5	11	3.1
U	3.2	3.9	0.7	0.6	0.8	0.6	0.7	0.7	0.2	0.1	3.5	0.9
Zr	259	143	42	39	107	92	100	133	159	91	100	24
Hf	7.0	4.3	1.5	1.4	2.7	2.3	2.6	3.6	5.3	3.0	2.8	1.2