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阿尔金北缘新太古代 TTG 片麻岩的成因及其构造意义*

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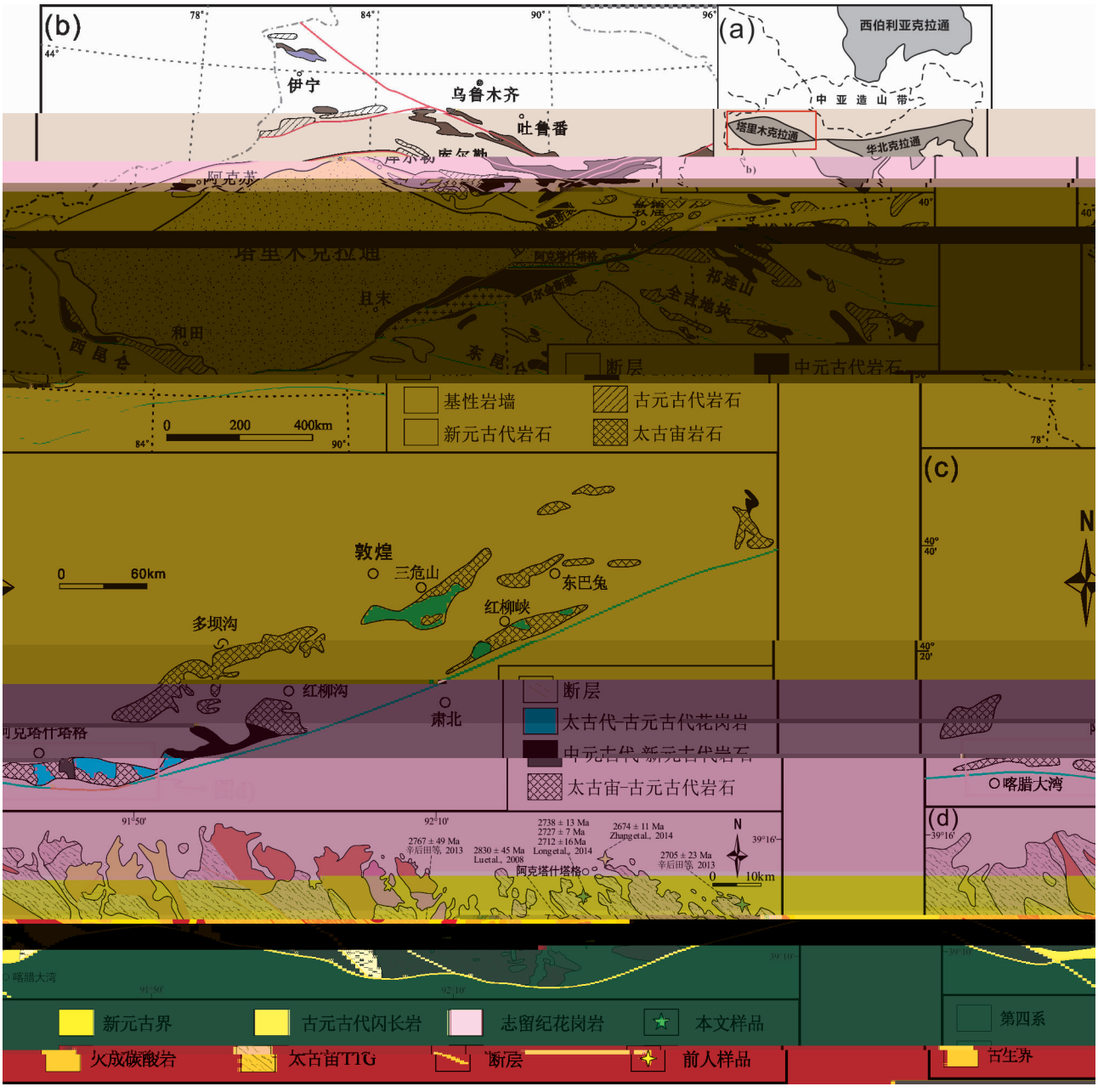
تحج شمخ

طوسلم



1

a b Lu *et al.* 2008 c - d 1997

Fig. 1 Simplified geological maps of studied area

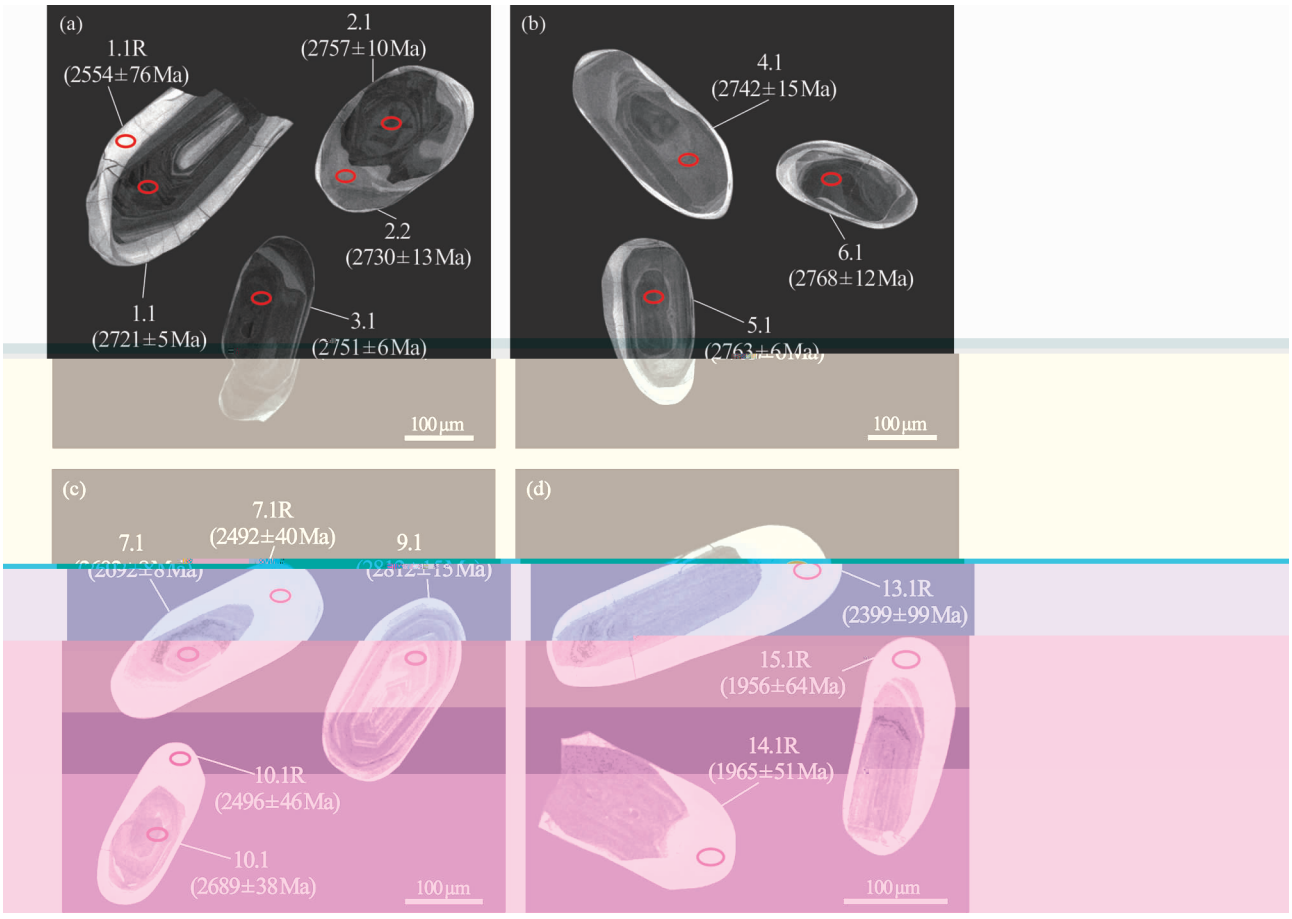
a simplified tectonic map of Central Asian Orogenic Belt CAOB showing the location of the Tarim Craton b geological map of the Tarim Craton showing the distribution of the Precambrian rocks modified after Lu *et al.* 2008 c simplified geological map of the North Altyn Tagh-Dunhuang area modified after Mei *et al.* 1997 d geological map of the North Altyn Tagh area

Wu *et al.* 2019 ~2.0Ga

Zhang *et al.* 2014 1d GPS 39°11′02.6″N 91°40′41.2″E 2012 ~1.85Ga OIB TTG 2a b TTG 1 5 TTG Zhang *et al.* 2014 2c

2
a b TG c d TG e-h TG . Amp-
Bi- Kfs- Pl- Q-

Fig. 2 Representative field photos and photomicrographs showing the Precambrian rocks in Kaladawan North Altyn Tagh area
a b Neoarchean TTG gneiss intruded by undeformed mafic dykes c d Neoarchean TTG gneiss show typical gneissic structure e-h representative photomicrographs of the Neoarchean tonalitic gneisses. Amp-amphibole Bi-biotite Kfs-K-feldspar Pl-plagioclase Q-quartz



3 CL

Ma

Fig. 3 CL images of representative zircons

Analytical spots and ages in Ma are shown

2d 45% ~55% 15% ~ 25% 5% ~10% 10% ~15% 5% ~10%

2e-g

2h

2

2.1 锆石 SHRIMP U-Pb 定年

SHRIMP U-Pb

17ALT06

TEMORA

CL

U-Pb SHRIMP Ⅱ

Williams 1998 O^{2-} 3 ~5nA 25μm

120

5

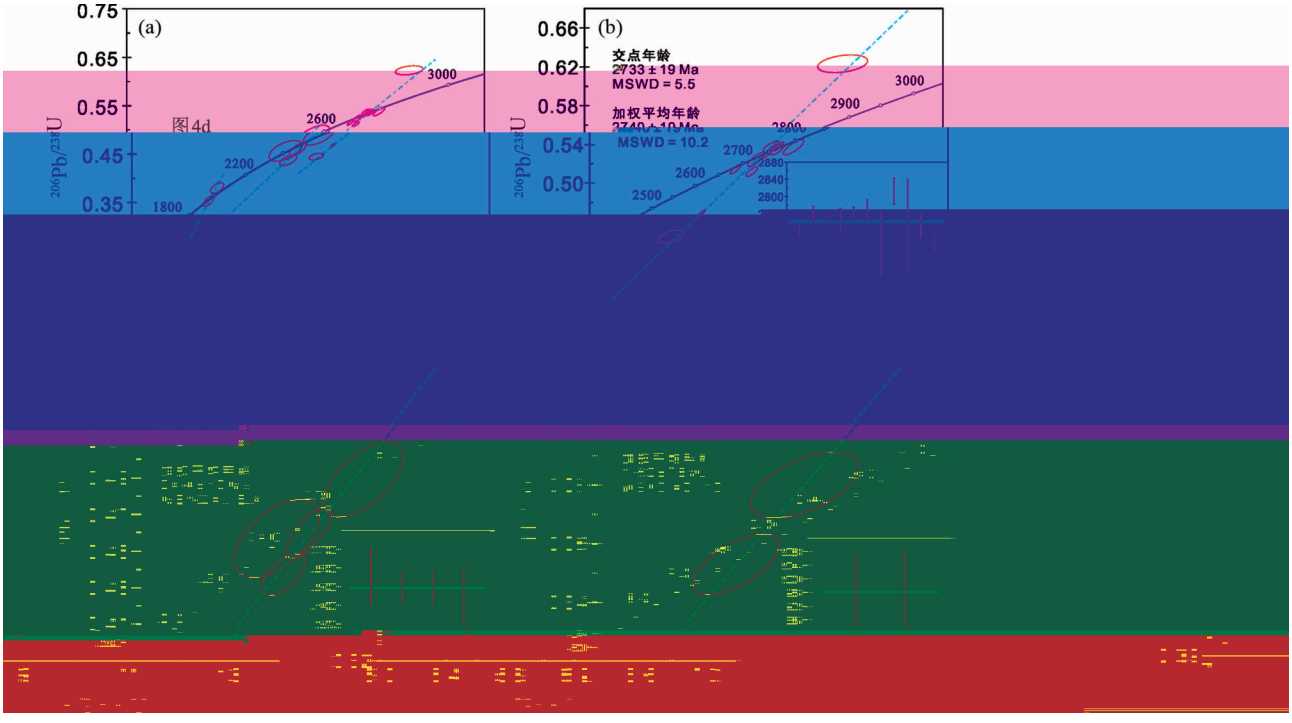
M257 U = 840 × 10^{-6} Nasdala *et al.* 2008 TEMORA 417Ma Black *et al.* 2003 U U-Pb 3 ~4 1 TEMORA U-Pb SHRIMP U-Pb SQIUD ISOPLOT Ludwig 2001 2003 1σ 95%

2.2 全岩主微量元素分析

X

Rigaku ZSK 100e

Li *et al.* 2000 0.5g 4g $Li_2B_4O_7$ 1200℃ XRF LOI



4 TG U-Pb

Fig. 4 Concordia plots of U-Pb zircon data for zircons from the Neoarchean gneiss in the North Altyn Tagh area

1000℃ 1 5%

ICP-MS Perkin-Elmer Sciex ELAN DRC-e ICP-MS Qi *et al.* 2000

200 50mg 1mL HF SiO_2 1mL HF 0.5mL HNO_3 200℃ 48 1mL HNO_3 2mL HNO_3 5mL 130℃ 8 500ng Rh 50mL GBPG-1 OU-6 GSR-1 GSR-3 10%

2.3 全岩 Sr-Nd 同位素分析

-Nd 200 100mg mL HF 0.3mL $HClO_4$ 1mL HNO_3 120℃ 6mL 6N HCl nL 2.5N HCL Rb-Sr AG50w × 12 Sr m-Nd P507 Sm Nd Thermo Fisher riton TIMS Nd $^{146}Nd/^{144}Nd = 0.7219$ SGS BCR-2 Nd/^{144}Nd 0.512641 ± 0.000004 2σ $^{87}Sr/^{86}Sr$ 0.704985 ± 0.000006 2σ

3

3.1 锆石 SHRIMP U-Pb 年龄

a

表[illegible]阿尔金北缘新太古代[illegible]片麻岩([illegible])锆石[illegible]年龄结果

[illegible]

[illegible]	[illegible] (%)	[illegible]	[illegible]	[illegible]	[illegible]*	同位素比值						[illegible]	同位素年龄([illegible])				[illegible]
		([illegible])			([illegible])	[illegible]*/[illegible]*	±σ(%)	[illegible]*/[illegible]	±σ(%)	[illegible]*/[illegible]	±σ(%)		[illegible]/[illegible]	±σ	[illegible]/[illegible]	±σ	(%)
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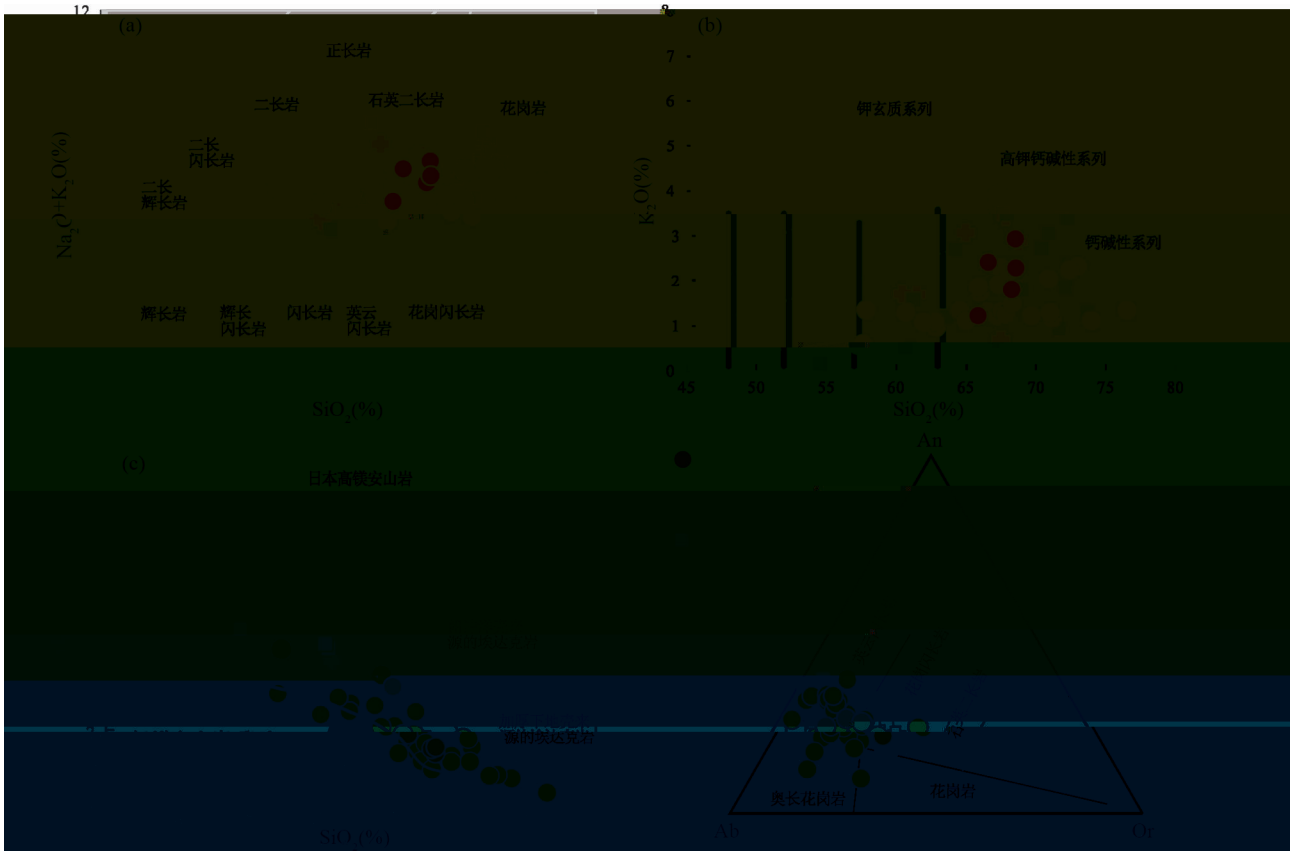


5 TTG

a Middlemost 1994 Irvine and Baragar 1971 b SiO_2-K_2O Le Maitre 1989 c SiO_2-MgO Xiong *et al.* 2014 d O'Connor 1965 . TTG Long *et al.* 2014 Zhang *et al.* 2014 TTG Zhang *et al.* 2013b Zong *et al.* 2013 TTG Long *et al.* 2010 Zhang *et al.* 2012a 6 8

Fig. 5 Geochemical discrimination diagrams for the Neoarchean TTG gneisses in the North Altyn Tagh area

a SiO_2 vs. total alkali $Na_2O + K_2O$ content diagram Middlemost 1994 and alkaline and subalkaline division is after Irvine and Baragar 1971 b SiO_2 vs. K_2O diagram after Le Maitre 1989 c SiO_2 vs. MgO diagram modified after Xiong *et al.* 2014 d normative feldspar classification after O'Connor 1965 . Data for North Altyn Tagh TTG from Long *et al.* 2014 and Zhang *et al.* 2014 data for Dunhuang TTG from Zhang *et al.* 2013b and Zong *et al.* 2013 data for Kuluketage TTG from Long *et al.* 2010 and Zhang *et al.* 2012a also in Fig. 6 and Fig. 8

6 Th $8 \times 10^{-6} \sim 15 \times 10^{-6}$ $6 \times 10^{-6} \sim 20 \times 10^{-6}$ Th/U 0.66 ~ 1.32 1

4 $^{206}Pb/^{238}U$ $^{207}Pb/^{235}U$ 4a 2512 ± 110Ma MSWD = 0.67 $^{207}Pb/^{206}Pb$ 2494 ± 53Ma MSWD = 0.52 n = 4 4c

2 $^{206}Pb/^{238}U$ $^{207}Pb/^{235}U$ $^{207}Pb/^{206}Pb$ 1964 ± 82Ma 1962 ± 78Ma

3.2 全岩主微量元素

2 TTG SiO_2 62.96% ~66.99% Na_2O 3.99% ~4.40% 2 TAS 5a LeMaitre 1989 5b TTG Condie 2005 Al_2O_3 14.82% ~ 15.71% CaO 2.97% ~ 4.03% MgO 1.33% ~3.08% 5c An-Ab-Or TTG 5d TTG REE $85 \times 10^{-6} \sim 272 \times 10^{-6}$ $La/Yb_N = 25 \sim 49$ Eu $Eu/Eu^* = 1.75$

表 2 阿尔金北缘新太古代 TTG 片麻岩主量元素(wt%)与微量元素($\times 10^{-6}$)地球化学数据

Table 2 Major wt% and trace $\times 10^{-6}$ elements of the Neoarchean TTG gneisses from the North Altyn Tagh aera

Sample No.	16AB06H1	16AB06H2	16AB06H3	17ALT01B	17ALT06B
SiO_2	66.92	66.91	65.12	66.99	62.96
TiO_2	0.42	0.47	0.46	0.44	0.55
Al_2O_3	15.30	15.49	15.71	14.82	15.24
$Fe_2O_3^T$	3.78	3.97	4.26	4.43	5.69
MnO	0.04	0.06	0.05	0.05	0.07
MgO	1.50	1.46	1.85	1.33	3.08
CaO	3.62	3.87	4.03	3.20	2.97
Na_2O	4.14	4.40	4.25	3.99	4.25
K_2O	2.24	1.78	2.37	2.88	1.18
P_2O_5	0.16	0.14	0.23	0.15	0.14
LOI	1.27	0.96	1.20	0.70	3.28
Total	99.39	99.51	99.53	98.98	99.41
$Mg^{\#}$	44	42	46	37	52
Sc	8.71	12.4	10.6	7.40	9.66
V	67.2	69.0	75.7	66.1	93.4
Cr	21.1	11.6	39.0	18.3	39.0
Co	256	280	199	204	79.0
Ni	25.8	22.9	33.4	22.5	30.3
Ga	22.9	23.9	20.4	20.0	19.0
Rb	65.8	39.3	56.2	82.1	32.5
Sr	581	554	529	764	469
Y	7.65	13.5	12.6	12.4	4.72
Zr	150	106	145	194	64.3
Nb	3.01	5.79	4.37	5.00	3.60
Cs	0.169	0.120	0.118	0.223	0.316
Ba	1020	656	1060	1710	602
La	36.5	42.1	36.5	69.6	22.5
Ce	68.2	81.8	75.9	123	39.3
Pr	7.12	8.67	8.69	14.9	3.95
Nd	25.7	31.0	32.9	47.3	13.4
Sm	3.54	4.95	5.40	6.32	1.74
Eu	1.02	1.09	1.24	1.30	0.911
Gd	2.81	3.79	4.36	3.68	1.46
Tb	0.300	0.491	0.524	0.543	0.184
Dy	1.27	2.19	2.48	2.42	0.831
Ho	0.233	0.407	0.431	0.441	0.176
Er	0.658	1.08	1.33	1.15	0.427
Tm	0.0780	0.154	0.168	0.145	0.0697
Yb	0.503	0.903	0.989	0.950	0.369
Lu	0.0621	0.129	0.126	0.146	0.0633
Hf	3.49	2.51	3.92	4.58	1.41
Ta	0.643	0.969	0.688	0.985	0.360
Th	4.30	9.72	1.10	10.1	0.751
U	0.234	0.332	0.257	0.419	0.564

表 3 阿尔金北缘地区新太古代 TTG 片麻岩 Sr-Nd 同位素组成

Table 3 Sr-Nd isotopic compositions of the Neoarchean TTG gneisses in the North Altyn Tagh area

	16AB06H1	16AB06H2
Rb $\times 10^{-6}$	65.8	39.3
Sr $\times 10^{-6}$	581	554
Sm $\times 10^{-6}$	3.54	4.95
Nd $\times 10^{-6}$	25.7	31.0
Age Ma	2740	2740
$^{87}Rb/^{86}Sr$	0.3280	0.2054
$^{147}Sm/^{144}Nd$	0.0832	0.0965
$^{87}Sr/^{86}Sr$	0.718598	0.714104
2σ	0.000007	0.000005
$^{143}Nd/^{144}Nd$	0.510768	0.510837
2σ	0.000003	0.000005
$^{87}Sr/^{86}Sr$ t	0.705583	0.705956
$^{143}Nd/^{144}Nd$ t	0.509260	0.509088
t_{DM1} Ga	2.77	2.99
t_{DM2} Ga	3.70	3.62
ε_{Nd} 0	-36.5	-35.1
ε_{Nd} t	3.6	0.2

CHUR $^{147}Sm/^{144}Nd = 0.1967$ $^{143}Nd/^{144}Nd = 0.512638$ $\lambda_{Sm} = 6.54 \times 10^{-12} y^{-1}$ Lugmair and Marti 1978 . $^{143}Nd/^{144}Nd_i$ ε_{Nd} t . t_{DM1} t_{DM2} Jahn *et al.* 1999

$10^{-6} \sim 13.5 \times 10^{-6}$ Yb $0.369 \times 10^{-6} \sim 0.989 \times 10^{-6}$ Sr/Y 41.03 ~ 99.36 Kay 1978 Defant and Drummond 1990 Martin *et al.* 2005 b-Ta Ti 6b

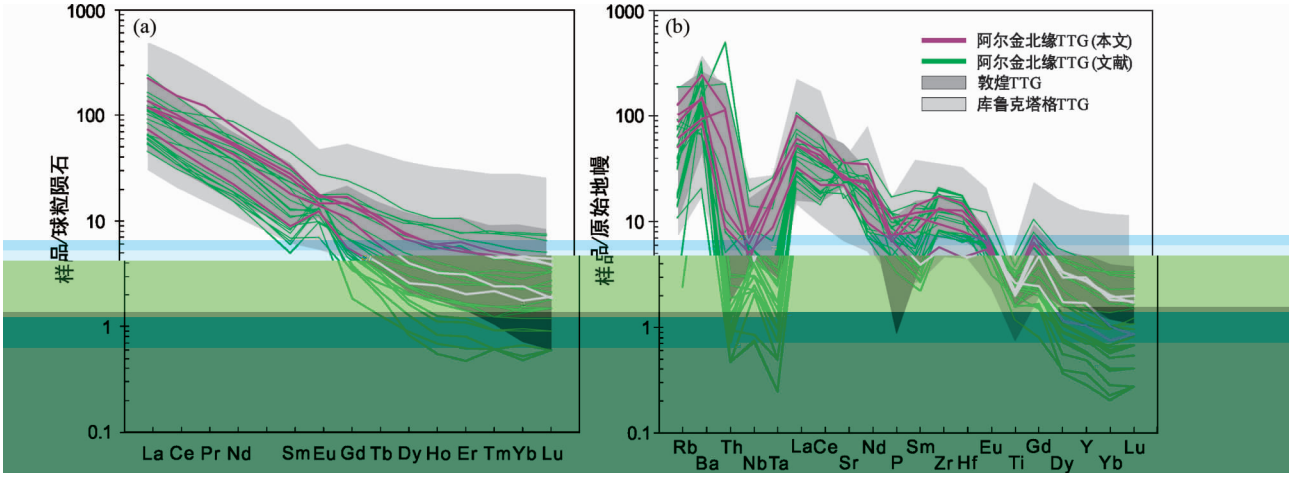
3.3 全岩 Sr-Nd 同位素组成

TTG b/Sr 0.11 0.07 $^{87}Sr/^{86}Sr$ 0.718598 0.714104 $^{87}Sr/^{86}Sr$ 0.705583 0.705956 3 $^{143}Nd/^{144}Nd$ 0.510768 0.510837 ε_{Nd} t 3.6 0.2 7 d t_{DM2} 3.70 ~ 3.62Ga 3

4

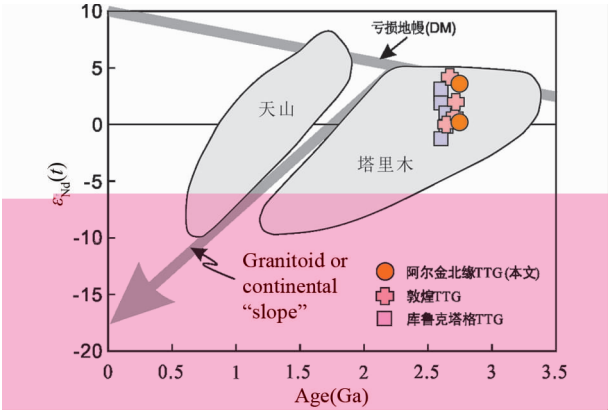
4.1 阿尔金北缘 TTG 片麻岩岩石成因

TTG TTG Tonalite Trondhejmite Granodiorite



6 TTG a Boynton 1984 b Sun and McDonough 1989

Fig. 6 Chondrite-normalized REE patterns a normalization values after Boynton 1984 and primitive mantle-normalized spider diagrams b normalization values after Sun and McDonough 1989 for the Neoarchean TTG gneisses in the North Altyn Tagh area



7 ε_{Nd} t Hu *et al.* 2000

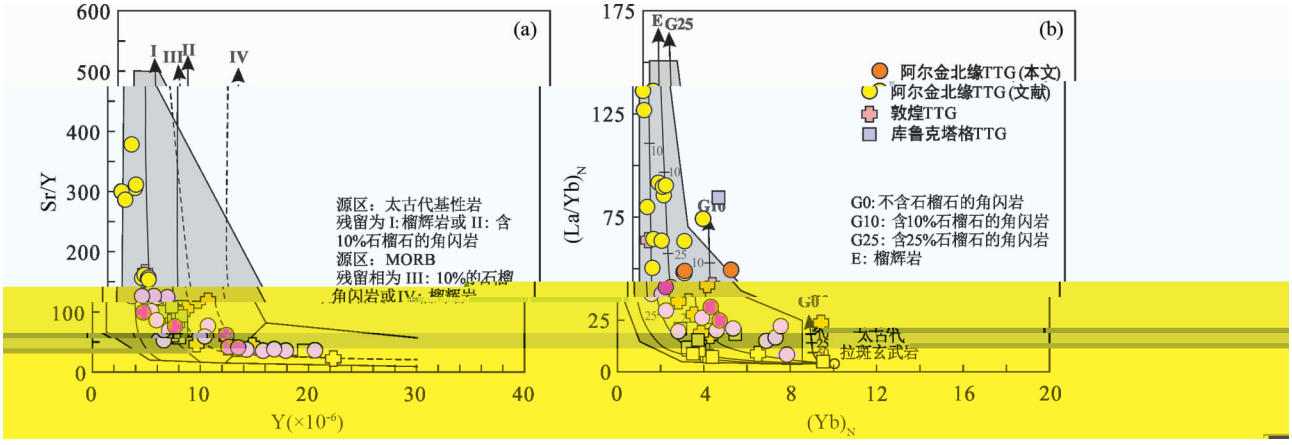
TTG 1998 Zong *et al.* 2013 TTG Zhang *et al.* 2012a

Fig. 7 Crystallization ages vs. ε_{Nd} t diagram modified after Hu *et al.* 2000

Data for Dunhuang TTG from Mei *et al.* 1998 and Zong *et al.* 2013 data for Kuluketage TTG from Zhang *et al.* 2012a

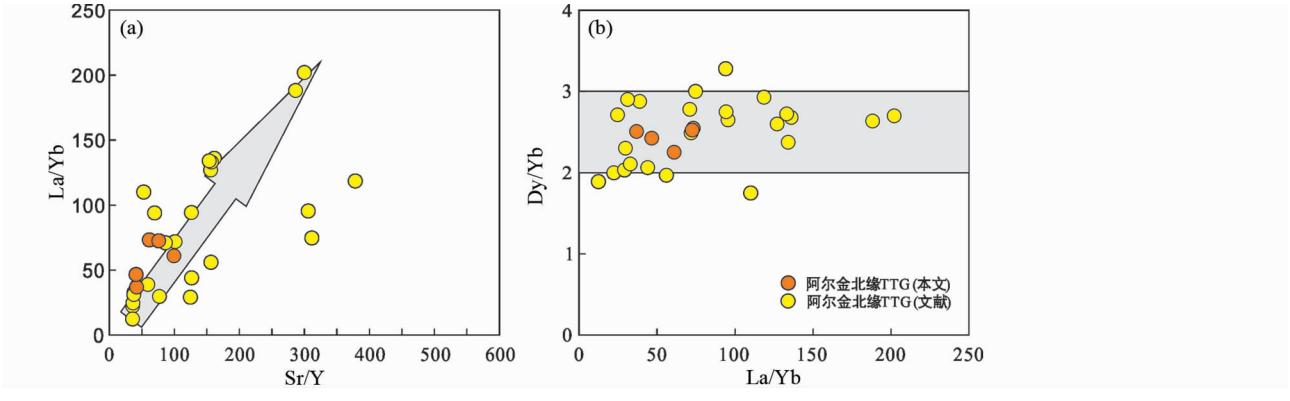
Martin and Arndt 2015 Condie 2005 Al_2O_3 TTG Barker and Arth 1976 Barker *et al.* 1976 Barker 1979 Halla *et al.* 2009 TTG 2017 TTG TTG 10kbar 10 ~ 25kbar 25kbar Moyen 2011

TTG Na_2O >5% Sr/Y 50 ~ 500 Yb $<1\times10^{-6}$ -TTG 65% ~72% 4% ~6% Yb $<1.5\times10^{-6}$ Sr/Y 10 ~ 200 Moyen and Martin 2012 TTG -TTG Moyen 2011 TTG -TTG TTG Arth and Hanson 1972 Martin 1987 Drummond and Defant 1990 Atherton and Petford 1993 Rapp and Watson 1995 Winther 1996 Foley *et al.* 2002 Rapp *et al.* 2003 Nair and Chacko 2008 Moyen and Martin 2012 Martin and Arndt 2015 Moyen and Martin 2012 TTG Willbold *et al.* 2009 Rollinson 2009 TTG Moyen and Martin 2012 TTG TTG MgO $Mg^{\#}$ Cr Ni Martin 1999 Martin *et al.* 2005 Martin and Moyen 2002 Smithies *et al.* 2009 Moyen 2009 TTG MgO $Mg^{\#}$ Cr Ni Atherton and Petford 1993 Rapp *et al.* 1999 Rapp and Watson 1995



8 TTG Sr/Y-Y a La/Yb_N-Yb_N b Moyen and Martin 2012 Drummond and Defant 1990

Fig. 8 Y vs. Sr/Y diagram a and Yb_N vs. La/Yb_N diagram b modified after Moyen and Martin 2012 melting curves from Drummond and Defant 1990 for the Neoarchean TTG gneisses in the North Altyn Tagh area



9 TTG Sr/Y-La/Yb a Dy/Yb-La/Yb b Long *et al.* 2014 Zhang *et al.* 2014

Fig. 9 Plots of La/Yb vs. Sr/Y diagram a and La/Yb vs. Dy/Yb diagram for the Neoarchean TTG gneisses in the North Altyn Tagh area

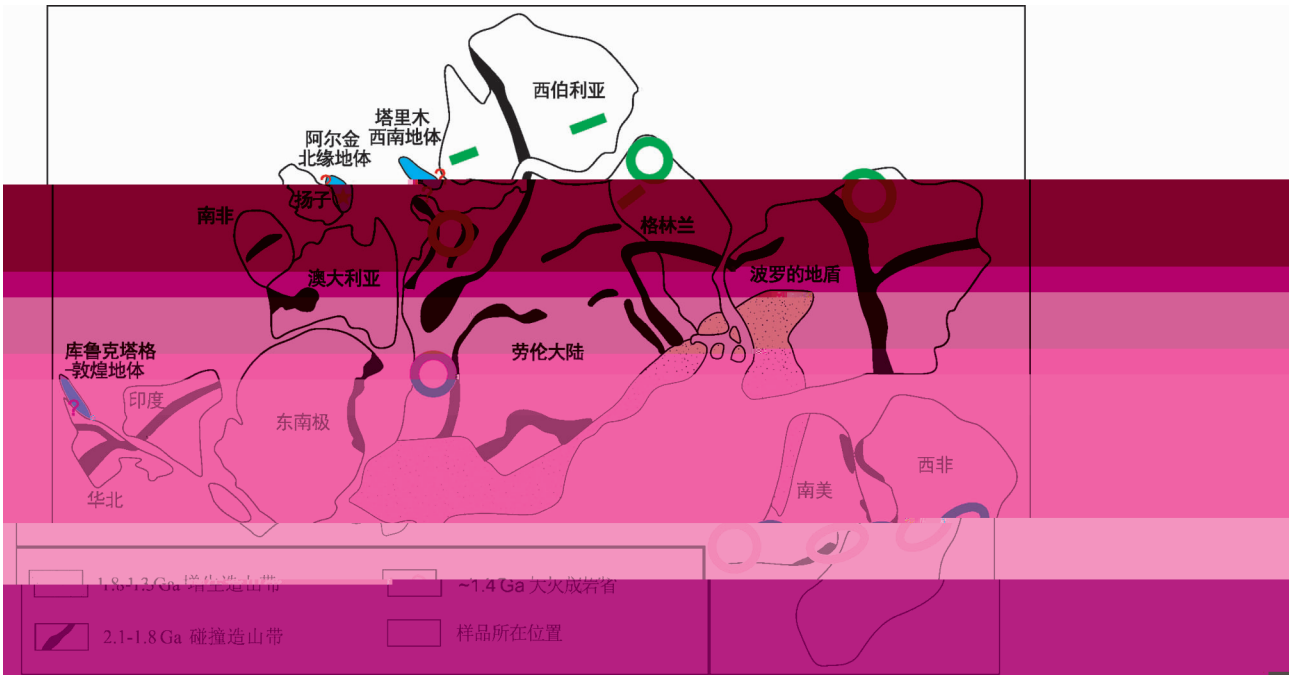
Data for North Altyn Tagh TTG from Long *et al.* 2014 and Zhang *et al.* 2014

Long *et al.* 2010 Zhang *et al.* 2014 TTG Sr Yb Sr/Y La/Yb_N Eu Eu TTG 8a b MgO $Mg^{\#}$ 0.65% ~ 3.50% 1.79% 26 ~ 60 44 TTG 5c 1.19×10^{-6} La/ $\sim 59.4 \times 10^{-6}$ 25.7×10^{-6} Ni 1.14×10^{-6} Yb $_N$ b_N $\sim 37.0 \times 10^{-6}$ 17.3×10^{-6} Martin *et al.* 2005 TTG TTG Nd Hf 3.6 ~ Nb/Ta Zr/Hf Zr/Sm 3.1Ga 0.9 ~ 0.4Ga Foley *et al.* 2002 Klemme *et al.* 2002 Xiong *et al.* TTG 2005 2007 TTG MREE > HREE > LREE Bottazzi *et al.* TTG TTG 1999 La/Yb -TTG Gd/Dy Dy/Yb

Sr/Y La/Yb Gd/Yb Dy/Yb
Davidson *et al.* 2007
TTG /Y La/Yb
9a Dy/Yb La/Yb
y/
Yb 2 ~ 3 9b
TTG
b-Ta Zr-Hf
6b
TG
1. 5GPa 45km
Rapp *et al.* 1991 2007

4. 2 TTG 岩浆活动与变 事件

SHRIMP U-Pb $^{207}Pb/^{206}Pb$
2740 ± 19Ma 4b TTG
2. 74Ga
TTG 2. 60 ~ 2. 74Ga ~ 2. 70Ga
2003 Long *et al.* 2014 Zhang *et al.*
2014
TG
TG
2. 46 ~ 2. 64Ga ~ 2. 57Ga
2006 Long *et al.* 2010 Zhang *et al.* 2012b
n TG
2. 50 ~ 2. 71Ga ~ 2. 59Ga
2013 1998 Zhang *et al*



10 - Columbia Zhao *et al.* 2002 Ye *et al.* 2016

Fig. 10 Possible positions of the North Altyn terrane Kuluketage-Dunhuang terrane and Southwest Tarim terrane in the Columbia supercontinent modified after Zhao *et al.* 2002 Ye *et al.* 2016

TTG 2. 41 ~ 2. 34Ga ~ 1. 90Ga Zhang *et al.* 2014 Ye *et al.* 2016 - 1 ~ 1. 8Ga Columbia Zhao *et al.* 2002 Rogers and Santosh 2002 ransamazonian Eburnean 2. 1 ~ 1. 8Ga Alkmim and Marshak 1998 rans-Hudson . 95 ~ 1. 85Ga Hoffman 1989 impopo . 0 ~ 1. 9Ga Kröner *et al.* 1999 Capricorn 2. 0 ~ 1. 9Ga Myers 1990 Nagssugtoqidian . 9 ~ 1. 8Ga Kalsbeek 2001 kitkan . 9 ~ 1. 8Ga Rosen *et al.* 2005 . 85Ga Zhao *et al.* 2001 -

10 Zhang *et al.* 2014 Ye *et al.* 2016 Columbia

2020

5

1 TTG ~ 2. 74Ga ~ 2. 5Ga ~ 1. 96Ga

2 TTG

45km

3 -

致谢

SHRIMP U-Pb

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