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The petrological and mineralogical characteristics of Cenozoic kamafugite and carbonatite association in West Qinling, Gansu province: China

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ABSTRACT. — Kamafugites are ultra-potassic volcanic rocks which occur in continental rifts. Kamafugites are associated to carbonatites and this occurrence, to our knowledge, is only known from a very few places all over the world.

The Cenozoic kamafugite and carbonatite association in West Qinling, Gansu province was not know in the world so far. This paper provide a description of the petrological and mineralogical characteristics of the West Qinling kamafugite and carbonatite rocks in some detail. Representative, whole rock and essential minerals compositions from both kamafugite and carbonatite are shown, as well as Ar/Ar and K/Ar dating of 18 extrusive pyroclastic centers and dykes. The dating indicate that the West Qinling kamafugites and carbonatites were emplaced during the Miocene. The volcanic rocks are poor in SiO_2 and Al_2O_3, but rich in MgO, CaO, TiO_2 and alkalies (K_2O+Na_2O). As a whole, bulk rock composition is very similar to that one from Toro-Ankole kamafugites of Uganda.

The carbonatites are Ca-carbonatite. They occur as lapilli-tuff in surges deposits and high temperature pyroclastic flows. They are composed of essential calcite with minor amounts of nepheline, apatite, phlogopite and rare clinopyroxene. Carbonatite composition show characteristic high content of CaO, relatively high content of SiO_2 and are very poor in alkalies. In general, the carbonatites in the West Qinling are very similar to other carbonatites associated to kamafugites elsewhere such as Fort Portal, (Uganda) and Polino (Italy).

RIASSUNTO. — Le kamafugiti sono rocce vulcaniche ultra-potassiche che si ritrovano in alcuni rift continentali. Le kamafugiti sono associate a carbonatiti e quest'associazione, a nostra conoscenza, è nota solo in pochi posti al mondo.

L'associazione kamafugitico-carbonatitica Cenozoica del Qunling Occidentale nella Provincia di Gansu, non era ancora nota a livello mondiale. Questo lavoro descrive le principali caratteristiche mineralogiche e petrologiche di queste rocce. In questo lavoro si riportano le analisi esemplificative delle rocce e dei loro minerali essenziali, insieme a datazioni Ar/Ar e K/Ar, provenienti da 18 centri effusivi e da dicchi. Le datazioni indicano che le kamafugiti e le carbonatiti del Qinling Occidentale sono Mioceniche. Queste vulcaniti e subvulcaniti sono povere in SiO_2 e Al_2O_3, ma ricche in MgO, CaO, TiO_2 ed alcali (K_2O+Na_2O). Nel complesso la loro composizione è molto simile a quella delle classiche kamafugiti del Toro-Ankole in Uganda. Le carbonatiti sono sempre Ca-carbonatiti. Si ritrovano come letti di tufo a lapillo in depositi da ondata piroclastica e da flusso piroclastico di alta temperatura. La fase più importante è la calcite con quantità accessorie di nefelina, apatite, flogopite e raro clinopirosseno. Le carbonatiti suddette mostrano contenuti caratteristicamente alti di CaO, contenuti relativamente alti di SiO_2 e contenuti molto bassi di alcali. In genere, le carbonatiti del Qinling sono molto simili alle altre carbonatiti associate a kamafugite come quelle di Fort Portal, Uganda e Polino in Italia.

KEY WORDS: *Miocene, Kamafugite–Carbonatite association, West Qinling-Gansu-China, tectonic setting.*

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INTRODUCTION

Kamafugite is a rare ultra-potassic type of magma associated with continental rifts. Although several studies appeared since the 1980s (Arima *et al.*,1983, Foley *et al.*,1987, Gallo and Giammetti, 1984, Lloyd *et al.*,1987, Peccerillo and Manetti, 1985; Stoppa and Lavecchia, 1992; Stoppa and Woolley, 1997; Stoppa *et al.*, this volume; Tappe *et al.*, this volume), there is little consensus concerning their petrogenesis, characteristics of the mantle source and geodynamic meaning.

The Western Qinling, Gansu Province is one of the few regions where outcrop kamafugites over the world and also the only outcrop of kamafugite reported in China so far. The Cenozoic magmatism of West Quiling was firstly recognized in the 1960s and its dating was based on field stratigraphyc relationship between the volcanic rocks and the sedimentary rocks. However, no specific studies on petrology, mineralogy and geochemistry of the volcanic rocks was carried at that time. The rocks were considered as kimberlite-like and prospected for diamonds, however the latter were not found.

Our studies paid particular attention on this volcanic province where we found deep-seated xenoliths and megacrysts in the volcanic rocks, and re-classified the rocks as kamafugites during the research project focused on the Qinling Orogenic belt carried out in the middle of 80s. The use of the term kamafugite triggered considerable debate and rumors among chinese petrologists. In spite of classical works from old master such as those of Sahama (e.g Sahama, 1974), the term kamafugite was approved by Chinese petrologists only at the end of 80s after the review Foley's 1987 article «The characteristics and classification of ultrapotassic rocks».

This paper provide a petrological, mineralogical and general geochemical insight of the kamafugite of the Western Qinling and a comparison with the world ultra-alkaline volcanic rocks and those of the Tibet plateau and adjacent areas. The Cenozoic kamafugite magmatism in the Western Qinling has to be interpreted in the bigger frame of collision of India and Asia continents and the strong uplift of the Tibet plateau. In particular the genesis of the Cenozoic kamafugite and carbonatite association may be related to the updraft of the asthenosphere and consequent low-degree partial melting of the thermal boundary at the base of lithosphere or from asthenospheric mantle. The genesis of the carbonatite is probably related to immiscibility between carbonatite and kamafugite magmas at low pressure.

GEOLOGICAL SETTING

The Cenozoic kamafugitic rocks of Western Qinling is located in the Northeastern boundary of Tibet Plateau (Fig. 1) near to Lixian, in the Tangchang and Xihe county of the Gansu province, an area crossed by the South—North tectonic belt (about 102°—105°E trending) of the Henan – Liupanshan and Kandian montains. Therefore, the West Qinling is located just on a relatively stable area of the Tethys and Paleo Asia ocean domains in China. The Cenozoic volcanic rocks are represented by a few and scattered small districts, located within, or at the margin of the Cenozoic basin of Tianshui-Lixian, that is a smaller basin with an area of only some hundreds square kilometers. A cluster of more than 30 outcrops occur in a plateau of about 2500m elevation. They are mainly pipes (datremes)- tuff rings and subvolcanic intrusions. In general, the single outcrop diameter is less than 1 km, but there are a few outcrops that cover an area of some square kilometers .

The sedimentary country rocks are mostly Holocene loess and Paleogene red sandstones. In the bedrock stratigraphy also occur minor Middle-Lower Jurassic sandstones and shales, Triassic sandstones and slates, Carboniferous limestones, limestone-shales and sandstones, Devonian slates, sandstones and phyllite (Fig. 2). Cenozoic kamafugite are often covered by Paleogene red sandstone a fact which is consistent with results of isotopic dating (Table 5).

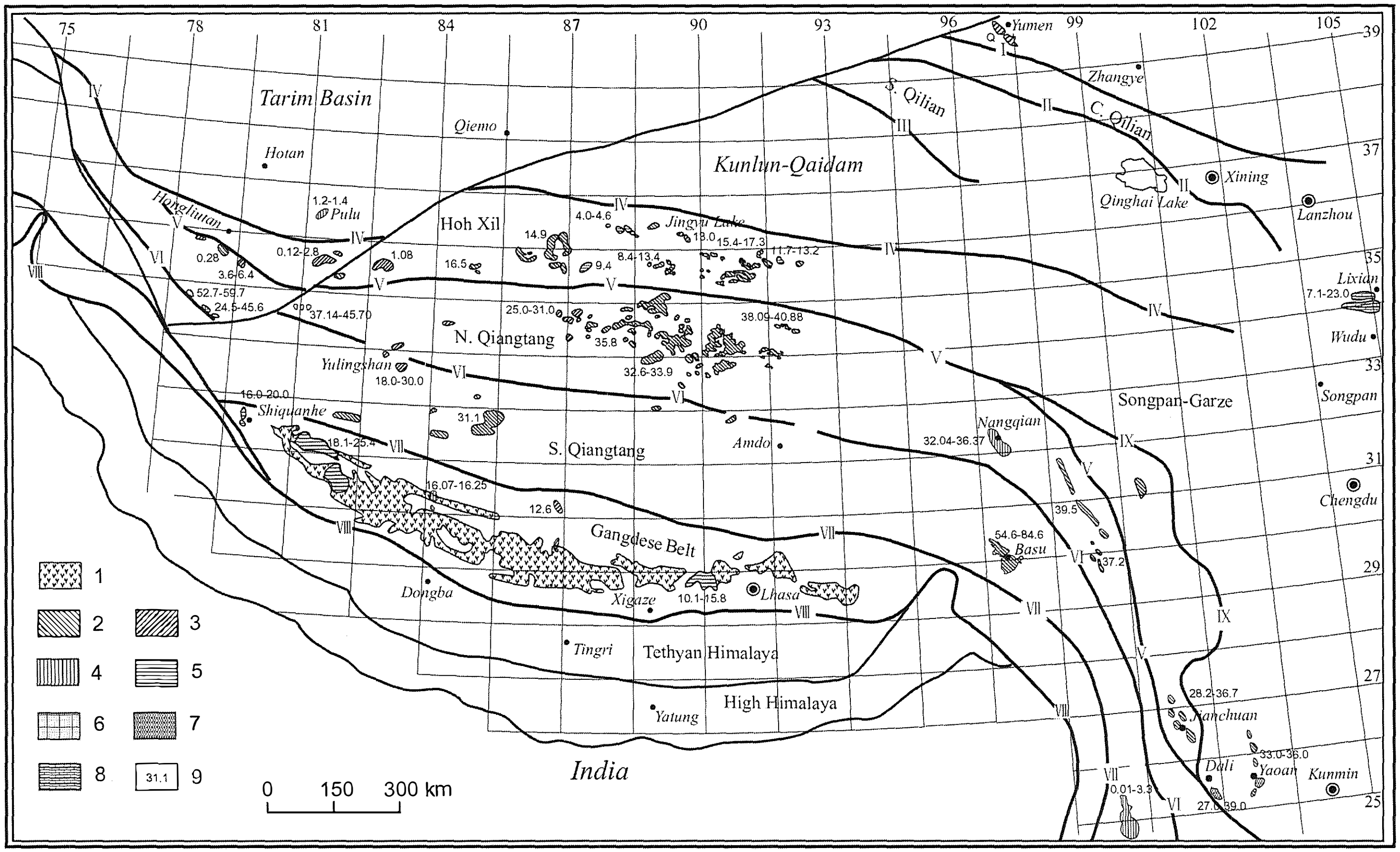

Fig. 1 – Sketch map of the distribution of potassic and ultrapotassic volcanic rock in Tibet and adjacend areas.

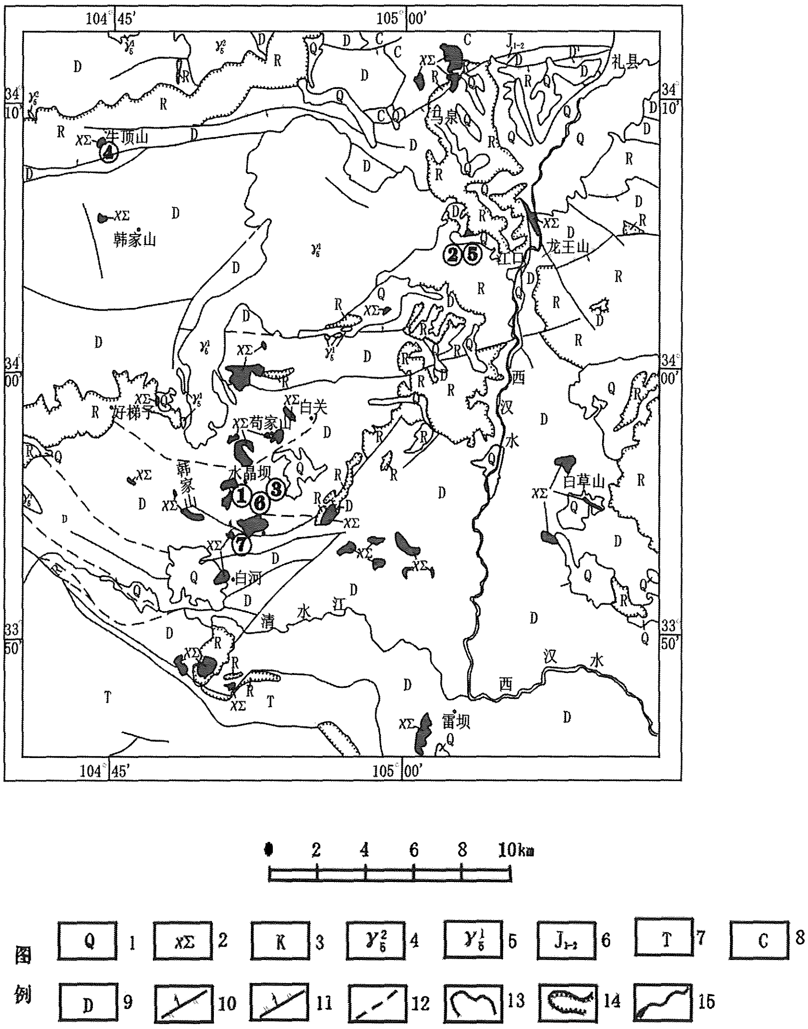

Fig. 2 – Locations and distribution of Cenozoic kamafugite and carbonatite in West Qinling. 1) Loess of Holocene - Quaternary; 2) Cenozoic Volcanic Rocks; 3) Red sandy-conglomerate and argillaceous sandstone of Paleogene; 4) Porphyritic Granite and Granite of Mesozoic; 5) Sandy shale and Conglomerate of Lower-Middle Jurassic; 6) Sandstone, Slate and Limestone of Triassic; 7) Limestone, Shale and Sandstone of Carboniferous; 8) Slate, Sandstone, Siltstone and Phyllite of Dorania; 9) Faults, 10) Geologic Boundary; 11) Rivers.

PETROLOGY AND MINERALOGY OF THE KAMAFUGITES AND CARBONATITES

Kamafugite

The Cenozoic kamafugites are found in central volcanoes formed by scoria cones of breccia (welded breccia), agglomerate and lava. In general subvolcanic rocks, such as pipe-breccias and dikes of kamafugite are well exposed, whereas only a few volcanic cones are preserved from erosion (Plate 1: photo1). However, volcanic vents (maar?) can be

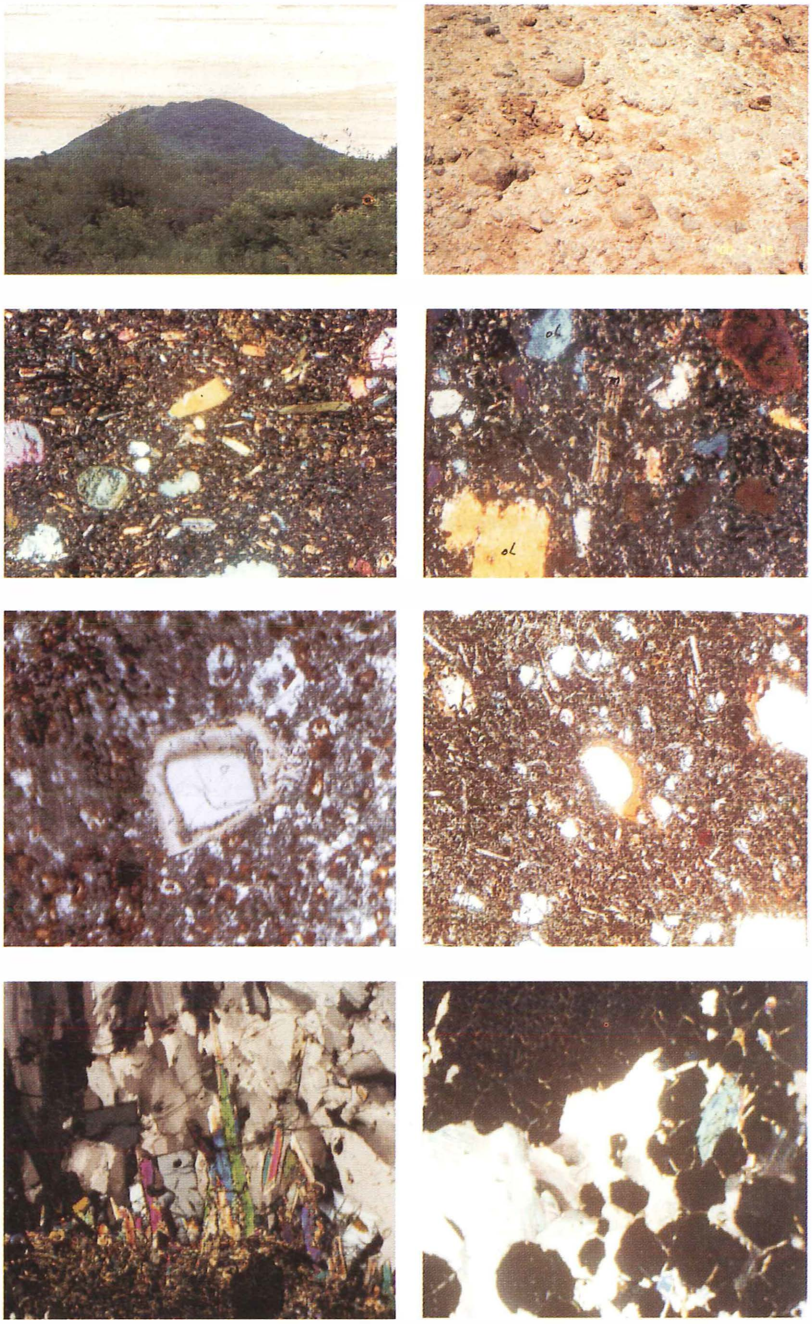

Plate 1 – Photo 1: A kamafugitic scoria cone in West Qinling, China; Photo 2: Kamafugite – carbonatite agglomerate; Photo 3 and 4: Porphyritic kamafugite showing Ol and Di/salite phenocrysts in a micropheno groundmass cpx and melilite; Photo 5: Zoned cpx phenocryst in kamafugite; Photo 6: Phlogopite corona reaction on olivine; Photo 7: Ocellus consisting of calcite and cpx in kamafugite; Photo 8: ocellus consisting of a polycrystalline leucite and calcite.

recognised as circular areas with negative elevation. They are rimmed by lavas, breccias, agglomerate (Plate 1, photo 2) and tuffs (Plate 2, photo 1). Over 40 pipes, cones and dikes are distributed in a Cenozoic graben borded by two hidden faults trending NNE. The geophysical data show that the hidden faults cross through the lithosphere and not only produced the formation of the basin, but also control the areal distribution of the Cenozoic kamafugites (Fig. 1 and 2)

The West Qinling kamafugites are porphyritic rocks. The phenocrysts are olivine, clinopyroxene, phlogopite and lesser monticellite (Plate 1, photo 4-6). Phenocrystic olivine is subhedral with Fo85 (Table 1) and is unzoned. The content of olivine phenocrysts varies from 1 to 20 % in volume in different volcanic pipes or dikes. In the kamafugites there are also anhedral olivine xenocrysts having kink-banding (Plate 3, photo 2). The Fo molar content in these olivine xenocrysts is higher than 90, therefore its origin is different from the phenocrystic olivine as confirmed by the kink-banding structures even if some compositional overlapping between olivine xenocrysts and phenocrysts can occur.

The subhedral—euhedral clinophyroxene phenocrysts are 5% to 30% in volume; their modal variation has a inverse correlation with the content of olivine. The chemical composition of the clinopyroxenes is very complex and vary in different pipes and dikes, but they are mostly diopside and/or Ca-rich salite. The diopside is rich in Ti and titanaugite can also occur. Most of the clinopyroxene phenocrysts show a zoning. Generally, the core is salite-rich with light green color, and the rim is Ti-rich diopside with light pink colour (Table 3, Plate 1-photo 5).

The phlogopite phenocrysts modal content is between 5% and 10%. However, in the kamafugite at Xiaodingshan pipe, phlogopite can reach 30% in volume. Here the phlogopite forms coronas around the olivine phenocryst (Plate1-photo 6). The color of phlogopites are generally red brown and exibits both normal and reverse pleochroism. The phlogopite is strongly enriched in Ti (TiO_2 mean 8.4 wt.%; Table 3), and Mg. This is reflected in the Mg# ($Mg/Mg+Fe^{+2}$) that is higher of 0.66 (Table 2).

The groundmasses in the West Qinling kamafugite are mostly microporphyritic. The microphenocrysts are Ca-rich clinopyroxene,

TABLE 1

Selected EMP analyses of olivine

Label phase	8617 OL	8619 OL	8621 OL	8754 OL	8755 OL	9114 OL	9117 OL	9125 OL	8626 OL	8731 OL	8523 OL	9106 OL
SiO_2	39.39	39.41	40.31	40.30	40.20	41.18	41.79	41.84	40.49	40.96	40.71	40.08
TiO_2	0.07			0.05				0.12	0.06	0.04		
Al_2O_3							0.37					
Cr_2O_3	0.09	0.20			0.29			0.10	0.05			0.04
NiO	0.35	0.20	0.24	0.12	0.46	0.36	0.38	0.23	0.22	0.55	0.36	0.56
FeO*	16.31	15.19	12.77	10.94	8.95	15.03	8.27	8.67	14.18	9.19	9.08	9.41
MnO	0.29		0.24	0.20		0.09	0.04	0.20	0.31	0.20	0.17	0.21
MgO	43.95	45.33	47.07	48.35	49.40	43.52	49.23	48.84	45.09	48.21	50.38	49.58
CaO	0.08	0.38	0.32	0.04		0.41		0.12	0.26	0.07	0.16	0.16
Total	100.53	100.71	100.95	100.00	99.30	100.59	100.08	100.12	100.66	99.22	100.86	100.04
[Mg]	82.8	84.2	86.8	88.8	90.8	90.8	91.4	90.2	84.2	90.4	90.8	90.4

* Total iron. [Mg] = $Mg/Mg+Fe^{2+}$.

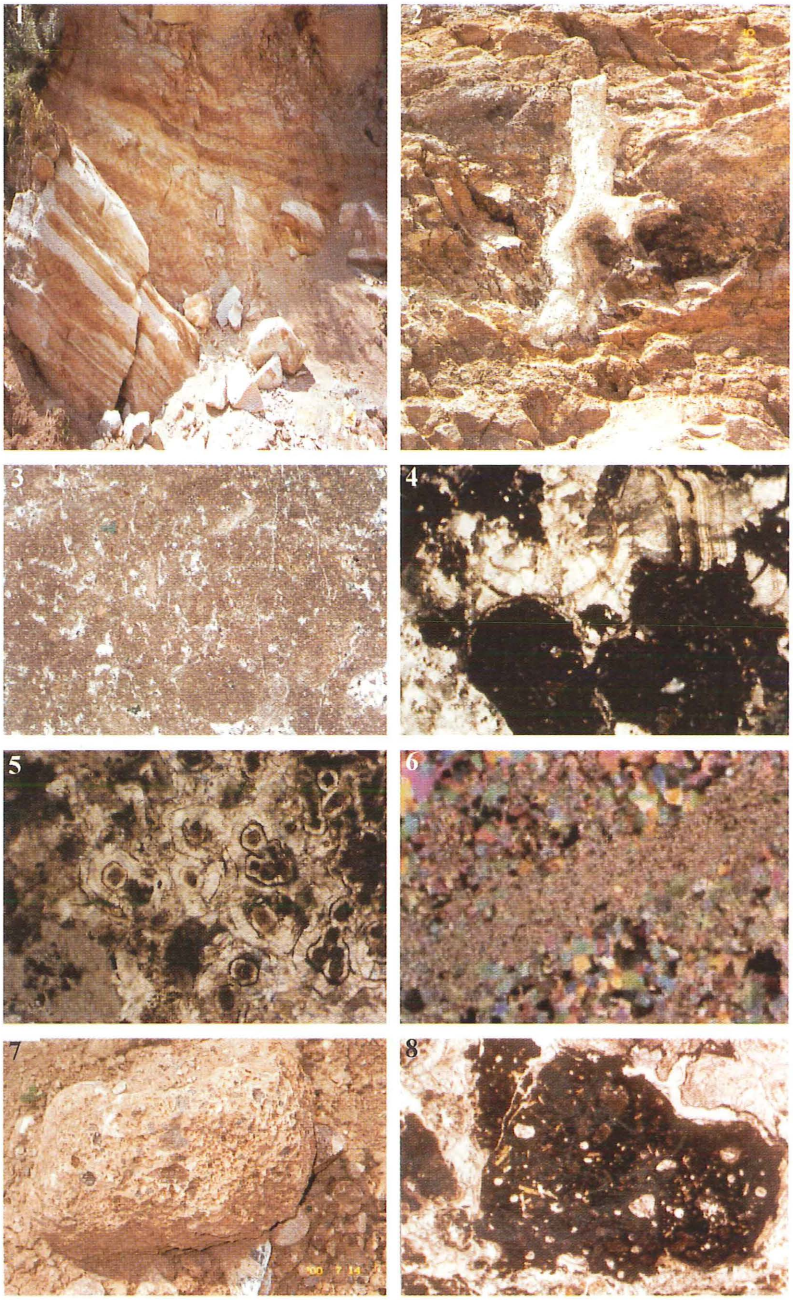

Plate 2 – Photo 1: Layered carbonatite tuffs topped by kamafugite lava flow (massive); Photo 2: Carbonatite intruded in kamafugite; Photo 3: Plastically molded, agglutinated composite lapillire crystallized in carbonatitic tuff; Photo 4: Carbonatite tuff with concretional calcite matrix (re crystallized) containing weathered lapilli; Photo 5: Calcite growing around silicate kernels (re crystallized). Photo 6: Different granularity after recrystallization in lava; Photo 7: Carbonatitic - kamafigitic agglomerate; Photo 8: Kamafugitic lapillus in carbonatite matrix.

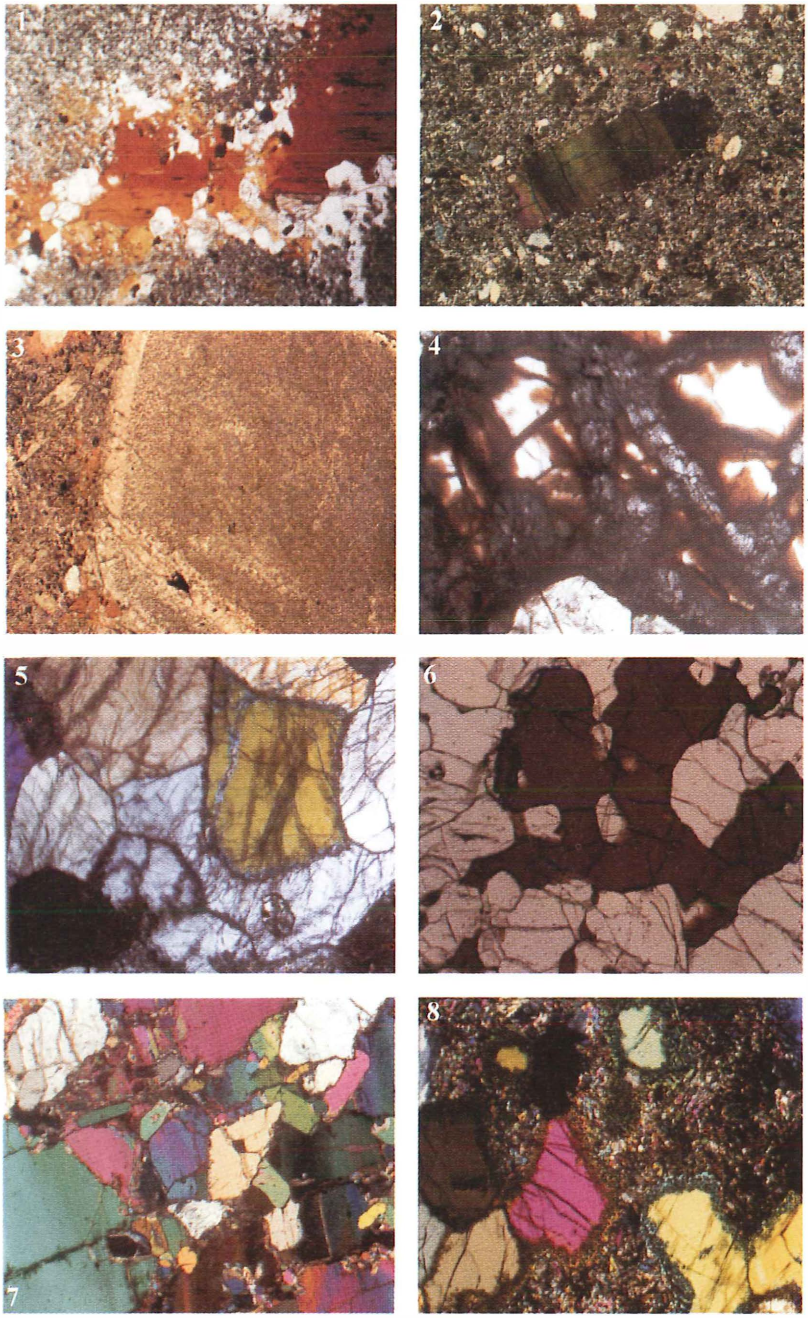

Plate 3 – Photo 1: Polycristalline segregation consisting of Ti-phlogopite, leucite and apatite in kamafugite; Photo 2: olivine xenocryst with kink band structure; Photo 3: Clinopyroxene megacryst the kamafugite: Photo 4: Garnet in lherzolite xenolith; Photo 5: Websterite xenolith; Photo 6:Spinel in lherzolite xenolith; Photo 7: Dunite xenolith; Photo 8: Pyroxenite xenolith.

TABLE 2

Selected EMP analyses of Phlogopite

Label phase	8617 Phl	8619 Phl	8755 Phl	9218 Phl	9117 Phl	9114 Phl
SiO_2	36.25	38.86	39.98	40.17	37.50	37.96
TiO_2	13.20	8.49	7.73	8.50	9.04	10.70
Al_2O_3	10.21	11.34	10.54	11.20	9.97	11.41
NiO	0.13	0.00	0.10	0.07	0.15	
FeO	11.18	9.35	9.94	10.02	10.90	9.04
MnO	0.18	0.20	0.03	0.12	0.05	0.13
MgO	13.97	16.93	16.80	17.46	15.34	17.89
CaO	0.01	0.37	0.22	0.38	0.13	0.10
Na_2O	0.12	0.02	0.00	0.03	0.25	0.52
K_2O	8.07	8.88	9.35	8.89	9.23	9.06
P_2O_5	0.39	0.21	0.00	0.14		
BaO					2.45	
Total	93.74	94.61	96.74	97.07	95.13	96.75
[Mg]	0.69	0.76	0.75	0.76	0.72	0.78

and/or needle-like, sharp melilite laths (Plate1-photo 2-6). Tabular minerals are flow arranged and form an intergranular - intersertal structure with leucite, calcite, phlogopite, kaliophilite, nepheline, apatite, zeolite, perovskite, titanomagnetite and glass. No plagioclase was found in the kamafugite. The chemical composition of the minerals in the groundmass are listed in Table 4.

Ocellar structures are a notable feature of the West Qinling kamafugite. Ocelli vary in size from millimeters to centimeters. Their shape can be rounded, oval amoeboidal or grading to fine, irregular veins. The ocelli infill is sometimes monomineralic with carbonates or zeolites, but sometimes the infilling is composed of an association of green clinopyroxene, leucite, phlogopite, richterite, kaliophilite, nepheline, apatite, perovskite, K-feldspar plus rare minerals. Ocelli are coarser than the hosting rock groundmass, which varies from phaneritic to microgranular or cryptocrystalline (Plate1-photo 7-8). These

TABLE 3

Selected EMP analyses of cpx

Label phase	8626 Cpx	8731 Cpx	9106 Cpx	8722 Cpx	9216 Cpx
SiO_2	51.15	51.62	50.29	50.38	49.32
TiO_2	51.15	51.62	50.29	50.38	49.32
Al_2O_3	2.29	2.06	1.15	6.45	5.13
Cr_2O_3		0.03		0.04	0.04
NiO			0.12	0.23	0.02
FeO	11.39	11.33	7.03	8.40	13.70
MnO	0.23	0.11	0.24	0.23	0.26
MgO	11.14	11.21	14.24	10.80	8.56
CaO	22.20	22.50	24.60	20.50	21.40
Na_2O	0.88	0.82	0.55	1.51	1.18
K_2O		0.05	0.03	0.04	0.18
BaO		0.23			
Total	99.53	100.00	99.43	100.55	99.97
[Mg]	86.3	87.3	91.1	87.2	92.2

TABLE 4

Selected EMP analyses of groundmass minerals in kamafugites

Label	9117	9215	9113	8617	8619	8754	8755	9114	8731	8523	8617	8619	8617	8617	8754
phase	mo	mo	perv.	perv.	Ti-Mt	mel.	mel	ne	kl	rec	rec	zeo	ap	lc	cc
SiO_2	48.57	52.18	0.1	0.48	0.05	31.76	45.79	40.99	39.37	49.96	38.55	44.43	0.04	47.93	0.12
TiO_2	3.05	0.56	57.3	58.9	22.7	0.09	0.09	0.05		4.65	10.8		0.01	3.19	0.06
Al_2O_3			0.11	0.21	0.02	4.78	5.55	31.85	26.52	0.68	9.98	28.25	0.29	22.46	0.04
Cr_2O_3			0.06		0.46	0.21		0.02	0.17	0.13		0.07	0.26		0.82
NiO	0.08	0.24			0.48	0.18	0.1		0.06		0.12	0.03	0.01	0.11	
FeO*	5.68	10.13	0.83	0.56	70.54	4.99	5.31	1.09	5.29	10.12	7.55	0.44	0.06	0.35	0.25
MnO	0.04	0.44			1.09	0.06	0.06	0.1		0.32	0.21	0.12	0.01		0.08
MgO	14.21	11.63	0.22		2.8	7.58	7.38	0.11	0.28	13.32	17.65		0.79	0.26	0.99
CaO	24.8	23.4	39	39.3	0.18	31.8	30.6	0.07		4.35		8.58	49.3	6.03	52.3
Na_2O	0.43	0.64	0.52	0.43		3.42	3.08	14.1	1.39	4.87	0.34	0.31	1.9	0.76	0.1
K_2O			0.12	0.34		0.07	0.13	10.8	25.67	4.39	10	2.25	6.11	2.92	0.15
P_2O_5			0.16	0.63	0.04	0.05									0.32
BaO					1.33	0.27				0.24			2.85		
SrO				1.3	0.2	0	0.2								
Total	99.97	99.22	98.42	100.9	99.27	99.07	97.27	100.39	98.84	93.15	99.8	94.34	61.63	84.01	55.23

mo:monticellite, perv: perovsckite, Ti-mt: titanomagnetite, meli: melilite, ne: nepheline, kl: kaliophilite, rec: richterite, zeo: zeolite, ap: apatite, lc; leucite, cc: calcite.

features suggest that the crystallization of the West Qinling kamafugites occurred in an open system and in disequilibrium conditions.

Carbonatites

In addition to carbonates forming the ocelli, possibly of primary igneous origin, carbonates occur in the matrix of the kamafugitic tuffs and ejecta, and form tuff layers and intrusions (Plate 1- photos 1- 2). The carbonatites *sensu strictu* outcrop associated with the kamafugites. Their mineralogy is dominated by calcite, so can be classified as calcite-carbonatites. Different carbonatite ocurrences have been recognised in the field, and they can be related to their extrusive or intrusive emplacement. Pyroclastic layers of carbonatite lapilli-tuffs are covered with black vesiculated kamafugite lava (Plate 2-photo1). This testify an eruption of carbonatite tephra followed by kamafugite lava flow. A similar volcanic sequence has been observed at San Venanzo and Cupaello, Italy (Stoppa, 1996; Stoppa and Cundari, 1995) . The lapilli-tuff consist of fine lapilli with a rounded or ellipsoidal shape similar to pelletal composite-lapilli (plate 2-photo 3). These lapilli tuffs exibit the typical texture of the extrusive carbonatite lapilli (Keller, 1989). The diameter of the lapilli is generally smaller than 5mm. The carbonatite tuffs are made for their 80% of lapilli. Fresh microcrysts or microphenocrysts of melilite or clinopyroxene are still preserved from weathering only in few lapilli. Some tuffs consist of a large number of very fine lapilli turned in a pure white powders by the weathering. A texture of very fine concentric ring and micro-crypto calcite recrystallized can be see in some tuffs in thin section (Plate 2, photos 4-5). Surge and pyroclastic flow deposits are also present. Carbonatite block ejecta have been found in kamafugite pipe breccia. Huge blocks composed of massive carbonatite are mixed up with kamafugite breccia and lapilli (Plate 2-photo 7) in a carbonatitic matrix (Plate 2-photo 8). This texture is very similar to other carbonatitic kamafugitic tuff from Uganda and Italy (Stoppa *et al.*, this volume). The carbonatite has a phaneritic structure, holocrystalline micro- to fine-grained calcite matrix, and a few fragments of clinopyroxene, phlogopite, apatite. There are coarse-grained areas probably due to recrystallisation (Plate 2-photo 6). This rock is crossed by a network of fine veins of white coarse-grained calcite. The vein are probably secondary as they not contain any silicate minerals, only calcite.

CHEMICAL COMPOSITION OF THE WEST QINLING KAMAFUGITES AND CARBONATITES

Kamafugites

30 whole rock chemical analyses of of West Qinling kamafugites collected from 13 different pipes or dikes are shown in Table 5. The West Qinling kamafugites are characteristically rich in MgO (average > 12

TABLE 5
K/Ar and Ar/Ar dating of the kamafugites of West Qinling

Localities	Types of volcanic rocks	K/Ar or Ar/Ar dating
Haoti	Lava, agglimerate	7.9-7.1
	Breccia	18.9
Xiaodingshan	Lava, breccia	18.3-15.1
	lava	15.7
	Phlogopite, Ar/Ar	22.93
	Phlogopite, Ar/Ar	23.08
Niudingshan	Lava	8.4
Fenshuiling	Lava	18.3
Wangping	Lava	13.8
	Breccia	8.7
Shangwenjia	Lava	14.6
	Agglomerate	13.1-14.8
Yingping	Lava	19.1
	Agglomerate	15.9

wt.%), CaO (average > 13 wt.%), TiO_2 (average > 3 wt.%), alkalies (Na_2O+K_2O average > 4 wt.%), but poor in SiO_2 (average < 40 wt.%), and Al_2O_3 (average < 10 wt.%). Whole rock Mg# is generally higher than 0.66.

The chemical compositions of the kamafugites are plotted in a series of diagrams showing their foiditic composition (Fig. 3a) and their potassic character (Fig. 3b). The rocks plot in the kamafugitic field of the discriminant ultrapotassic rock diagram (Fig. 4; after Foley, 1987). The whole rock chemistry of the West Qinling kamafugite is distinct from other potassic rocks such as Leucite Hill leucitites or micaceous kimberlites but are very like to that high potassic volcanic rocks from East Africa rift and similar to Italy (Fig. 5). Notably, China kamafugites are always in the between Uganda and Italy rocks (Stoppa *et al.*, this volume). In addition, the relationship among major oxides of the Qinling kamafugites show that the latter are very different from potassic and ultrapotassic volcanic rocks from Tibet and adjacent areas in China, such as North Tibet,

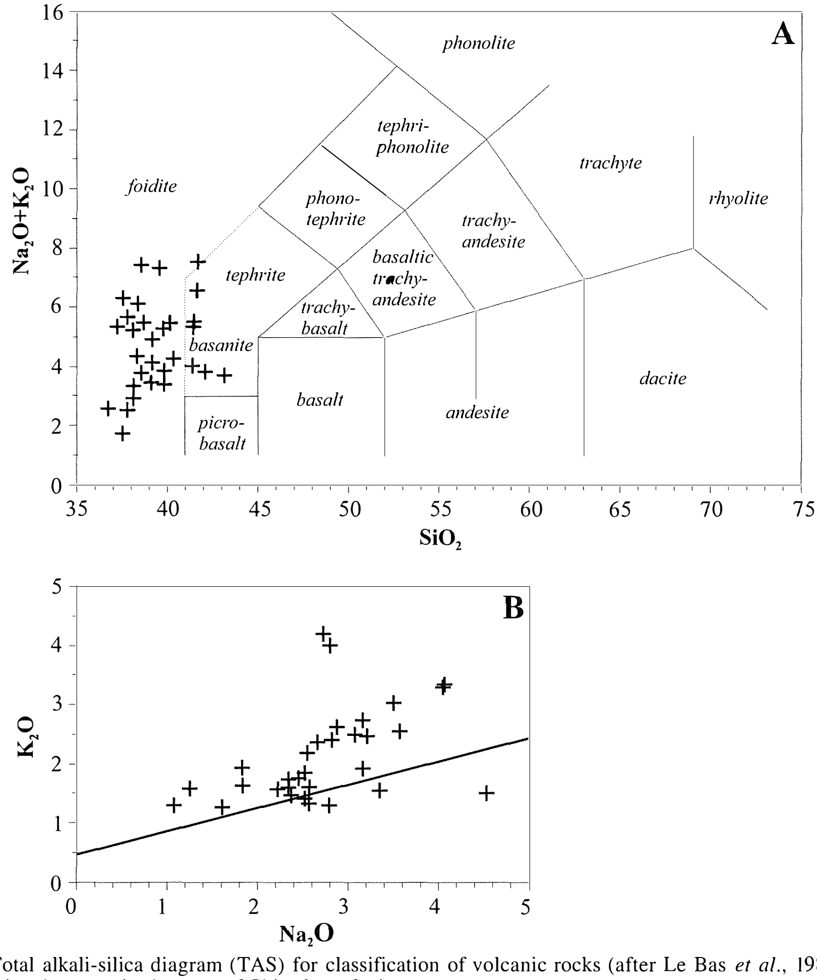

Fig. 3 – a- Total alkali-silica diagram (TAS) for classification of volcanic rocks (after Le Bas *et al.*, 1986), b- Alkali diagram showing the potassic character of China kamafugites.

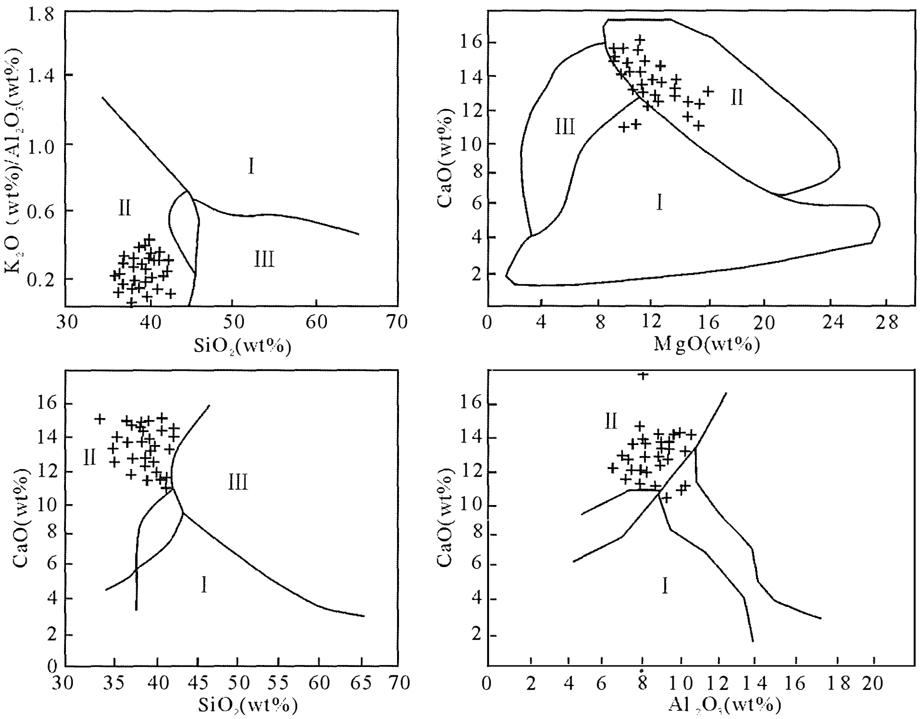

Fig. 4 – Classification fields for ultrapotassic volcanic rocks after Foley (1987).

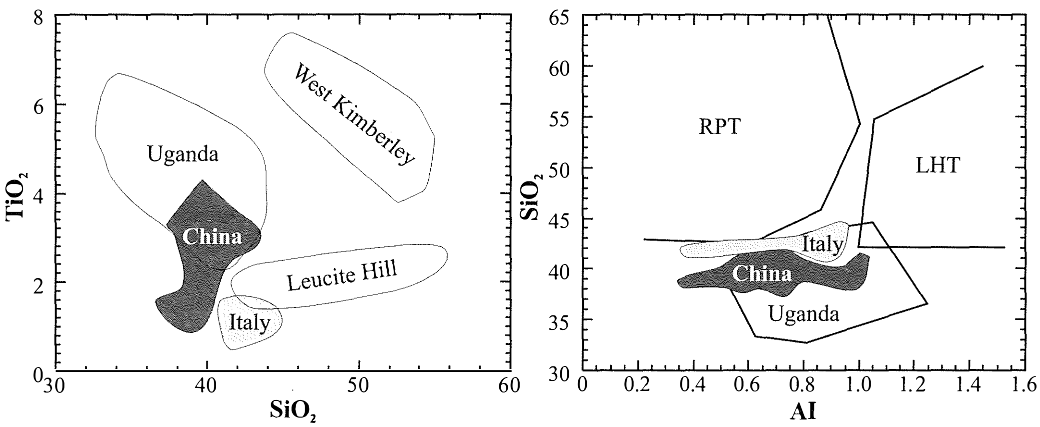

Fig. 5 – SiO_2 vs TiO_2 (wt%) and SiO_2(wt%) vs (K+Na)/Al comparing West Qinling kamafugites and other potassic rocks in the world including kamafugites from Uganda and Italy.

TABLE 6

Selected analyses of kamafugite

Label	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
phase	8610	8617	8618	8619	8620	8752	8755	8756	8628	9113	9167	9118	9126	8753	8756
SiO_2	39.4	39.13	38.85	39.57	39.23	38.04	39.1	39.73	38.68	37.68	38.63	41.15	41.57	39.38	40.48
TiO_2	3.96	3.64	3.9	3.35	3.41	2.84	3.02	3.09	3.6	4.02	3.63	3.76	3.84	3.05	3.57
Al_2O_3	9.51	9.35	9.42	9.44	9.2	7.78	8.48	7.96	9.71	9.08	8.9	9.41	10.24	8.82	9.35
Fe_2O_3	4.14	4.84	5.07	5.38	6.69	4.28	5.08	8.44	8.12	5.64	6.52	6.81	5.82	6.28	5.08
Cr_2O_3	0.03	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.04	0.02	0.03	0.02	0.02	0.05	0.05
NiO	0.04	0.04	0.04	0.04	0.04	0.05	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.04	0.03
FeO	7.46	6.65	6.94	6.23	4.55	6.25	6.22	2.38	4.06	7.22	5.49	4.54	6.52	4.17	6.48
MnO	0.19	0.18	0.19	0.18	0.18	0.17	0.18	0.19	0.18	0.27	0.21	0.19	0.23	0.15	0.18
MgO	12.84	13.62	13.13	13.38	14.26	16.69	16.73	14.25	11.63	11.38	14.38	10.77	9.83	12.02	13.16
CaO	13.8	13.05	13.47	13.21	13.47	12.94	12.16	14.64	14.18	14.4	12.55	13.68	11.11	14.33	12.8
Na_2O	2.6	2.69	2.8	2.29	1.26	1.62	1.92	2.1	3.27	3.53	3.15	3.55	4.07	0.72	2.55
K_2O	2.1	1.74	2.43	1.07	0.88	1.3	1.2	1.16	2.87	2.79	2.5	3.01	3.46	1.23	1.84
P_2O_5	1.08	1.28	1.28	1.17	1.13	1.46	1.35	1.24	1.37	1.43	1.23	1.34	1.7	1.18	0.95
H_2O	2.14	2.52	1.64	3.23	4.44	4.15	4	2.56	1.88	2	2.4	1.48	1.18	3.51	2.94
CO_2	0.09	0.12	0.07	0.22	0.18	1.84	0.19	1.93	0.16	0.23	0.37	0.13	0.17	3.31	0.22
F	0.13	0.12	0.13	0.12	0.12					0.11	0.12	0.15	0.13	0.12	0.11
Total	99.35	99.17	99.4	98.92	99.08	99.46	99.7	99.76	99.77	100.2	100.5	100.4	100.2	98.36	99.79
[Mg]	67	69	67	68	71	69	68	60	74	74	72	65	62	70	65
K_2O/Al_2O_3	0.22	0.18	0.26	0.11	0.1	0.17	0.14	0.15	0.3	0.31	0.28	0.32	0.34	0.14	0.2
K/Na	0.53	0.42	0.57	0.3	0.45	0.54	0.42	0.35	0.58	0.53	0.53	0.56	0.56	1.08	0.49

TABLE 6. *Continuation*

Label	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
phase	8748	8624	8625	8639	8774	8733	8736	8531	8721	8710	9108	9117	9215	9233	9218
SiO_2	35.91	42.68	43.15	41.39	40.33	37.55	40.9	37.99	39.06	40.44	38.63	38.87	39.68	37.36	39.74
TiO_2	3.61	3.03	2.64	2.84	3.21	3.56	2.86	2.93	2.96	2.81	3.63	3.69	1.81	1.5	2.22
Al_2O_3	8.51	9.88	9.77	9.88	9.5	8.05	9.64	10.97	9.01	8.47	8.9	9.05	10.3	9.27	10.3
Fe_2O_3	8.21	4.79	4.66	5.61	6.2	5.39	5.63	11.17	6.18	4.64	6.52	5.28	5.13	6.16	5.79
Cr_2O_3	0.04	0.04	0.04	0.04	0.03	0.04	0.03	0.04	0.04	0.05	0.03	0.03	0.03	0.06	0.03
NiO	0.03	0.03	0.02	0.02	0.03	0.04	0.04	0.03	0.04	0.03	0.04	0.03	0.02	0.05	0.02
FeO	3.03	5.46	5.1	4.92	5.19	4.23	5.35	0.47	5.12	4.89	5.49	6.83	6.08	5.22	7.09
MnO	0.13	0.08	0.15	0.16	0.13	0.12	0.16	0.15	0.22	0.15	0.21	0.23	0.19	0.17	0.18
MgO	8.74	10.74	11.16	10.63	12.01	13.31	13.76	12.78	11.97	15.95	14.38	12.26	11.32	15.5	11.08
CaO	18.09	14.37	14.32	14.19	13.17	14.23	13.54	14.6	14.66	11.41	12.55	13.9	15.07	12.44	12.36
Na_2O	0.57	2.8	2.63	2.34	3.26	4.56	2.54	0.16	2.59	2.81	3.15	2.46	1.82	1.16	2.82
K_2O	0.69	1.03	1.03	1.54	1.85	1.31	1.77	0.49	1.77	2.58	2.5	1.39	1.76	1.47	4.21
P_2O_5	1.6	1.12	1.14	1.14	0.75	0.59	0.97	1.42	1.19	1.27	1.23	1.19	1.53	1.41	1.02
H_2O	4.05	2.05	3..12	3.6	2.17	3.02	2.35	2.93	2.8	2.99	2.4	3.79	3.35	2.01	0.64
CO_2	6.72	1.68	0.22	0.39	2.11	2.15	0.12	1.59	2.18	0.48	0.37	0.84	0.29	0.58	0.29
F	0.09	0.1	0.12		0.13	1.08	0.07	0.13	0.11	0.12	0.13	0.12	0.09	0.1	0.05
Total	100.02	99.88	99.27	99.23	100.07	99.23	99.73	95.85	99.9	99.09	100.16	99.96	98.47	94.46	97.84
[Mg]	60	66	68	66	67	80	70	69	67	76	70	66	66	72	62
K_2O/Al_2O_3	0.08	0.1	0.11	0.16	0.19	0.16	0.18	0.05	0.2	0.3	0.28	0.15	0.17	0.16	0.41
K/Na	0.78	0.24	0.26	0.42	0.42	0£Æ18	0.46	2£Æ01	0.45	0.6	0.53	0.38	0.66	0.84	1

Tengchong and Dali-Jianchuan of Yunnan province and Northeast China – Wudalianchi (Fig. 6). We deduce that Qinling is the only kamafugitic province of China, described so far.

Carbonatite

Seven selected chemical analyses of carbonatite whole rock are listed in Table 7. The content of CaO in the carbonatite varies between 28.8 and 54.1 wt.%, alkalies are low

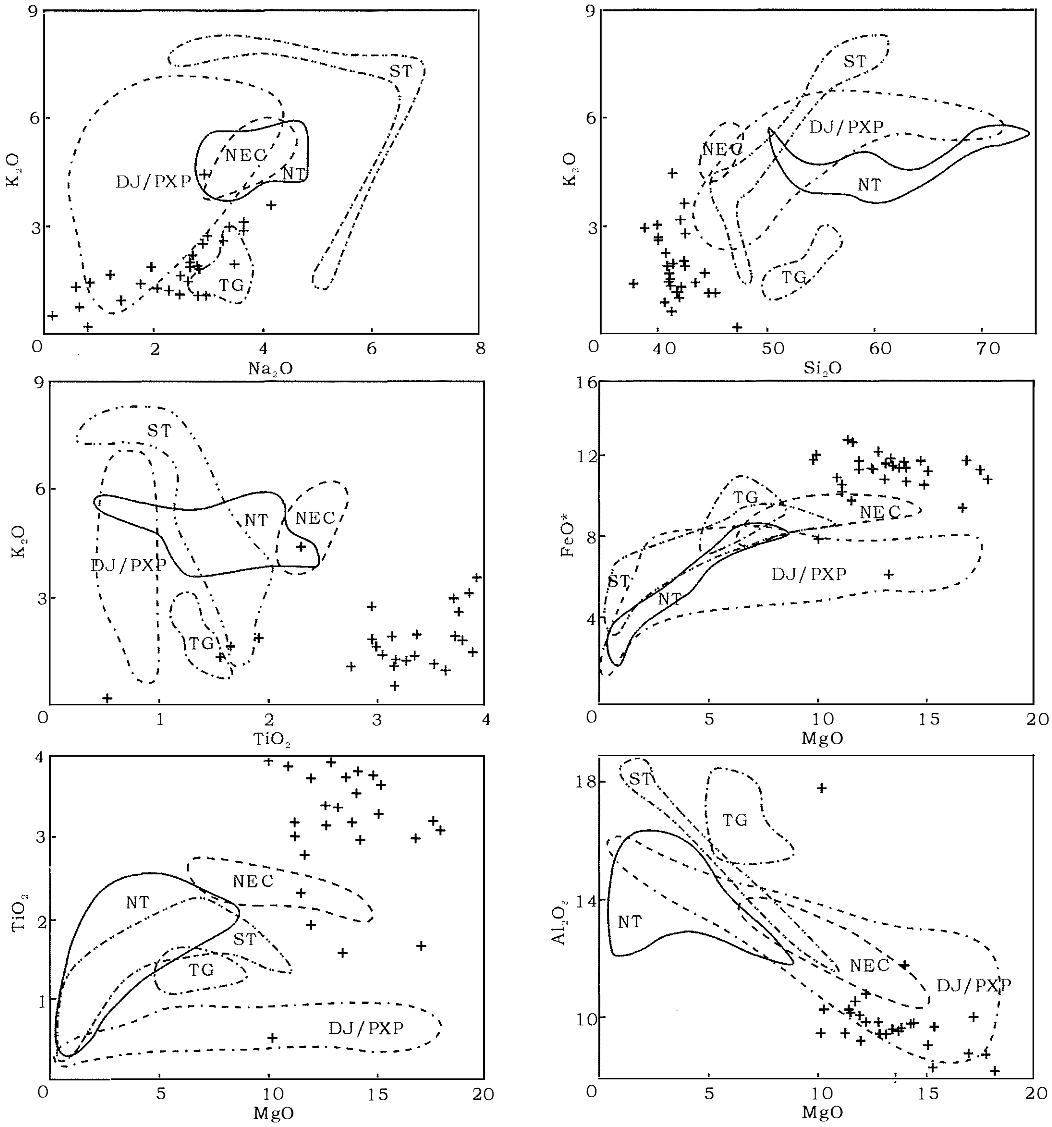

Fig. 6 – Correlations among the major oxides of the kamafugites from West Qinling and other potassic volcanic rocks from Tibet and adjacent areas: ST and NT: North Tibet potassic rocks, TG: Tengchong of West Yunnan province. NEC: Wudalianchi of Northeast China, DJ/PXP:dali-jianchuan/ North Vietnam

TABLE 7

Selected chemical analyses of carbonatite

	2001	2002	2005	2007	2013	2015	2019
SiO_2	13.28	1.47	23.62	11.49	2.72	2.02	21.1
TiO_2	1.04	0.05	2	0.14	0.05	0.1	1
Al_2O_3	2.86	0.4	5.18	2.98	0.54	0.46	5.22
Cr_2O_3	0.02	0	0.03	0.01	0.01	0.01	0.03
Fe_2O_3	3.69	0.29	5.88	0.14	0.12	0.06	2.9
FeO	0.17	0.13	1.3	0.35	0.23	0.23	0.17
MnO	0.05	0.03	0.15	0.08	0.04	0.01	0.02
NiO	0.03	0.01	0.04	0.01	0.01	0.01	0.02
MgO	1.83	0.2	6.31	0.56	0.37	1.4	2.61
CaO	41.49	54.16	28.77	46.21	53.49	53.26	34.67
K_2O	0.03	0.16	0.27	0.89	0.21	0.05	0.54
Na_2O	0.01	0.04	0.27	0.05	0.03	0.2	0.34
P_2O_5	3.76	0.04	1.18	0.03	0.03	0.2	0.34
CO_2	29.36	42.55	20.8	36.32	41.56	42.1	26.05
H_2O	2.13	0.32	3.82	1.21	0.4	0.45	3.35
Tatal	99.75	99.85	99.64	100.47	99.81	100.43	98.27
[Mg]	0.93	0.93	0.96	0.97	0.96	0.99	0.96
Mg/Ca	0.06	0.05	0.31	0.02	0.01	0.04	0.1
Al/Si	0.25	0.32	0.24	0.31	0.23	0.27	0.29
K/Na	1.99	2.61	0.66	11.66	4.64	0.47	1.54

(K_2O+Na_2O varies between 0.04 and 0.94 wt.%). Characteristically, the whole rock chemical composition of the West Qinling Carbonatites is very like to that of the carbonatites rich in CaO but poor in K_2O+Na_2O from Fort Portal area of Uganda and Polino Italy. The SiO_2 content of each type of carbonatite has large variation, the lapilli tuffs have the highest amount of SiO_2. In carbonatites, Al_2O_3, TiO_2, FeO, Fe_2O_3 and MgO have a positive correlation with SiO_2; the content of CaO has a negative correlation with SiO_2, K_2O+Na_2O and P_2O_5; CaO does not show any relations with SiO_2.

DEEP-SEATED XENOLITHS AND MEGACRYSTS IN THE KAMAFUGITE

Deep-seated xenoliths and megacrysts are very common in the West Qinling kamafugites. The xenoliths generally are fresh and < 5 cm in diameter: They are spinel- or garnet-bearing lherzolite, harzburgite, dunite, pyroxenite and websterite. Megacrysts of clinopyroxene, phlogopite and olivine have been also found in the kamafugites (Plate 3- photos 2-7). In some cases, calcite and phlogopite have bee noted in the xenoliths, but we do not know whether these minerals are primary because the xenoliths have not been studied in detail, so far. The xenoliths of spinel lherzolite and garnet lherzolite have granular mosaic or tabular crystalloblastic texture. Sometimes triple junctions and olivine kink bands have been observed. The olivine is rich in MgO(Fo>90) similarly to xenocrystic olivine in kamafugite. The clinopyroxenes is typically a Cr-diopside with bright green color and have spongy resorption rims. The chemical composition of orthopyroxene is also MgO-rich (MgO/MgO+FeO^{+2}>0.9). The garnet in the lherzolite xenoliths is MgO-rich (MgO/MgO+FeO^{+2}>80) with a high pyrope molar solution and has a high content of Cr_2O_3 (up to 4.17 wt.%). The chemical composition of spinel in the lherzolite xenoliths is complex, one of which is rich in Al with brown green color, the other one is rich in Cr with brown red color. The garnet websterite consists of clinopyroxene and orthopyroxene, with no olivine. The websterite has a granular or cataclastic texture, but the mineral chemistry of clinopyroxene, orthopyroxene and garnet are not different from that one of lherzolites.

Equilibruim temperature and pressure of xenoliths of spinel lherzolite, garnet lherzolite and garnete websterite have been calculated by mineralogical thermobarometer of En exchange in Opx/Cpx, Ca solution in Opx, Ca distribution between Ol and Cpx and Al distribution in Opx and Grt. The result show that the equilibrium temperature and pressure are as higher as 1220°C and 3.3 Gpa for garnet lherzolithe, 1200°C and 3.0 Gpa for garnet websterite, and 970°C and 18.9 Gpa for spinel lherzolite. The temperature and pressure to which originated megacryst of clinopyroxene have also been calculated by the relations between of Al and temperature and pressure in clinopyroxene (Thompson, 1974) the result is 1329°C and 1.8 Gpa for the core and 1179°C and 0.4 Gpa for the rim.

CONCLUSIONS

According to the data and mineralogy and petrology inferences deduced from the kamafugites and carbonatites of the West Qinling, we can make a conclusion as follows:

The ultrapotassic rocks of West Qinling are typically rich in CaO, TiO_2, MgO and K_2O+Na_2O, but poor in SiO_2 and Al_2O_3. The petrography and geochemistry of the rocks show that katungite, mafurite, ugandite, (kamafugites) rock-types occur as well as extrusive Ca-carbonatites.

The whole rock chemistry of the kamafugites is in general very like to that of lavas from Toro-Ankole of Uganda and similar to Italian kamafugites. In addition, the carbonatites of West Qinling are very like to the carbonatites from Fort Portal (Uganda) and Polino (Italy).

The studies on Sr, Nd, Pb isotopic and trace element geochemistry of the Kamafugites suggest that the magmatism of Cenozoic Qinling districts may be related to mantle plume (Yu Xu *et al.*, 2001, 2003).

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