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Research Paper

Unearthing of the Time of Emplacement of the Sillai Patti Carbonatite, Khyber Pakhtunkhwa, Pakistan: Constraints from $^{206}Pb/^{238}U$ Zircon Dating

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Abstract

Another massive carbonatite complex has been documented from Sillai Patti (SP) situated within the Peshawar Plain Alkaline Igneous Province, situated about 35 kilometers west of Dargai near the town of Sillai Patti. It is an intrusive body of carbonatite having a sheet like appearance and is located along a southward dipping and SSW-NNE striking fault and is having a thickness of about 2-20 m and an outcrop length of about 12 km. The carbonatite sheet is intruded either into the metasedimentary rocks or along their faulted contact with the granite gneiss. Petrogenic, geochronological and tectonic history of this complex has not yet been properly understood till date. Therefore, ^{206}Pb-^{238}U dating study on zircon samples from the complex was conducted for the first time for resolving these critical issues. A Pb-U (^{206}Pb-^{238}U) Zircon age of 85.7 ± 0.9 Ma was acquired on the carbonatite samples of the complex using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS). This newly determined high temperature age of 85.7 ± 0.9 Ma is substantially higher than the low temperature Potassium-Argon biotite (31 ± 2 Ma), Fission-Track (FT) Zircon (32.1 ± 1.9 Ma) and FT Apatite (29.40 ± 1.49 Ma) ages of the former researchers. This ^{206}Pb - ^{238}U aging 85.7 ± 0.9 Ma is closely similar with the $^{40}Ar/^{39}Ar$ aging 80 Ma on Phlogopite from a group 1 carbonatite of the Waziristan Ophiolite Complex (WOC), found at the Pakistan-Afghanistan border, about 244 km SW of Peshawar in Waziristan Agency. Close resemblance of the ^{206}Pb-^{238}U Zircon age of this study with the $^{40}Ar/^{39}Ar$ age on phlogopite from the carbonatites intruding the WOC clearly indicates that carbonatite and alkaline magmatism may have taken place on a much wider range extending from the Silla Patti area in the north up to Waziristan Agency adjacent to the Afghanistan Pakistan borderline in the west of Bannu District in the Late Cretaceous, when the leading western and northern margins of the Indian plate were obducted by the ophiolite complexes. Close resemblance betweeen the FT and K-Ar ages on the carbonatite from SP and the FT and K-Ar ages from the adjoining carbonatites advocates on rapid uplift and exposure of the SP carbonatite to shallow level during the Oligocene Period. This was followed rapid cooling process to nearby surface temperatures (less than about 60°C) essential for the full preservation of FT within the mineral apatite.

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1. Introduction

The carbonatite Complex of SP is one of the major carbonatite complexes of Pakistan and is located about 13 miles west of Malakand and approximately 44 miles north of Peshawar city close to the town of SP, in Malakand Division in the Khyber Pakhtunkhwa province (Fig. 1). Ashraf and Chaudhry (1997) were the first to report this dyke-like body. It occurs as a sheet like intrusive body along a thrust fault dipping in southernly direction between granite gneisses and schists located to its south and amphibolites to its north (Le Bas, 2008). The Kot-Prang Ghar Melange Complex in the south of SP has been assigned Late Jurassic to Cretaceous (Mesozoic), the schistose rocks have been assigned Middle to Late Paleozoic and the Sillai granite gneisses have been assigned Cambrian ages by Hussain et al. (1984). Le Bas et al.1(987) proposed that this carbonatite complex was emplaced in the form of a sheet like intrusion of 2-20 m thickness and 12 km length along the SP thrust. According to Butt et al. (1989) the SP carbonatite sheet has been intruded either at the contact of granite gneiss and metasediments or else has been emplaced within the metasediments. This fault has been considered to be a part of the well-known northward dipping Main Mantle Thrust (MMT) located at a distance of about 13 miles in the north of the complex (Tahirkheli, 1979; Tahirkheli et al. 1979; Windley 1983). The Le Bas et al. (1987) reported tjat SP fault represents a significant thrust related with the initial phases of collision amongst the Kohistan Island Arc and the Indian plate.

The SP carbonatite is the 2^{nd} largest carbonatite complex of northern Pakistan (Fig.2). Tectonic setting in addition to emplacement time of the SP carbonatite has been under extensive dispute amongst the former researchers since ancient times.

For the establishment of its petrogenetic relationship between the alkaline and carbonatite complexes found elsewhere in the alkaline province of Pakistan and for better understanding of its emplacement time, a ^{206}Pb-^{238}U dating studies on zircon crystals isolated from three carbonatite samples, and two sets of samples of handpicked zircon crystals from the out crop of the carbonatite of the complex, were carried out. The finding of the study were then compared with several age determinations from similar geological features including potassium-argon ages on biotite (Le Bas et al., 1987), FT age on zircon (Qureshi et al. 1991), FT age on apatite (Khattak et al., 2012) from same carbonatite and FT together with other high temperature radiometric ages from the adjoining carbonatites and alkaline complexes found in the north of Peshawar valley. Furthermore, this study looked at the Argon-Argon ages on the carbonatite complex of WOC (Waziristan Ophiolite Complex) of Waziristan area, at the border of Pakistan and Afghanistan in the west of District Bannu (Fig. 3).

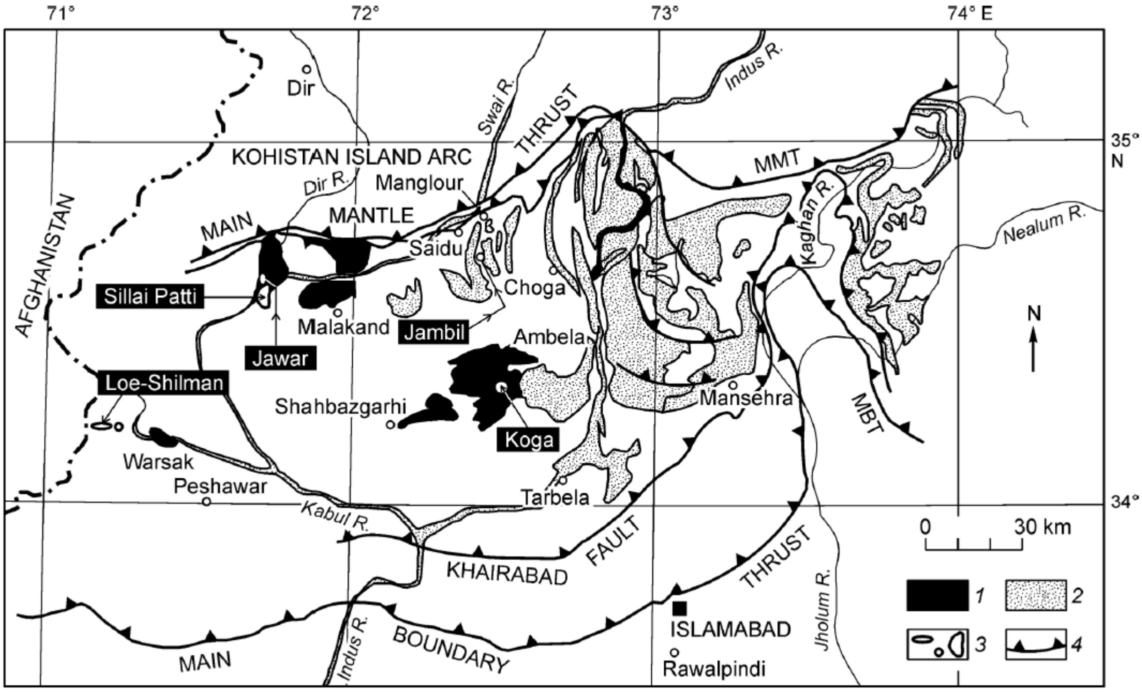

Fig. 1. Geological sketch map of northern Pakistan showing location of the Sillai Patti and other carbonatite complexes and associated alkaline rocks of the alkaline belt of northern Pakistan (After Butt, 1983; Khattak et al., 2001).

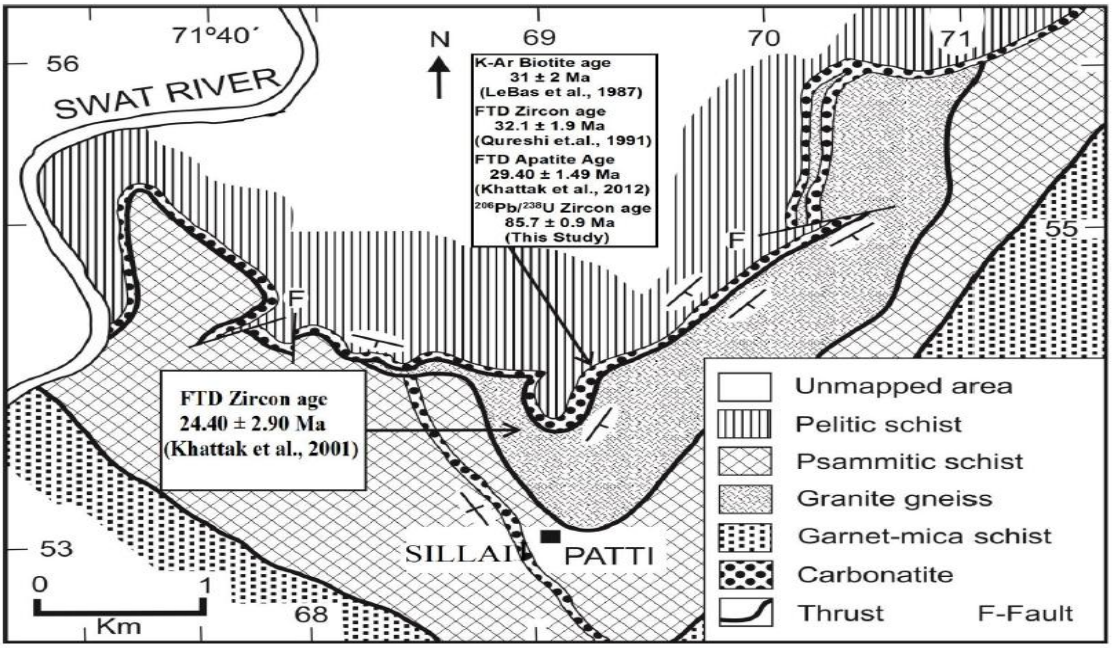

Fig. 2. Geological map of the Sillai Patti carbonatite complex, Malakand Agency showing ^{206}Pb-^{206}U and other radiometric ages (modified after Le Bas et al., 1987).

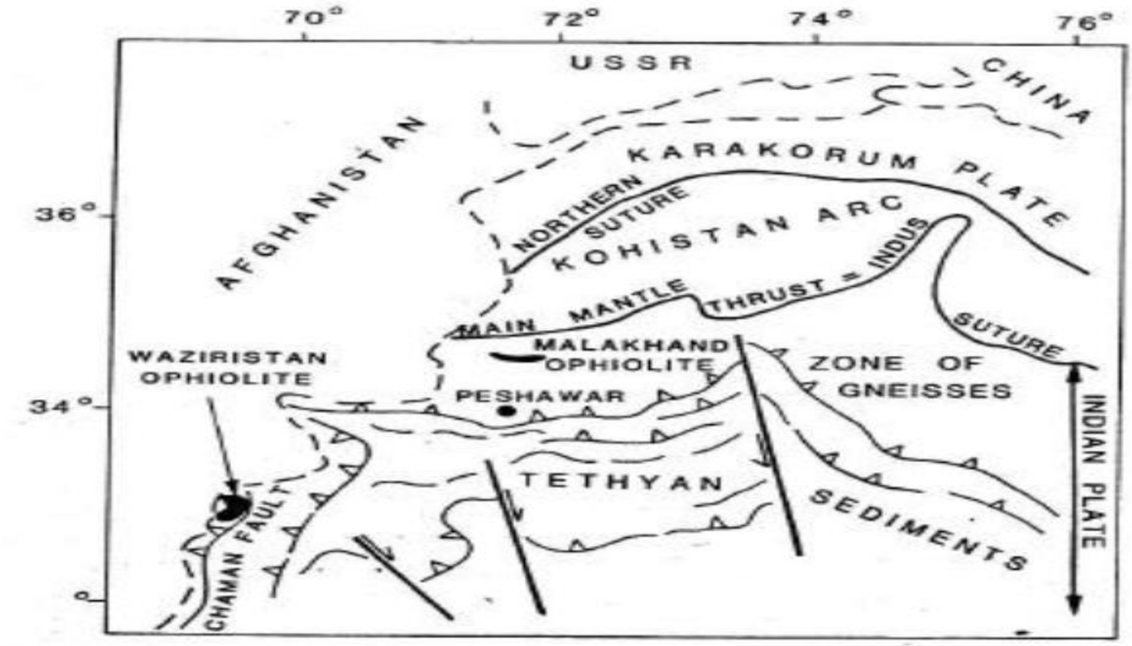

Fig. 3. Geologic sketch map of northern Pakistan showing the location of the Waziristan ophiolite in the belt of thrusted Tethyan sediments (After Jan et al. 1985).

2. Regional Geological Setting

Northern Pakistan has been divided into 3 major tectonic zones: 1) Eurasian plate (EP), 2) Kohistan Island arc (KIA), and 3) Indian plate (IP).

These tectonic regimes are partitioned from each other by the two well-known tectonic features, the MMT demarcating the boundary between the KIA in the north and the IP in the south, and the Main Karakoram Thrust, separating the Eurasian plate in the north from the KIA in south (Tahirkheli, 1979). Occurrence of all the carbonatites complexes of Pakistan is restricted only to the south of MMT in the IP region.

3. Local Geology

The SP carbonatite has been positioned along a regional thrust as an intrusive body resembling a sheet. It is dipping approximately towards the south and is striking in the NNE-SSW direction (Fig. 2). On its top the carbonatite body is in contact with Malakand granite gneiss (Le Bas et al., 1987; Butt et al. 1989). A biotite-carbonatite sheet (of white color) and a later more widespread amphibole-carbonatite sheet (of brown color) are the dominant varieties. Occurrence of fenitization has been noted at the direct contact of the carbonatite with the superimposing Malakand granite gneisses. However, some xenolithic blocks of metasomatized granitic gneiss are also found as fenites within the carbonatites themselves (Le Bas et al., 1987; Butt et al. 1989).

Le Bas (2008) found that the biotite carbonatite is well developed in the eastern part, where it has resulted in the potash-metasomatism of the overlying granitic gneiss. The granitic gneiss found at contact with the carbonatite is generally well foliated and medium to coarse in gain size but friable and weathered. The loss of quartz and muscovite within the area is indicative of the beginning of potash fenitization and the foliation is evident from the orientation of Fe oxides, mica (biotite) and K-feldspar. The grain size generally decreases away from the contact, the orthoclase crystals (Or_{88-96}) of size equal to about 2 × 3 cm are found at the contact and are usually encircled in bunches of tiny grains of albite (Ab_{99}).

Adjacent to the touching base between the granitic gneiss and amphibole carbonatite veins intruding the potash-fenitized gneiss are encircled in soda pyroxene crystals, representing the inflowing of subsequent sodium bearing solutions (Le Bas, 2008). Recrystallization of the gneiss adjacent to the carbonatite body to fenite of syenitic composition has also been observed. The fenites near to the carbonatite contact have been found to be rich in feldspar along with the lined-up masses and prisms of green colored aegirine-augite. In the fenites of phaneritic texture orthoclase and albite are in the ratios of 1:2 with this ratio rising up to 1:3 in the finer-grained fenite. These irregular proportions do not display any affiliation to the interval from the boundary. Nevertheless, the surface outcrops do advocate an affiliation of distance to the previously formed fractures in the gneiss, through which the finitizing solutions are supposed to have travelled (Le Bas, 2008).

The carbonatite from the study area is fine to medium grained porphyritic to sub porphyritic rock body. Calcite is the dominant carbonate mineral in this carbonatite complex (ranging from 50-90 %) along with subordinate amounts of $FeCO_3$, $FeTiO_3$ /Fe_3O_4, arfvedsonite, chlorite, orthoclase and apatite, exhibiting irregular distribution (Kempe & Jan, 1980). Amphibole and biotite grains are generally subhedral to anhedral, whereas calcite is found as anhedral grains (Butt et al. 1989). Apatite have a tendency to occur as euhedral crystals and is sporadically totally encircled in calcite (Butt et al. 1989). At Sillai Patti the country rocks have been subjected to Barrovian type of regional metamorphism of a minimum of not lesser than biotite grade. Within the area the peak of metamorphism appears to have taken place at around 42 ± 2 Ma (Maluski & Mate, 1084). The Sillai Patti carbonatite contains Rare Earth Elements (REEs) and can be a best potential source of these precious elements in future if properly investigated and explored.

4. Experimental Procedure

Both, Uranium-Lead dating of zircon and trace element analysis (TEA) on carbonatite samples from the Sillai Patti area were synchronously carried at the Wuhan Sample Solution Analytical Technology Co., Ltd., Wuhan, China by LA-ICP-MS. Full analytical procedure used for the ICP-MS device and the laser ablation system (LAS) and data reduction was identical as defined previously by the earlier researchers (Zong et al., 2017). A GeolasPro LAS comprising of a COMPexPro 102 ArF excimer laser having 200mJ maximum and 193nm wavelength and a MicroLas optical system for the accomplishment of laser sampling. We used an Agilent 7700e ICP-MS apparatus for obtaining ion-signal intensities. Helium was utilized as a transporter gas. Argon was utilized as a make-up gas and mixed via a T-shaped connector with the transporter gas before entering into the ICPMC. A “wire” signal levelling tool was contained within the laser ablation apparatus. The laser spot size was set to 32 nm and frequency to 250 Hz. Glass NIST610 was utilized as external canons for calibration of trace element and Zircon 91500 for U-Pb dating. Each examination combined a background achievement for a period of 20-30 s afterward tracked by acquiring data for time span of 50s from the sample under study. We used ICPMSDataCal, a software tool in Excel-based software, for conducting off-line tasks such as selecting and integrating of background and investigated signals, correcting time-drift and performing quantitative calibration for U-Pb dating and TEA (Liu et al. 2008; Liu et al. 2010). Using Isoplot/Ex_ver3 concordia diagram and weighted mean calculation were completed (Ludwig, 2003).

6. Results

A group of seventeen (17) concordant analyses performed on eight (8) magmatic zircon grains from carbonatite (Z-1) yielding the weighted-average uranium -lead ($^{206}Pb/^{238}U$) aging 85.7 ± 0.9 Ma (1 sigma, mean square of weighted deviation, MSWD = 1.2, n = 17). Concordia diagram of ^{206}Pb-^{238}U zircon ages on carbonatite rocks from Sillai Patti has been shown in the Fig. 4

Weighted mean Pb-U age on zircon crystals from the studied carbonatite have been shown in Fig. 5.

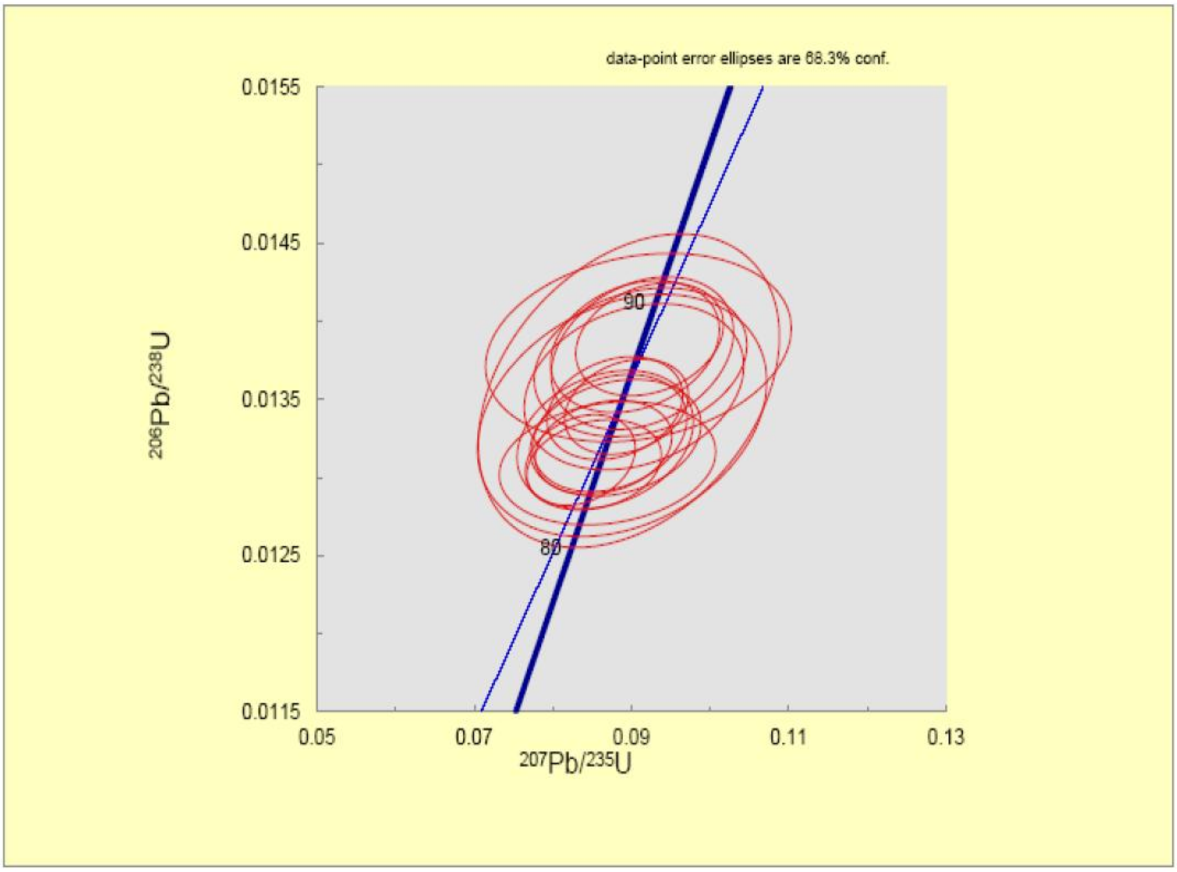

Fig. 4. Showing Concordia diagram of Pb-U dating on Zircon from Sillal Patti Carbonatite.

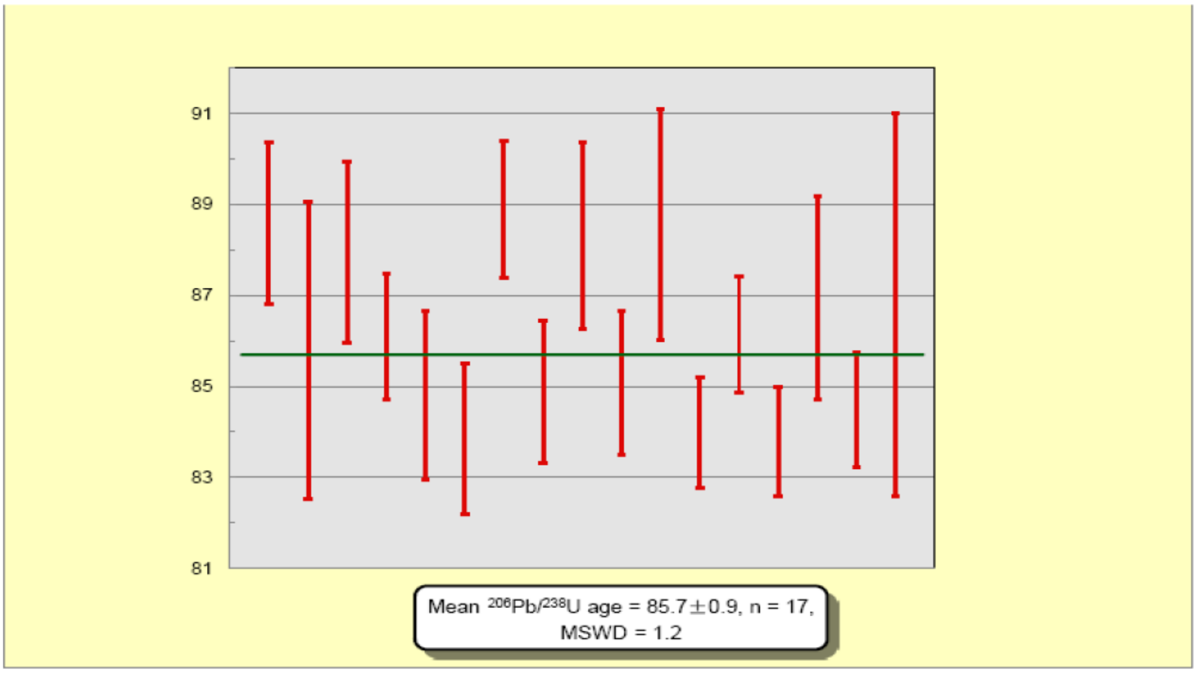

Fig. 5. Showing mean ^{206}Pb-^{206}U age on zircon from the Sillai Patti Carbonatite, Malakand Division, Pakistan.

7. Discussion

In the recent past two opposite viewpoints, single versus multiple event of carbonatitic magmatism were presented by the researchers from different schools of thought for enlightening the timing and emplacement nature of the carbonatite complexes occurring in NW Pakistan. There has also been no consensus upon the prevalence of the nature of tectonic environment during at the time of emplacement of these carbonatites within the province. According to one school of thought all the alkaline rocks and their associated carbonatites of Pakistan were formed in a rift related setting whereas according to the other school of thought emplacement of these complexes took place in a compressional orogen along thrust faults.

1. ***Idea of Poly magmatic events.*** Some of earlier researchers like Tilton et al. (1998) and Le Bas et al. (1987) were of the belief that emplacement of all the alkaline complexes and carbonatites found in northern Pakistan took place in no less than at least two distinct magmatic events of (i). during the Carboniferous and (ii). during Oligocene (Tertiary) periods. They construed the emplacement of carbonatites in the SP and Loe-Shilman areas to have taken place post-Himalayan, specifically during the Tertiary (Oligocene) period, while the carbonatites and syenite rocks in the Koga region were believed to have intruded during the Permo-Carboniferous period. Le Bas et al. (1987) founded their proposition on the K^{40}-Ar^{40} biotite ages of 31 ± 2 mean age from the SP and Loe-Shilman carbonatites and the Rb^{87}- Sr^{87} (whole rock) ages of 297 ± 4 mean age and 315 ± 15 mean age on ijolite and syenite from the Koga igneous complex. The authors also noted the absence of evidence linking the emplacement of the carbonatite complexes in northern area of Pakistan to the Himalayan collision, and reported that no clue of rifting within the region during the emplacement of the Sillai Patti and Loe-Shilman carbonatites. Tilton et al. (1998) floated the proposal of poly carbonatitic and alkaline magmatic events in the region

based on isotopic data. These researchers pointed out that a distinguishing feature of the syn-orogenic carbonatites at SP and Loe-Shilman is their high $^{87}Sr/^{86}Sr$ ratios and extremely negative values of ε_{Nd} contrary to the lower $^{87}Sr/^{86}Sr$ values paired with the positive ε_{Nd} values for the Koga carbonatites of pre-Himalayan age.

According to earlier researchers (Le Bas et al. 1987; Mian & Le Bas. 1988) carbonatitic and alkaline magmas were intruded at the locality of Loe-Shilman along a N dipping thrust fault flanked by the slates and phyllites (Precambrian) on the south, and dolerites and Paleozoic metasediments on the north. The carbonatites of Sillai Patti are also believed to have been emplaced along a thrust fault connected with collision of India-Eurasia plates somewhere in the middle of the Oligocene (Qureshi et al, 1991). Some of researchers (Tilton et al. 1998) believe that carbonatitic and alkaline magmatic activity at localities of Sillai Patti ant Loe-Shilman took place at about 30 Ma in a post collisional setting along thrust faults. Khattak et al. (2008, 2012) on the basis of FT apatite ages of 30.0 ± 1.5 and 29.40 ± 1.49 Ma from the Loe-Shilman and Sillai Patti carbonatites claimed that their emplacement in the northern Pakistan took place in the two carbonatitic and alkaline magmatic events, that is of, Carboniferous and Tertiary (Oligocene), separately. However, they are of the opinion that the Oligocene alkaline and carbonatitic magmatic event took place along rift zones instead of thrust faults during the period of post collisional rifting in the region.

2. *Idea of a Mono magmatic event*.

Tahirkheli (1980) has indicated the presence of a crescent shaped rift valley in the south of Main Mantle Thrust (MMT) and in the north of Peshawar basin extending from Tarbela area in the east up to Pakistan-Afghanistan border near Loe-Shilman area in the west. According to him carbonatitic and alkaline magmatism within the rift valley of Peshawar occurred within Middle to Upper Eocene. Likewise, Kempe and Jan (1980) suggested that the Peshawar valley is actually an uneven rift vale stretching eastward for about two hundred kilometers. According to them the proposed rift zone stretches from the Pakistan-Afghanistan border adjacent to Loe-Shilman in the west via Sillai Patti, Dargai (Malakand) and subsequently continue towards east. It was further stated by them that alkaline magmatic activity within the Peshawar Plain alkaline Igneous Province was induced by the lithospheric doming triggered by mantle plumes in the interior of a rift system formed by compression release or rebound relief tension, subsequent to the initial plate collision perhaps in Early Tertiary or Late Cretaceous time. Afterward, Jan & Karim (1990) and Butt et al. (1989) mentioned that the carbonatitic and alkaline magmatic activity in north Pakistan actually took place before the Himalayan orogeny during the Permo-Carboniferous tensional rifting and break-up of Gondwana. The idea of a mono magmatic episode was supported on the basis of the presence of epidote mineral in the rocks of the Sillai Patti carbonatite complex. Butt et al. (1989) were of the opinion that during Himalayan Orogeny the Sillai Patti carbonatite and its accompanying host rocks were subjected to greenschist or epidote-amphibolite facies of regional metamorphism. They considered that the K-Ar biotite ages of 31 ± 2 Ma from the two main carbonatite complexes denote reset older Permo-Carboniferous ages and mentioned that these complexes are comagmatic with the Koga carbonatite of carboniferous age in the area. Jan and Karim (1990) favored the idea of emplacement of all the carbonatites and alkaline complexes of the region in the Carboniferous time on the basis of their absence from the post Paleozoic sequence. They assigned Late Paleozoic age to the Sillai Patti and Loe-Shilman carbonatites and to the alkaline rocks of Malakand, Shewa-Shahbazgarhi and Ambela area.

Almost all of the earlier researchers have now totally agreed upon the Carboniferous phase of alkaline and carbonatitic magmatic activity in this region of Peshawar Basin. However, there persists a ongoing debate regarding the existence of Tertiary (Oligocene) alkaline and carbonatitic magmatic activity in the region.

Qureshi et al. (1991) documented a FT zircon aging 32.1 ± 1.9 Ma for zircon extracted from the SP carbonatite. Similarly, Khattak et al. (2008) documented a FT apatite aging 30.0 ± 1.5 Ma from the Loe-Shilman carbonatite situated in the Khyber Agency at the western edge of the Alkaline Province adjacent to the Pakistan-Afghanistan border.

Le Bas et al. (1987), Mian and Le Bas (1988), Qureshi et al., (1991), Tilton et al. (1998) and several other researchers believe that Loe-Shilman carbonatites are located between the Precambrian phyllites and slates in the south and the Paleozoic metasediments and dolerites in the north along a northward dipping thrust fault (Warsak Thrust). We refute the idea of the earlier researchers that the north dipping fault at the Loe-Shilman is a thrust fault along which the slates of the older Precambrian age in the southern footwall have been thrusted over by the younger Paleozoic rocks of the hanging wall in the north. Rather, we are of the opinion that the north dipping fault is in fact a normal or gravity fault with southern footwall lifted upward and towards the south compared to the northern hanging wall.

Another famous association of carbonatites and alkaline rocks has recently been discovered in the Waziristan Ophiolite Complex (WOC) (Badshah et al. 2003). It is located at the Pakistan-Afghanistan border, about 244 Km SW of Peshawar in Waziristan Agency. In Waziristan area Emplacement of the ophiolite onto the shelf sediments of the Indian plate took place during the Late Cretaceous-Paleocene (hornblende from the metamorphic sole of the ophiolite has Ar-Ar age of 89 Ma). The WOC is unconformably overlain by latest Maastrichtian (uppermost stage of the Late Cretaceous epoch) to Paleocene flysch sediments.

The alkaline rocks and carbonatites in the WOC are irregularly distributed in a NE-SW trending belt measuring 50×3 km. They occur in the form of small intrusions, the largest of which constitutes a subcircular mound some 40 m across. ln terms of field relations the rocks can be grouped into: 1) dykes, sheets and subcircular masses of alkaline rocks and carbonatites in ophiolitic basalts and cherts, and 2) small dykes and dyklets of carbonatite intruding the ophiolite as well as Eocene (?) shales.

Phlogopite from a group 1 carbonatite has an Ar-Ar age of 80 Ma, consistent with its confinement to the ophiolite and absence from the overlying Early Tertiary rocks. The sovite intruding the sediments apparently of Eocene (?) age may also be Late Cretaceous and their field relationships may require re-interpretation.

Our newly determined ^{206}Pb -^{238}U aging 85.7 ± 0.9 Ma on zircon crystals from the carbonatite samples is substantially higher than the K-Ar age of 31 ± 2 Ma on Biotite (Le Bas et al. 1987), FTr aging 32.1 ± 1.9 Ma on Zircon (Qureshi et al 1991) and FT aging 29.40 ± 1.49 Ma on apatite (Khattak et al. 2008). This age of 85.7 ± 0.9 Ma is similar to Ar-Ar aging 80 Ma on Phlogopite from a group 1 carbonatite of the Waziristan Ophiolite Complex (WOC) of Badshah et al. (2003). Close resemblance of the ^{206}Pb-^{238}U age of 85.7 ± 0.9 Ma with the Ar-Ar age on phlogopite from the carbonatites intruding the WOC clearly indicates that carbonatite and alkaline magmatism may have taken place on a much wider scale extending from the Silla Patti area in the north through Loe-Shilman in the west till Waziristan Agency adjacent to the Afghanistan - Pakistan boundary in the west of District Bunnu latter part of the Cretaceous period, when the leading northern and western margins of the IP were abducted by the ophiolite complexes.

Several million years before the collision between Eurasian and Indian plates took place and is continuous even now have resulted in the development of Himalayan ranges and Tibetan plateau. There have been two schools of thoughts about the collision of the two continents with each other. According to one group of researchers Kohistan Ladakh Arc collided with Asia during 102–75 Ma, subsequently followed by its collision with the Indian continent during 55–50 Ma (Petterson et al, 1991; Rowley, 1996; Bignold & Treloar, 2003) and many others), However, the other school of thought favors the collision of India with the KLA first (at about 95–60 Ma) prior to its impact with Asia in Tertiary time (Tahirkheli et al. 1979; Yin & Harrison, 2000;Khan et al, 2009 and many others).

It has also been reported by numerous workers that the Late Cretaceous– Paleocene events in the Indus suture zone shows abduction of ophiolites on top of the Indian plate just before collision (Searle et al, 1997; Robertson, 2002; DiPietro & Lawrence, 1991; DiPietro et al., 2000; Corfield et al, 2001).

Moreover, existing models of collision between IP and Asia are in favor of either a double collision including an early India–Kohistan Arc collision afterward followed by the last and ultimate collision between Asia and combined India/Arc (Yang et al. 2015) or of a direct, single continent-continent collision between Asia and Greater India (Jagoutz et al. 2015).

India rifted away from Madagascar in the Late Cretaceous (~88 Ma), and started to move northward, secluded from the other continents of Gondwana. Therefore, floor of the Neotethyan ocean started to subduct underneath Asia thus allowing the northward movement of the IP (Chatterjee & Bajpai, 2016).

It is vital to understand that in what manner and at what time Kohistan Ladakh Arc (KLA) became stuck between Asia and India. Though some of the researchers (Clift et al. 2002) are of the opinion that collision of KLA first took place with Asia around 95-75 Ma, several others (Burg et al, 1996; Chatterjee et al. 2013) believe that India first collided with KLA in the Late Cretaceous (95-65 Ma) earlier than India's final collision with Asia.

Occurrence of huge blocks of ophiolite complexes have been reported from the mountains of Indonesia, Andaman Islands, southern Tibet, Kohistan, Ladakh and as for west as Oman. Searle (2013) reported that these ophiolitic complexes provide the direct indication of continent-island collision during Late Cretaceous period. As it is a widespread subduction region extending from east to west across Neotethys oceans, it is probable that collision between India and Kohistan-Ladakh Arc occurred synchronously during the Late Cretaceous (~ 80 Ma). This collisional history is in line with the paleomagnetic and radiometric data also revealing that the KL Arc was located in close proximity of the equator not far awayfrom the IP (~30ºS). Contrarywise, the Lhasa block was in excess of 3000 km in the far north, representing a gigantic area of the Neotethys ocean north of the IP (Khan et al. 2009; Burg, 2011).

In the light of the above-mentioned facts we are compelled to believe on the idea that Kohistan-Ladakh Arc collided first with the Indian plate during Late Cretaceous much earlier than the combined collision of the Kohistan Ladakh Arc and India with Asian plate during Tertiary time. We also believe that shortly before the collision between IP and Kohistan Ladakh Arc, the IP was abducted by ophiolites. During subsequent continental collision between the IP and the KL Arc, the weight of the descending block may have led to the development of an extensional environment in the descending plate, letting separation of the downdip, condensed oceanic lithosphere, from the adjoining lighter continental lithosphere through a lithosphere piercing the normal sense of shear zone. The continental crust attached to the descending oceanic slab may have experienced extensional faulting during this separation. The closeness of asthenosphere to crust may have triggered alkaline magmatism and regional metamorphism inside the continental plate. DiPietro (2001) has reported concordant 89 Ma ^{206}Pb-^{238}U ages on zircon from the Kishar Formation of Swat region. Under the hydrothermal or metamorphic conditions, the zircons may have crystallized and, therefore, date the initial stages of the regional metamorphism that later became widespread across the hinterland of Pakistan. If convergence between the continents is continued following detachment of the slab, a compressive tectonic format will be re-established within the region.

Subsequent to abduction the establishment of rifting environment along the northern boundary of the India may have given rise to regional heating and lithospheric thinning because of the diapiric uprising of the hot asthenosphere. The uprise asthenosphere could resulted in initiating fractional melting of an augmented lithospheric mantle source beneath the northern margin of the IP as a result of decompression, subsequently initiating alkaline and carbonatitic magmatic activity in the northwestern margin of the IP. The asthenospheric upwelling would also bring about high temperature that melted the crust and produced of granitic complexes (Sacks & Secor, 1990).

Closure temperature of Pb-U zircon ages is about 900 ^{O}C. This indicates that $^{206}Pb/^{238}U$ zircon age of 85.7 ± 0.9 Ma from the SP carbonatite complex represents emplacement of the complex somewhere during the Late Cretaceous time at depths of about between 7-25 Km, assuming a paleo geothermal gradient of about 35 ^{O}C/Km to have prevailed in the region, and due to subsequent rapid uplift experienced by the complex during the Oligocene above the track annealing zones of apatite and zircon. Following this rapid uplift above the isotherm of the track stability zones of zircon and apatite, the low temperature FT ages stabilized in the complex.

Close resemblance of the $^{206}Pb/^{238}U$ zircon age of 85.7 ± 0.9 Ma from the SP carbonatite with the Ar-Ar age of 80 Ma on phlogopite from the group 1 carbonatite of WOC indicates that the carbonatitic and alkaline magmatic activity in the northern Pakistan occurred on a much wider scale extending from Sillai Patti in the north up to Waziristan region in the south west during the Late Cretaceous time.

8. Conclusions

1. Emplacement of the SP carbonatite took place during Late Cretaceous time subsequent to the abduction of the ophiolite complexes on the northern and western margins of the IP about 89 Ma before.
2. Similarity of the $^{206}Pb/^{238}U$ zircon age of 85.7 ± 0.9 Ma on the carbonatites from SP with the Ar-Ar age of 80 Ma on phlogopite from the group 1 carbonatite of WOC indicates that the carbonatitic and alkaline magmatic activity in the northern Pakistan occurred on a much wider scale extending from Sillai Patti up to Waziristan region during the late Cretaceous time.
3. Indian plate collided first with KLA during Late Cretaceous prior to the combined collision of the KLA and Indian plate with Asia as a single plate in Tertiary time.
4. Emplacement of the SP carbonatite complex took place at depth between about 7-25 Km during the Late Cretaceous time and later on the complex was rapidly uplifted to shallow crustal level during Oligocene time above the fission track retention temperatures of zircon and apatite.

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