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Geology of Northern Sulaiman Foldbelt, Shirani and Waziristan Regions (South Punjab, Balochistan and Khyber Pakhtunkhwa): New Tomistominae (Miocene False Gharial) from Sakhi Sarwar Area of Dera Ghazi Khan (South Punjab), Pakistan

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Abstract

Northern Koh Sulaiman foldbelt, Shirani, North and South Waziristan (South Punjab, Balochistan and Khyber Pakhtunkhwa) comprised mostly PermoTriassic to Recent sediments with subordinate igneous and metamorphic rocks. These sedimentary strata folded and faulted by geodynamic and tectonic forces occurred during Late Cretaceous to Recent revealed through anticlinal and synclinal foldings and active faultings. The Northern Koh Sulaiman foldbelt, Shirani, North and South Waziristan areas host many economic minerals like copper and chromite, construction stones, marble limestones, gypsum and cement resources, uranium and other radioactive mineral resources, low-quality iron, phosphate and muddy coal, high-quality gemstones, petroleum potential and excellent water resources and many other rocks and minerals. High-quality window and faden quartz crystals deposited in fractures and fissures as vugs and veins deposited by high-temperature hypothermal solution created by the tectonic compression process. The area has economic chromite and magnesite deposits. The Northern Koh Sulaiman foldbelt, Shirani, North and South Waziristan areas have large cement raw materials/resources (limestones, gypsum and shale/clays available mostly on same sites) which vitally need to install many cement industries in these areas because the ideal central location and now only one cement industry (Dera Ghazi Khan cement industry) is in operation. The Northern Koh Sulaiman foldbelt, Shirani, North and South Waziristan consists of excellent surface water resources which need the construction of smaller and medium-sized dams on different rud kohi/streams/rivers for the development of the area. Sakhi Sarwar area of Dera Ghazi Khan (South Punjab) yielded fossil of new Tomistominae (False Gharial) Gavialidae and further its surroundings recently yielded fossils of famous vertebrates like reptiles (dinosaurs, crocodiles, pterosaur and snake), birds and mammals, and tracks/trackways of Late Cretaceous archosaurs like Sauropaonia, Ornithopaonia and Pteropaonia.

Keywords

Stratigraphy, Tectonic Structures, Economic Minerals, New False Gharial, Northern Sulaiman Foldbelt, Shirani, North and South Waziristan, Pakistan

1. Introduction

Pakistan is comprised of the Indus basin (Gondwanan fragment), Hindukush-Karakoram basin (Asian/Eurasian/Laurasian part) and Balochistan Basin and Kohistan-Ladakh magmatic arc (Tethys). The Hindukush-Karakoram basin is connected with the Kohistan-Ladakh magmatic arc via Karakoram Suture. The Indus basin is connected with Kohistan-Ladakh magmatic arc via the northern Indus Suture. The Balochistan basin is connected with the Indus basin via the western Indus basin. Indus Basin is a major sedimentary basin of Pakistan located in the central and eastern part of Pakistan which is further subdivided into northernmost Indus or uppermost Indus or Khyber-Hazara-Neelam basin, north Indus or upper Indus or Kohat-Potwar-Kotli basin, middle Indus or Sulaiman basin, and south Indus or lower Indus or Kirthar basin (**Figure 1**). The Mesozoic stratigraphy and also Cenozoic stratigraphy of Pakistan (including the Sulaiman basin) [1] [2] [3] [4] [5] and their mineral resources [6] [7] [8] [9] [10] were presented well. Some southern, eastern and northern parts of the Northern Koh Sulaiman foldbelt (including Shirani, North and South Waziristan) were not geologically mapped previously [1] [11] [12]. Recently stratigraphy and mineral resources of Sulaiman basin [13] [14] [15] [16] [17] and different aspects of geology like stratigraphy, tectonic structures and economic geology of Southern Koh Sulaiman Foldbelt (Mari Bugti hills and surroundings; Balochistan, South Punjab and Sindh) was reported [18]. Much geological information was lacking regarding the Northern Koh Sulaiman foldbelt, Shirani, North and South Waziristan regions (Saraikistan/South Punjab, Balochistan and Khyber Pakhtunkhwa). The Northern Sulaiman basin (**Figure 1**) is under the territory of South Punjab in the east, Balochistan in the center and west, and Shirani and Waziristan (Balochistan and Khyber Pakhtunkhwa) in the north. Here the revised

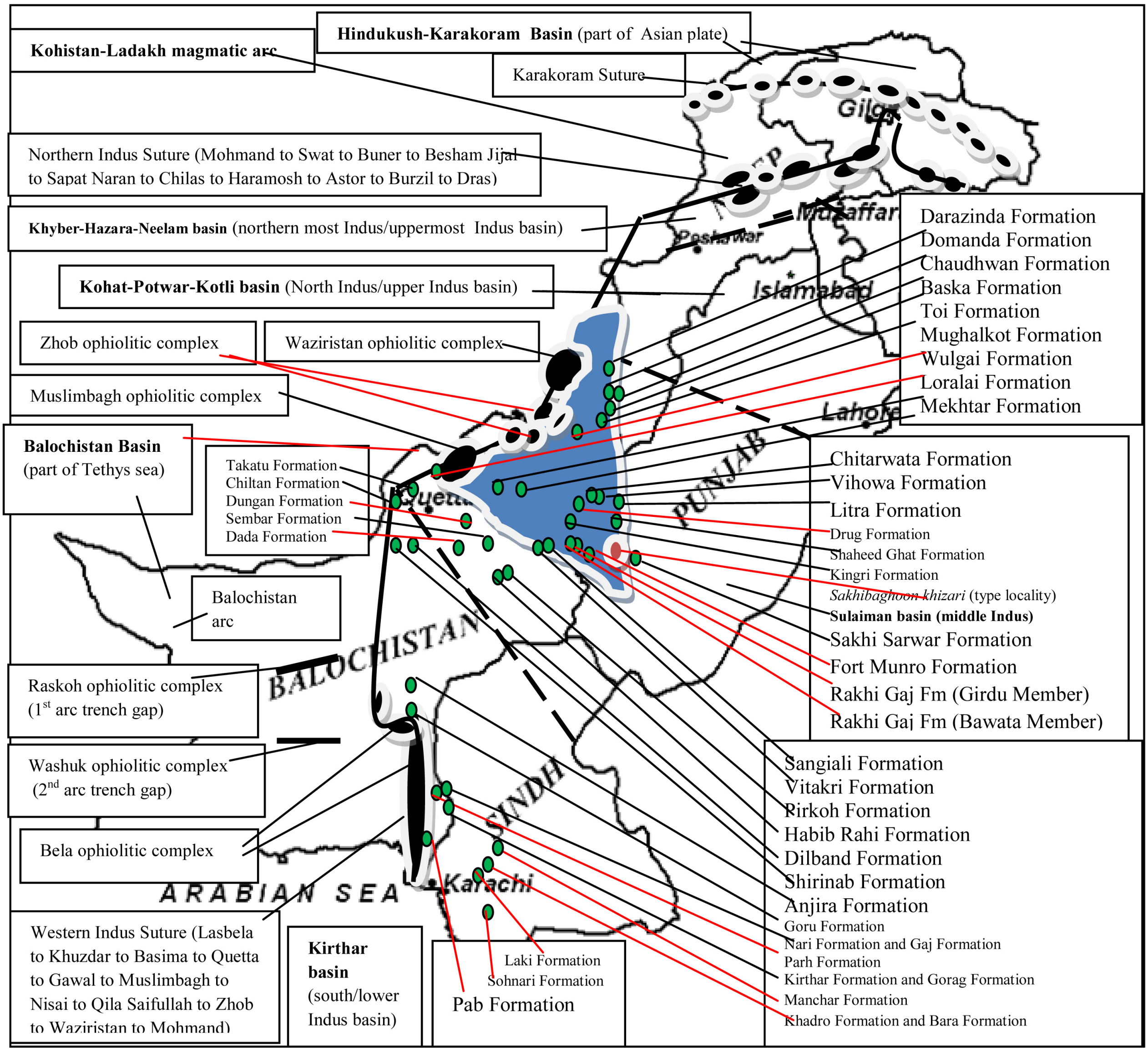

Figure 1. The different tectonic and sedimentary basins of Pakistan separated by sutures. The blue coloured area represents study area of northern Sulaiman basin, Shirani and Waziristan regions (South Punjab/Saraikistan, Balochistan and Khyber Pakhtunkhwa), Pakistan. Type localities of different geologic formations in Sulaiman and Kirthar foldbelts are shown as green oval. Long dashed lines show boundary between basins. Karakoram Suture is found between Hindukush-Karakoram basin (part of Asian plate) in the north and Kohistan-Ladakh arc (part of Tethys) in the south. Northern Indus Suture (North Indus Suture) is boundary between Kohistan-Ladakh magmatic arc in the north and Khyber-Hazara-Neelam (northern most Indus) basin in the south. Western Indus Suture (West Indus Suture) is a boundary between Balochistan basin (Tethys part) in the west and Indus basin (part of Indo-Pakistan plate which is a fragment of Gondwana) in the east. Western Indus suture hosts Bela ophiolitic complex (Gadani to Ornach to Wad and then westward turn to Pir Umar to east Basima and again northward turn), Muslimbagh ophiolitic complex (Gawal to Muslimbagh to Nisai), Zhob ophiolitic complex (Mina west of Mina Bazar, SE of Zhob, Naweoba and Zizha) and Waziristan ophiolitic complex (northwest of Wana and west of Razmak and Boya). Northern Indus suture hosts Malakand, Buner, Besham (Jijal), Sapat (Naran), Chilas, Burzil and Daras (Astor) ophiolitic complexes. Karakoram suture hosts Mirkani (between Lowari pass and Mirkani), Drosh (in Shishi stream Chitral), Sor-Laspur (SW of Shandoor pass), Yasin Valley (east of Shandoor pass), Chatorkhand (in Ishkuman valley), Chalt (Hunza valley), Hispar valley, Panmah, Shigor, Hushe and Machelu ophiolitic mélanges. Raskoh Suture shows 1st arc trench gap and host Raskoh ophiolitic complex which obducted at the early subduction of Arabian Sea plate into Balochistan basin of Tethys. Washuk Suture shows 2nd arc trench gap and hosts Washuk ophiolitic complex which obducted at the later phase by shifting of arc trench gap southward.

stratigraphy, tectonic structures and economic geology of Northern Koh Sulaiman foldbelt, Shirani, North and South Waziristan regions (South Punjab/Saraikistan, Balochistan and Khyber Pakhtunkhwa) and new fossil of Miocene Tomistominae (False Gharial), Gavialidae from the Sakhi Sarwar area of Dera Ghazi Khan District, South Punjab (Saraikistan), Pakistan is being presented here.

Institutional Abbreviations: GU, Ghazi University, Dera Ghazi Khan, South Punjab, Pakistan.

PCGU, Paleontological Collection of Ghazi University, Dera Ghazi Khan, South Punjab, Pakistan.

GSP, Geological Survey of Pakistan.

2. Materials and Methods

The materials belong to compiled data from previous work especially mentioned in references and also new field data collected during numerous field seasons and also by remote sensing regarding the stratigraphy, tectonic structure and economic minerals of Northern Sulaiman Foldbelt, Shirani, North and South Waziristan (South Punjab/Saraikistan, Balochistan and Khyber Pakhtunkhwa) and fossil of Miocene new Tomistominae (False Gharial) Gavialidae from Sakhi Sarwar area of Dera Ghazi Khan, South Punjab (Saraikistan), Pakistan. The methods applied here are many disciplines of purely geological procedure and description.

3. Results and Discussion

Here the results and discussion are represented regarding the stratigraphy, tectonic structure and economic minerals of Northern Sulaiman foldbelt, Shirani, North and South Waziristan (South Punjab/Saraikistan, Balochistan and Khyber Pakhtunkhwa) and fossil of Miocene new Tomistominae (False Gharial), Gavialidae from Sakhi Sarwar area of Dera Ghazi Khan, South Punjab (Saraikistan), Pakistan (**Figure 1**).

3.1. Stratigraphy of Northern Sulaiman Foldbelt, Shirani, North and South Waziristan (South Punjab/Saraikistan, Balochistan and Khyber Pakhtunkhwa), Pakistan

The Northern Sulaiman Foldbelt, Shirani, North and South Waziristan (South Punjab/Saraikistan, Balochistan and Khyber Pakhtunkhwa) host mostly sedimentary sequence (**Figure 2**) with ophiolitic complexes, Igneous, sediments and metamorphic rocks. Tectonically these ophiolitic rocks are obducted on plate boundaries and sutures. In Pakistan there are Indus Suture (subdivided into Northern Indus Suture and Western Indus Suture), Karakoram Suture, Raskoh Suture (representing 1st arc trench gap) and Washuk Suture (representing 2nd arc trench gap) (**Figure 1**). The north south trending Western Indus Suture (**Figure 1**) is a suture between Indus basin (Gondwanan Fragment) in the east and Balochistan basin (Tethys) in the west. Western Indus Suture hosts Bela (ophiolitic complex belt from Gadani to Ornach to Wad and then westward turn to Pir

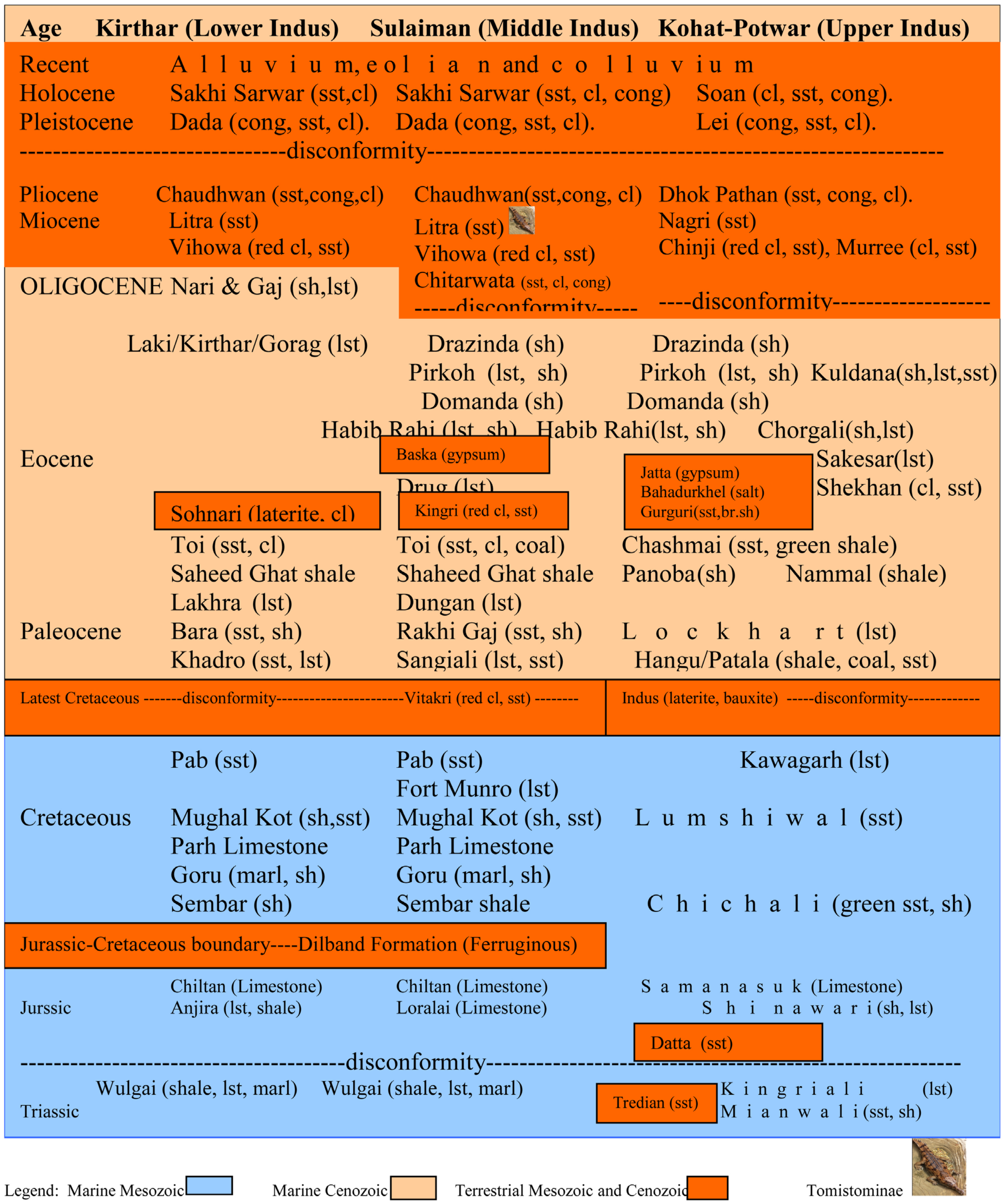

Figure 2. Stratigraphic sequence chart of Sulaiman basin/middle Indus basin (which includes the study area) correlated with North/Upper Indus basin (Kohat-Potwar-Kotli basin) and South/Lower Indus basin (Kirthar basin).

Umar to east Basima and again northward turn, **Figure 1**), Muslimbagh (including Gawal, Muslimbagh and Nisai ophiolites), Zhob (Naweoba, Zizha, SE of Zhob and Mina west of Mina Bazar) (**Figure 1**) and Waziristan ophiolitic complexes (NW of Wana, west of Razmak and SW of Miran Shah) (Figure 1 and Figure 3). Northern Indus Suture hosts Malakand, Buner, Besham (Jijal), Sapat (Naran), Chilas, Burzil and Daras (Eastern extremity of Astor) ophiolitic complexes (Figure 1). Northern Indus Suture represents contact of Indo-Pakistan shield and platform sediments of Khyber-Hazara-Neelam (northernmost Indus) basin with ophiolitic rocks (Mantle thrust), while Western Indus Suture represents contact of platform sediments of Indus basin of Indo-Pakistan plate with ophiolitic rocks (Mantle thrust). Karakoram Suture hosts Mirkani (between Lowari pass and Mirkani), Drosh (in Shishi stream Chitral), Sor-Laspur (SW of Shandoor pass), Yasin Valley (east of Shandoor pass), Chatorkhand (in Ishkuman valley), Chalt (Hunza valley), Hispar valley, Panmah, Shigor, Hushe and

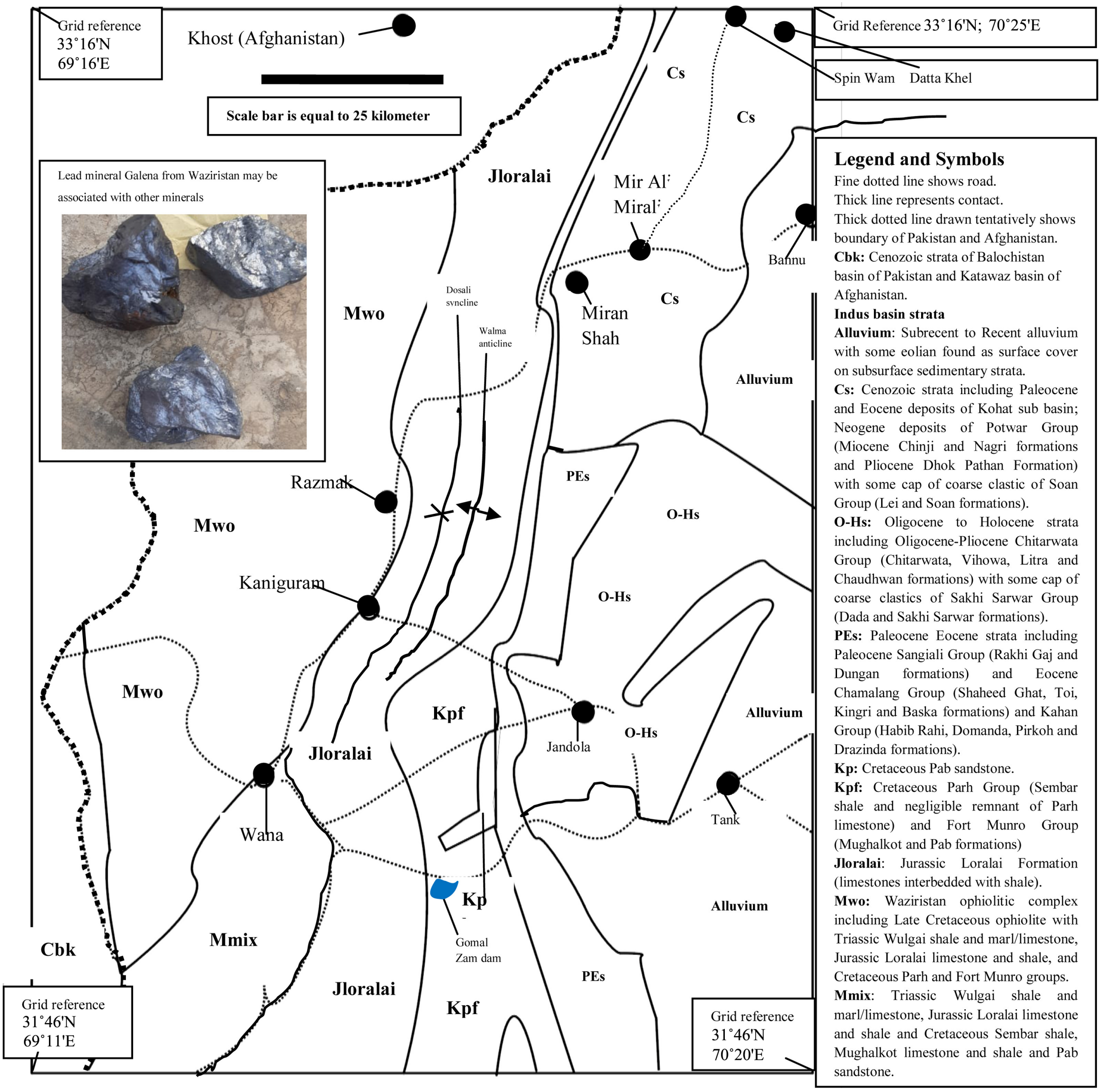

Figure 3. Geological map of Waziristan areas (North Waziristan and South Waziristan districts), Khyber Pakhtunkhwa, Pakistan.

Machelu ophiolitic mélanges (**Figure 1**). Raskoh Suture shows 1st arc trench gap and host Raskoh ophiolitic complex (**Figure 1**) which obducted at the early subduction of Arabian Sea plate into Balochistan basin of Tethys. Washuk Suture shows 2nd arc trench gap and hosts Washuk ophiolitic complex (**Figure 1**) which obducted at the later phase by shifting of arc trench gap southward.

The stratigraphy of Shirani area (of both Balochistan and Khyber Pakhtunkhwa), South Waziristan District and part of North Waziristan District (**Figure 3**) is the extension of stratigraphy of Sulaiman Foldbelt. The northeastern part of North Waziristan located in the vicinity of Bannu represents inter-fingering of Sulaiman Foldbelt and Kohat Foldbelt (**Figure 3**). Correlation and terrestrial and marine strata of North Indus (Kohat-Potwar-Kotli), middle Indus (Sulaiman) and south Indus (Kirthar) basins are presented as chart (**Figure 2**).

Stratigraphy of the North Waziristan and South Waziristan districts (**Figure 3**) comprised of Triassic Wulgai (shale and marl/limestones) and Jurassic Loralai (alternation of limestone and shale) formations of Sulaiman Group, Early Cretaceous Sembar (maroon to blue shale with limestone olistoliths (olistrostromes) of Parh Group, Late Cretaceous Mughalkot (red and green shale with lithographic limestone, and Pab (maroon to red sandstone with some shale) formations of Fort Munro Group, Early Paleocene Rakhi Gaj shale and sandstone and Dungan (limestones with minor shale) formations of Sangiali Group, Early Eocene Shaheed Ghat (green, grey and variegated shale), Toi (marine green to grey shale alternated with sandstone), Kingri (terrestrial maroon to red sandstone and shale) and Baska (shale with gypsum beds) formations of Chamalang Group, Early to middle Eocene Habib Rahi (limestones and shale), Domanda (mainly shale), Pirkoh (limestones and shale) and Drazinda (mainly shale) formations of Kahan Group, Oligocene Chitarwata (maroon to red ferruginous sandstone, conglomerate and shale), Miocene Vihowa (maroon to red shale, sandstone and conglomerate), Miocene Litra (mainly green sandstone with some shale) and Pliocene Chaudhwan (chocolate mud/shale alternated with sandstone and conglomeratic sandstone) formations of Vihowa Group, and Pliocene-Pleistocene Dada (dominantly conglomerate) and Holocene Sakhi Sarwar (sandstone alternated with chocolatic shale/mud, gritstones and conglomerate) of Sakhi Sarwar Group, and Subrecent and recent alluvial and colluvial deposits (**Figure 2** and **Figure 3**). Stratigraphic sequence (**Figure 2**) of northern Sulaiman foldbelt, Shirani, North Waziristan and South Waziristan regions is being described here. The type localities of different geologic formations of Sulaiman and Kirthar foldbelts are shown as green ovals in **Figure 1**.

Sulaiman Group: Sulaiman limestone was first used by [19]. Its type section between Mughal Kot and Dhana Sar (Lat. 31˚26'N; Long. 70˚01'E) was formally described by [20]. The Triassic-Jurassic Sulaiman Group [14] [15] [16] comprised of Wulgai, Loralai, Chiltan and Dilband formations [17] [18].

Wulgai Formation: Wulgai Formation was established from village Wulgai [20] (Lat. 30˚42'N; Long. 67˚29'E, near Muslimbagh, **Figure 1**) between Muslimbagh and Khanozai towns. It includes lower and upper shale units sandwiched by central limestone unit. Its base is not exposed while its upper shale unit is contacted with limestone (thin to medium bedded commonly) of Loralai Formation as transitional. The Permo-Triassic age was assigned.

Loralai Formation: It was named by [20]. Loralai Formation (named after Loralai area with Zamari Tangi type section Lat. 30˚32'10"N; Long. 68˚18'40"E, **Figure 1**) was a member of previously named Shirinab formation [1] named after Shirinab valley of Mastung District (Lat. 29˚41'20"N; Long. 66˚40'56"E, **Figure 1**). It comprised of thin to medium bedded grey limestones alternated with shale and marl. Its thin to medium bedded limestones is differentiated from upper shale unit of Wulgai and thick to massive limestones of upper Chiltan Formation. Age is lower to middle Jurassic.

Chiltan Limestone: It was established from Koh Chiltan near west of Quetta [20]. It comprised of thick bedded to massive limestones. Its thick to massive limestone is differentiated from lower thin to medium bedded limestone of Loralai Formation and upper brown to black desert varnish type ferruginous siltstone, limestones and shale. Age vary from Middle to Late Jurassic.

Dilband Formation: It was established from Koh Dilband (Lat. 29˚28'48"N; Long. 67˚06'46"E, north of Johan village, **Figure 1**) south of Kolpur. It consists of lacustrine ironstones/siltstones/limestones weathered as black desert varnish found with shale. Its age may be Jurassic-Cretaceous boundary.

Parh Group: The Lower Cretaceous Parh Group [14] [15] [16] [17] comprised of Sembar, Mekhtar, Goru and Parh formations.

Sembar Formation: It was established from Sembar Pass [20] south of Duki and west of Pazha. It comprised of greenish grey shale with negligible marl/siltstone beds. Its greenish grey shale is differentiated from the ferruginous siltstone/marl/shale of Dilband Formation (lower contact) and sandstone of Mekhtar Formation or marl unit of Goru Formation. Age is Lower Cretaceous. In Waziristan the Sembar shale described as Ahni Tangi Formation which contains green and red shales with large olistostromes blocks (olistoliths) [12] [21].

Mekhtar Formation: It was introduced by [5] [9] [10] from the Mekhtar town. It comprised of sandstone/siltstone and shale. Its dominant sandstone is differentiated from shale of Sembar Formation (lower contact) and also shale and marl of Goru Formation (upper contact). Age is Lower Cretaceous.

Goru Formation: It was established by [20] from Goru Range of Moola Zahri area of Khuzdar District. It comprised of greyish grey shale units and white weathered of greyish marl units. Its shale/marl is differentiated from lower sandstone/siltstone of Mekhtar Formation (lower contact) and white limestones of Parh Formation (upper contact). Age is Lower Cretaceous.

Parh Formation: It was established by [22] from the Parh Range in Khuzdar district. It comprised of white limestone with minor grey shale/marl. Its white limestone is differentiated from marl of Goru Formation (lower contact) and shale of Mughalkot Formation (upper contact). Age is lower Cretaceous.

Fort Munro Group: Fort Munro Group (of Late Cretaceous) was first used by

[14]. It comprised of Mughalkot, Fort Munro, Pab and Vitakri formations.

Mughalkot Formation: It was established by [20] from the Mughalkot village of Shirani area of D.I.Khan. It includes grey shale, sandstone and rarely limestone. Its dominant shale is differentiated from white limestone of Parh (lower contact) and limestones of Fort Munro, or sandstones of Pab Formation when Fort Munro was not developed (upper contact). Age is upper Cretaceous. In Waziristan the Mughalkot Formation was described as Shinkai Post Formation which consists of red and green shale with lithographic limestone and marl sequence [12] [21].

Fort Munro Formation: It was established by [20] from the Fort Munro area (Lat. 29˚57'57"N; Long. 70˚05'00"E; **Figure 1**; longitude was slightly mistyped by [2]) of D. G. Khan. It comprised of limestone with minor shale. Its limestone is differentiated from shale and sandstone of Mughalkot Formation (lower contact) and sandstones of Pab Formation (upper contact). Age is upper Cretaceous.

Pab Formation: It was established by [20] [23] from Pab Range north of Hub town (west of Shrine of Syed Bilawal Shah Noorani at Lahoot La Makan valley; **Figure 1**; Somalji trail, west of Wirahab Nai/Nala Lat. 25˚31'12"N; Long. 67˚00'19"E which was mistyped by [5]. Pab Formation has 3 members laterally differentiated as Dhaola member [5] [18] [24] (type Dhaola Range; white quartzose sandstone) exposed in eastern Sulaiman foldbelt and Laki anticline, Kali member [5] [18] [24] (Type section Tor Thana of Loralai district; muddy black weathering quartz bearing sandstone) exposed in Tor Thana (Loralai area) and Pab Range and surroundings (Hub, Bela and Khuzdar areas), and Sor member (Type Sor Muzghai near Musafarpur Lat. 30˚57'36"N and Long. 69˚08'24"E; dominantly maroon shale and sandstone) exposed in Qila Saifullah to Manikhawa Shirani to Waziristan. Pab Formation is marined everywhere except in the section of Bara Nai/Khadro Nai/nala where it is terrestrial and located in the core of thrusted Laki anticline. It includes sandstones and minor shale. Its sandstone is differentiated from Fort Munro Formation limestone (lower contact) and terrestrial shale and sandstone of Vitakri Formation (upper contact). Age is Late Cretaceous. In Waziristan the Pab Formation was described as Khajuri Post Formation which contains siliciclastic, thick bedded, cherty, faintly cross bedded sandstone [12] [21].

Vitakri Formation: It was established by [14] [15] [24] from the Vitakri village of Barkhan district. It comprised of terrestrial grey, maroon, red and variegated shale and greyish white sandstones. Its lower shale unit is differentiated from sandstone of Pab Formation (lower contact) and its upper sandstone unit is contacted with marine greenish grey shale (nautiloid bearing) and sandstone of Sangiali Formation or sandstone and shale of Rakhi Gaj Formation (upper contact). Its age is deduced upper Maastrichtian [25] (Pages 416-418 in [26]).

Muslimbagh Ophiolitic Complex: It is exposed in Gawal, Muslimbagh and Nisai areas (**Figure 1**). It comprised of ultrabasic to acidic rocks with sediments and metasediments. Its obduction age seems to be Late Cretaceous.

Zhob Ophiolitic Complex: It is exposed in the northern and southern vicinity of Zhob city (**Figure 1**). It comprised of ultrabasic to acidic rocks with sediments and metasediments. Its obduction age seems to be Late Cretaceous.

Waziristan Ophiolitic Complex: It is exposed in the western part of North and South Waziristan (**Figure 1**). It comprised of ultrabasic to acidic rocks with sediments and metasediments. Its obduction age seems to be Late Cretaceous.

Sangiali Group: It was established by [14] [15]. It comprised of Sangiali, Rakhi Gaj and Dungan formations. Its coeval in eastern Kirthar foldbelt is Ranikot Group consisting of Khadro, Bara and Lakhra formations (**Figure 1**).

Sangiali Formation: It was established by [14] [15] from Sangiali village north of Vitakri. It comprised of marine greenish grey shale (nautiloid bearing), green sandstone and brown limestones. Its lower green shale is contacted with upper sandstone of Vitakri Formation and its upper limestone is contacted with marine greenish grey sandstone and shale Rakhi Gaj Formation. Age is Early Paleocene. Its coeval in eastern Kirthar foldbelt is Khadro Formation (Bara Nai; Lat. 26˚07'06"N and Long. 67˚53'12"E; **Figure 1**).

Rakhi Gaj Formation: It was established by [13] [20] from the Rakhi Gaj nala. It includes marine greenish grey to brown sandstone and greenish grey shale. Its lower shale is contacted with limestone of Sangiali Formation in Vitakri and surroundings. Its lower Girdu sandstone [13] (Gorge beds [27]) is contacted with lower shale unit of Vitakri Formation. Its upper Bawata member (shale unit) [15] is contacted with limestone of Dungan formation. Age is Early Paleocene. Its coeval in eastern Kirthar foldbelt is Bara Formation (Bara Nai; Lat. 26˚07'06"N and Long. 67˚53'12"E; **Figure 1**).

Dungan Formation: It was established by [20] [28] from Dungan mountain near Harnai. It varies from massive nodular limestone to thin limestone beds and shale from place to place. Its limestone is contacted with shale of Rakhi Gaj (lower) and shale of Shaheed Ghat Formation (upper contact). Age is Paleocene. Its coeval in eastern Kirthar foldbelt is Lakhra Formation (southern plunge of Lakhra anticline; Latitude 25˚29'58"N and Longitude 68˚13'32"E; **Figure 1**).

Chamalang Group: Chamalang Group was established by [5] [16] [17]. It includes Early Eocene Shaheed Ghat, Toi, Kingri, Drug and Baska formations. Its coeval in eastern Kirthar foldbelt is Sohnari Formation (SW of Meting, Jhampir; latitude 25˚00'30"N and longitude 67˚55'58"E; **Figure 1**) of Laki Group.

Shaheed Ghat Formation: It was established by [29] from Shaheed Ghat near Zinda Pir Ziarat in Taunsa District. It comprised of greenish grey shale with minor sandstone/siltstone. Its shale is contacted with Dungan limestone (lower contact) and Toi sandstone in the western, central and northern Sulaiman foldbelt, while its upper contact with Drug nodular limestone is found in the southern and eastern Sulaiman foldbelt. Age is Lower Eocene.

Toi Formation: It was established by [13] from Toi Nala near Mughalkot. It includes deltaic sandstone and shale with conglomerate, coal and carbonaceous shale. Its sandstone is contacted with shale of Shaheed Ghat (lower contact) and nodular limestone of Drug Formation (upper contact). Age is Lower Eocene.

Kingri Formation: It was established by [14] from the Kingri area of Musakhel, Balochistan. It includes terrestrial sandstone and red to maroon shale with conglomerate and rare carbonaceous shale. Its red coloured shale and sandstone is contacted with greenish grey shale and sandstone of Toi (lower contact) and nodular limestone of Drug Formation (upper contact). Age is Lower Eocene.

Drug Formation: It was established by [29] [30] from Drug town. It includes nodular limestone and grey shale. Its shale and marl is contacted with red shale and sandstone of Kingri (lower contact) and gypsum beds and shale of Baska Formation (upper contact). The reference [13] mentioned Toi formation is above the Drug formation. In actual field position of Toi Formation is below the Drug Formation. It is confirmed in the north and southwest of Sulaiman foldbelt where both formations coexist. It is exposed well in Harnai, Duki, Chamalang, Kingri, Toi Nala, Mughalkot and Drazinda and surroundings. Age is Lower Eocene.

Baska Formation: It was established from Baska village near Mughalkot [11]. It comprised of gypsum beds and grey shale. Its gypsum and shale is contacted with nodular limestone and shale of Drug (lower contact) and with light brown limestone of Habib Rahi (upper contact). Age is Early Eocene.

Kahan Group: The name Kahan Group was established by [31] after Kahan village of Kohlu district. The Kahan Group includes the Early to middle Eocene Habib Rahi, Domanda, Pir Koh and Drazinda formations. It is coeval to Kirthar Group of western and northern Kirthar foldbelt (shale and limestone of Kirthar Formation named Kirthar Range at Gaj River section, west of Gorakh/Gorag hill station under Balochistan Lat. 26˚51'16''N and Long. 67˚08'15''E, and mainly resistant peak forming limestone of Gorag Formation named after Gorag/Gorakh hill station under Sindh, Lat. 26˚51'16''N and Long. 67˚08'45''E south of Gaj River; **Figure 1**) and Laki Formation (shale and limestone; Mari Nai; Latitude 26˚06'N and Longitude 67˚51'E on western limb of Laki anticline; **Figure 1**) of Laki Group in eastern Kirthar foldbelt.

Habib Rahi Formation: It was established after Habib Rahi nala [32] located southern limb of Pirkoh anticline and west of Dera Bugti town. It comprised of light brownish limestone with subordinate greenish grey shale. This formation consists of many hiatus type ochre thin beds. Its limestone is contacted with shale and gypsum of Baska (lower contact) and greenish grey shale of Domanda Formation (upper contact). Age is Early Eocene.

Domanda Formation: It was established after Domanda village (located between Mughalkot and Sheikh Manda villages) [11]. It includes marine greenish grey to chocolate shale. Its greenish grey shale is contacted with light brown limestone of Habib Rahi (lower contact) and its chocolate shale is contacted with white limestone of Pirkoh Formation (upper contact). Age is Early Eocene.

Pirkoh Formation: It was established from the Pirkoh Ziarat located northwest of Dera Bugti town [3] [20]. It comprised of white limestone and grey shale. Its white limestone is contacted with chocolate shale of Domanda (lower contact) and green shale of Drazinda Formation (upper contact). Age is Early Eocene.

Darazinda Formation: It was named after Darazinda town [11]. It includes grey shale in lower part and chocolatic shale in upper part. Its grey shale is contacted with Pirkoh limestone (lower contact) and its chocolatic shale is contacted with sandstone of Chitarwata Formation (upper contact). Age is Early-Middle Eocene.

Vihowa Group: It was established after Vihowa rud [14] [15]. It includes Oligocene-Pliocene Chitarwata, Vihowa, Litra and Chaudhwan formations.

Chitarwata Formation: It was established from Chitarwata village [11] of Vihowa area of Taunsa district. It comprised of white to grey sandstone, grey to brown shale, conglomerate and ironstone. Its sandstone and conglomeratic sandstone is contacted with chocolatic shale of Darazinda (Darazinda) and lower sandstone with red shale of Vihowa Formation. Age is Oligocene. It is terrestrial in Sulaiman basin while its coeval in Kirthar basin is marine Nari Formation (type locality, Lat. 26˚56'12"N; Long. 67˚10'10"E; **Figure 1**) and marine with rarely evaporitic Gaj Formations (type locality, Lat. 26˚51'40"N; Long. 67˚17'18"E; **Figure 1**) of Gaj Group. Both type localities are found in lower Gaj River of Johi area and also south of Kutey di Qabar or Dog's grave peak of Kirthar Range.

Vihowa Formation: It was established from Vihowa (Vehova) rud kohi/nala [11] of Taunsa district. It comprised of red shale and red weathered sandstone and a few conglomerate and thin coal seam. Its red coloured shale and sandstone is contacted with white to grey sandstone (black weathering) and brown to grey shale of Chitarwata Formation (lower contact) and with green to greenish grey sandstone of Litra Formation (upper contact). Age is Miocene.

Litra Formation: It was established from Litra nala [11] located south of Vihowa town of Taunsa district. It includes bluish grey sandstone with subordinate shale and conglomerate. Its dominant sandstone is contacted with red shale and sandstone of Vihowa (lower contact) and with chocolatic shale and grey sandstone of Chaudhwan Formation (upper contact). Age is Miocene.

Chaudhwan Formation: It was named after Chaudhwan village [11] of D.I.Khan district. It is comprised of chocolatic muds/shale and greyed to brown sandstone and conglomerate. Its chocolatic mud and sandstone is contacted with greenish grey sandstone of Litra Formation (lower contact) and with thick conglomerate of Dada Formation (upper contact). Age is Miocene-Pliocene. Its coeval in eastern Kirthar foldbelt is Manchar Formation (Lat. 26˚20'50"N; Long. 67˚50'07"E) named after Manchar lake just west of Sehwan (**Figure 1**).

Sakhi Sarwar Group: It was named after Sakhi Sarwar town [33]. Its type section (latitude 29˚59'37"N and longitude 70˚18'04"E) is located at west and northwest of Sakhi Sarwar town. Sakhi Sarwar Group [4] [5] [33] includes the Pliocene-Pleistocene Dada (mainly conglomerate) [1] and Pleistocene-Holocene Sakhi Sarwar (clays, silt, sandstone and conglomerate) formations [33].

Dada Formation: It was named after the Dada River (lat. 29˚50'N; long. 68˚03'E) at south of Spintangi Railway station [1]. It is coeval to Urak conglomerate. It comprised of thick conglomerate (resistant and elongated ridge formatting) with subordinate brown gritstone, sandstone and brown shale. Its conglomerate is contacted with chocolatic mud of Chaudhwan Formation (lower contact) and brown coloured shale and sandstone/gritstone of Sakhi Sarwar Formation (upper contact). Age is Pliocene -Pleistocene.

Sakhi Sarwar Formation: The name Sakhi Sarwar Formation was established from Sakhi Sarwar town [33] with type section (latitude 29˚59'37''N; longitude 70˚18'04''E) west and northwest of Sakhi Sarwar town. It comprises of varicolored clays, sandstone, siltstone and conglomerate. Its lower contact with Dada conglomerate and upper contact with Subrecent alluvium is transitional and at places anugular. Age is Pleistocene-Holocene.

Subrecent and Recent deposits: These are found as Terrace Alluvial deposits; Fan Alluvial deposits; Colluvial deposits; Mixed sand, silt and clay deposits (non-cultivated lands); Mixed sand, silt and clay deposits (cultivated lands); and Present Channel alluvial deposits.

3.2. Tectonic Structures of Northern Sulaiman Foldbelt, Shirani and Waziristan (South Punjab/Saraikistan, Balochistan and Khyber Pakhtunkhwa), Pakistan

Here many folds and faults of the study areas are being described.

3.2.1. Alternated Anticlinal and Synclinal Foldings in the Northern Sulaiman Foldbelt, Shirani and Waziristan (South Punjab/Saraikistan, Balochistan and Khyber Pakhtunkhwa), Pakistan

Structurally and geologically most of the study area was mapped as shown in **Figures 3-8**. A comprehensive geological map of North Waziristan and South Waziristan districts are being presented (**Figure 3**) which show Mesozoic to Subrecent and Recent sediments and ophiolite which obducted during Late Cretaceous. The Jurassic Loralai limestone and shale show a single fold (Dosali syncline and Walma anticline), the shale and limestone of Mughalkot formation show close folding in the South Waziristan while in North Waziristan it mostly seems dipping toward east. However the Cenozoic and especially Late Cenozoic strata represent close foldings (repeated anticlines and synclines). These anticlines seem significant for petroleum resources. These foldings continue toward Bannu, Karak, Laki Marawat, Kohat, Hangu and eastern Parachinar areas. The Waziristan area represents oldest rocks close to Western Indus Suture and becoming younger toward east (**Figure 3**). Traversing from D.G.Khan to Rajanpur in the east and extending toward Narwel, Vitakri and Siah Koh in the west (**Figure 4**). Traversing from southwestern Tangi Sar to Hinglun Burg Pusht to Pir Gahanro to Kharar Buzdar in the east and extending toward eastern Murgha Kibzai to western Khajuri in the west (**Figure 5**). Traversing from east of Mekhtar to west of Barkhan in the east and extending toward west of Loralai to Sanjawi

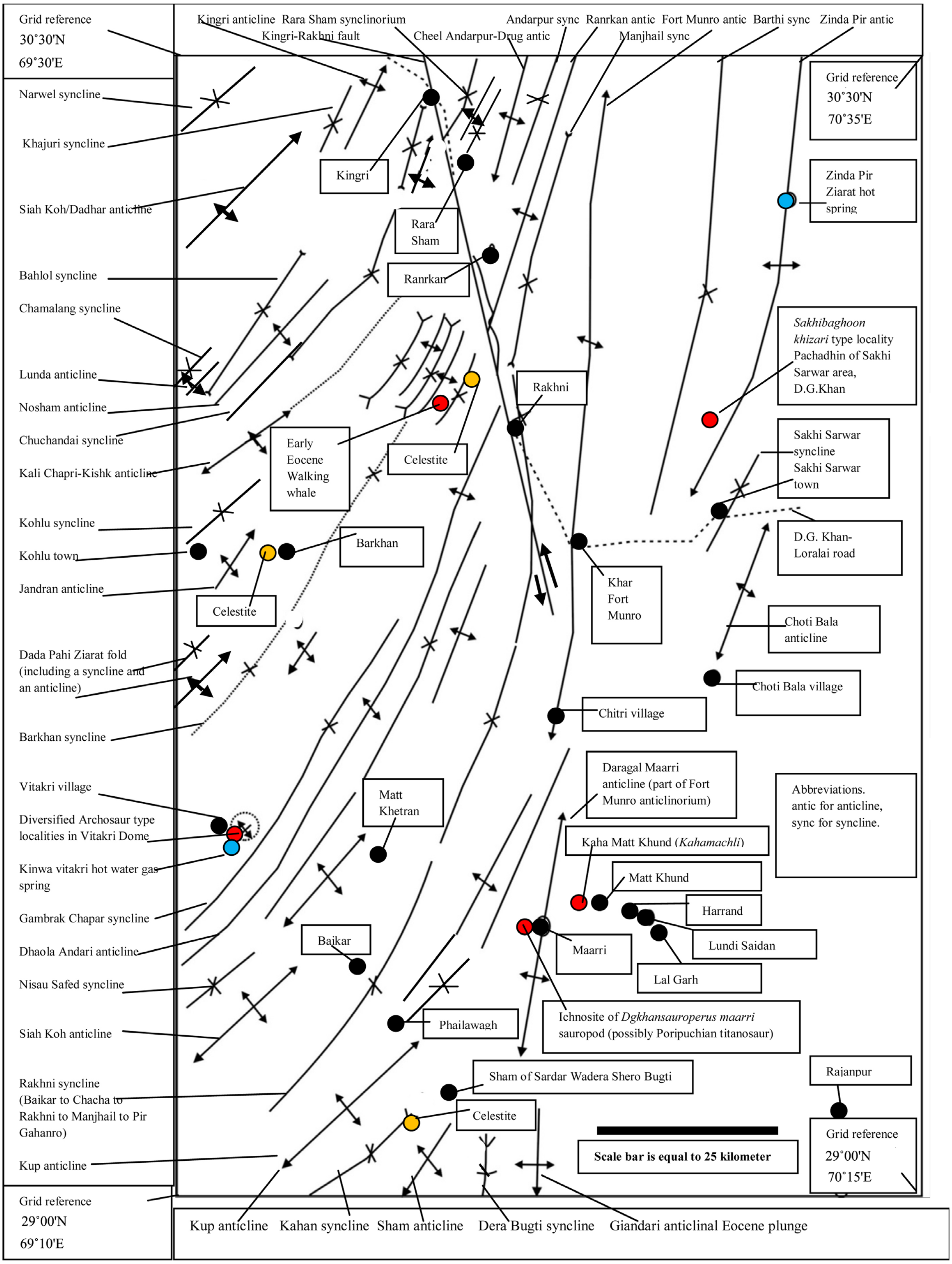

Figure 4. Tectonic structural folds (anticlines and synclines) and faults Map of eastern Sulaiman Foldbelt (southern part of Koh Sulaiman Range; Balochistan and South Punjab), Pakistan. Map also shows some significant recently discovered fossil localities as shown by red circle.

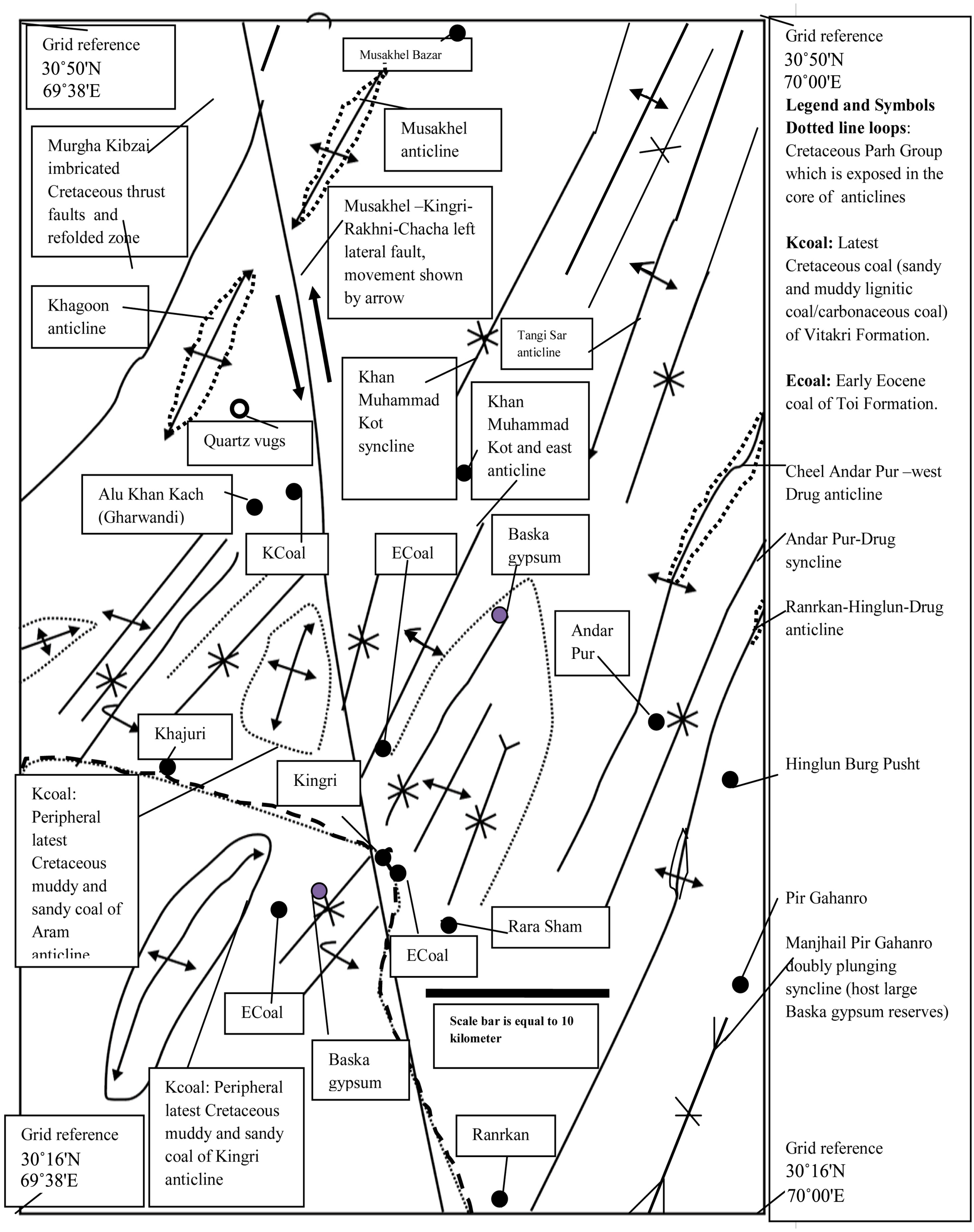

Figure 5. Geological and structural Map of Kingri, Rara Sham, Alu Khan Kach, Musakhel and Khan Muhammad Kot areas and surroundings, Musakhel, Zhob and Barkhan districts of Balochistan, and Taunsa district of South Punjab (Pakistan). This map also shows localities of significant mineral commodities. Thick dotted line forming loops in the core of anticlines show Early Cretaceous Goru marl and shale and Parh limestones of Parh Group.

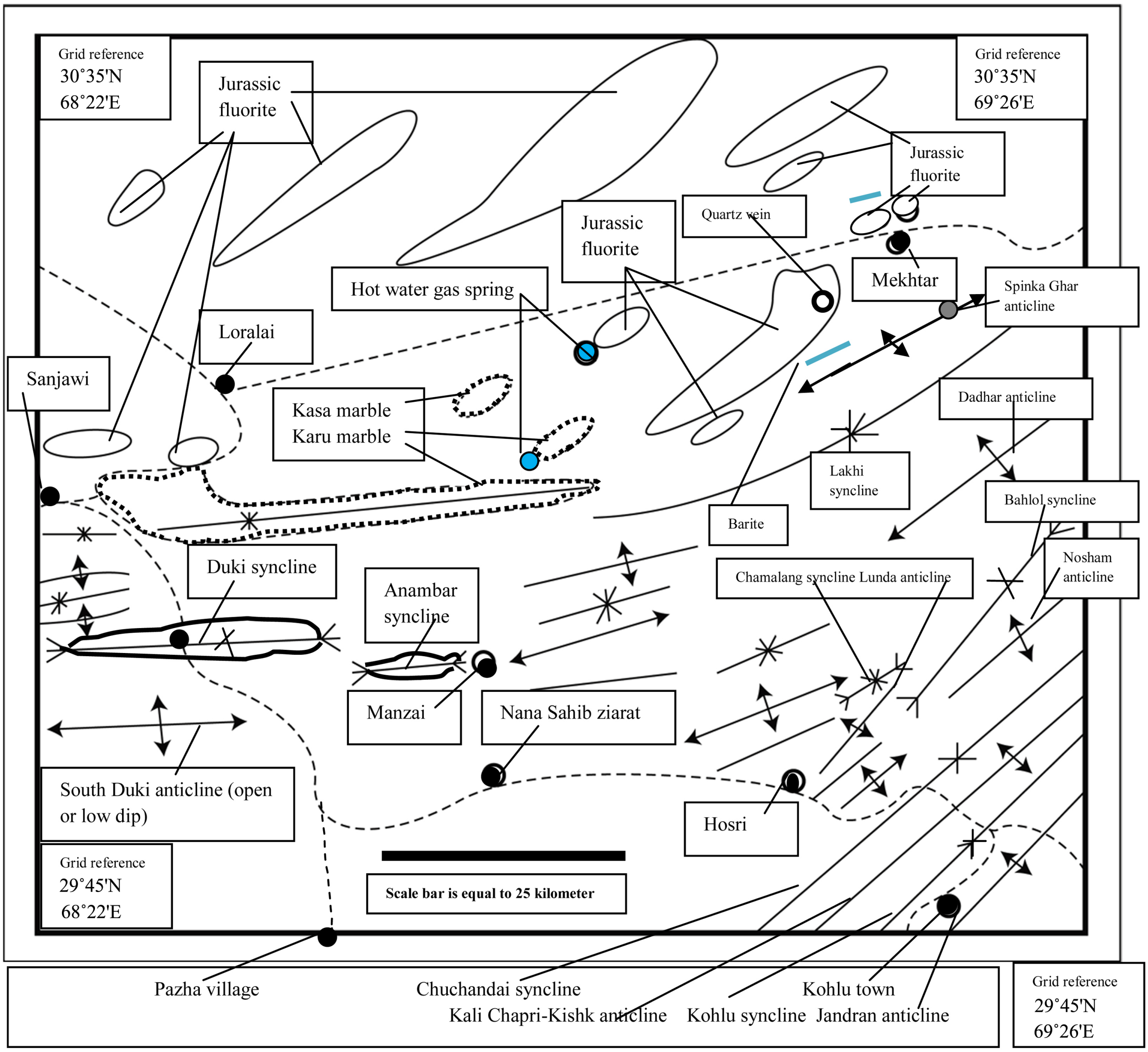

Figure 6. Geological and structural map of Loralai, Mekhtar, Zarah, Duki, Nana Sahib Ziarat, Hosri, Chamalang, Kali Chapri, Kohlu and surrounding areas of Loralai, Zhob and Kohlu districts of Balochistan Province, Pakistan. Thick dotted line oval areas represent Dungan limestones commonly called marble (rarely Chiltan limestones in the northwest of southern large oval area; area just west of Pathankot. Blue circle represents Mahiwal hot water gas spring (northern blue circle) and Karu hot water gas spring (southern blue circle). Black circle line filled white colour in the south west of Mekhtar town represents quartz-fluorite veins. The black line circle areas host fluorite mineralizations in the Loralai and Zhob districts. The thick black line oval represents coal deposits especially in Duki syncline and Anambar syncline. Chamalang coal is found in the western and eastern limbs of Chamalang syncline (also called Anokai syncline) and Bahlol syncline. Minor showings are also found in Kali Chapri and Mirri Wah areas. Carbonaceous shale which is shown by grey circle (south east of Mekhtar) in the Early Cretaceous Sembar shale of Spinka Ghar anticline. Blue lines in the north and Southwest of Mekhtar town represent large barite nodules arranged in lines.

to Duki in the west (Figure 6). Traversing from Dera Ismail Khan to north of D. G. Khan in the east and extending toward west of Takht Sulaiman to west of Ra-ra Sham in the west (Figure 7). Five different geological zones are being established in the northern Sulaiman Foldbelt (Figure 8). First zone represents the marine and terrestrial strata of Kakar Khorasan block of Balochistan basin and

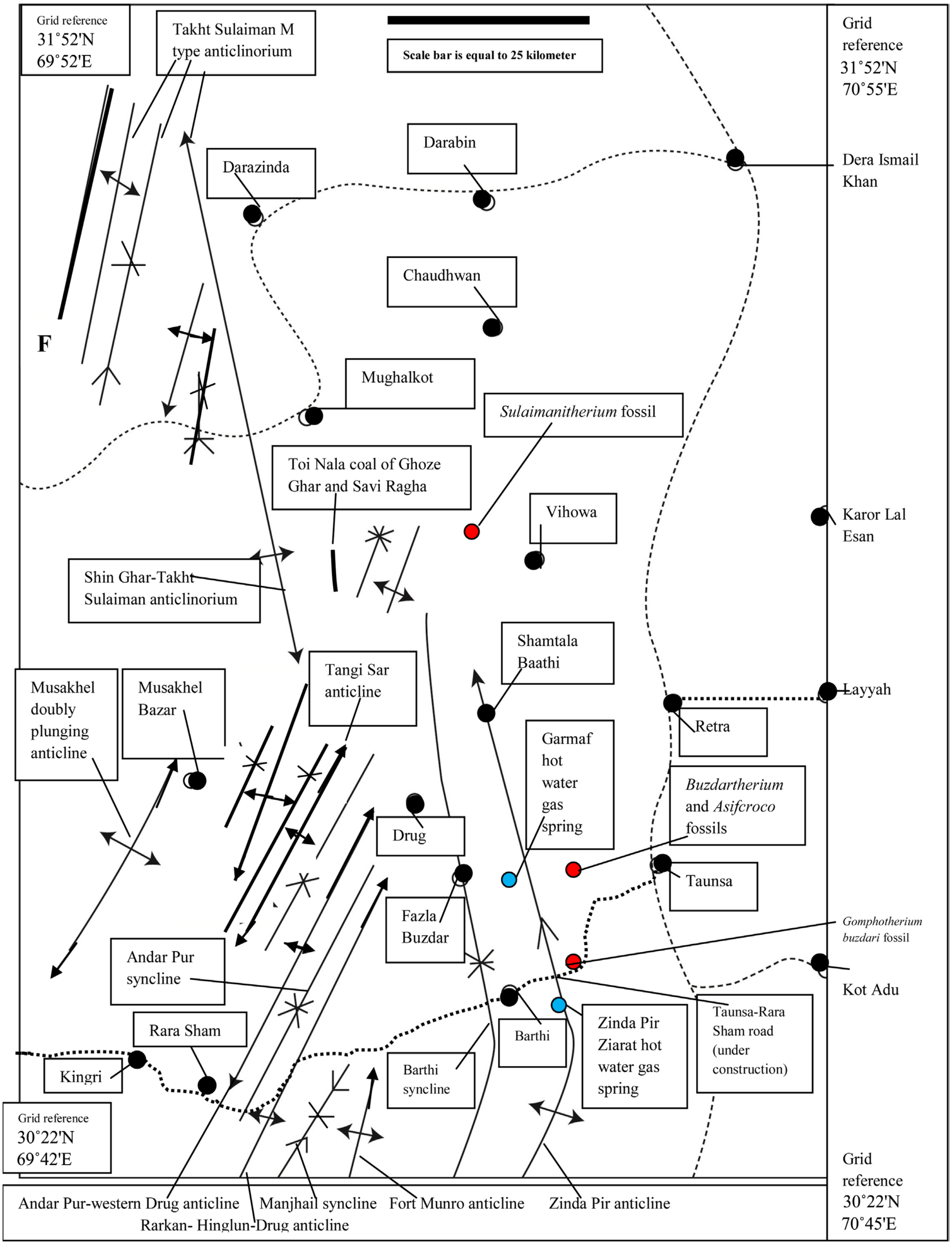

Figure 7. Tectonic structural (anticlinal and synclinal foldings and some faults) map of northern Koh Sulaiman Range, Balochistan, South Punjab and Khyber Pakhtunkhwa, Pakistan. Red circle show recently discovered fossil localities. F is symbol for fault.

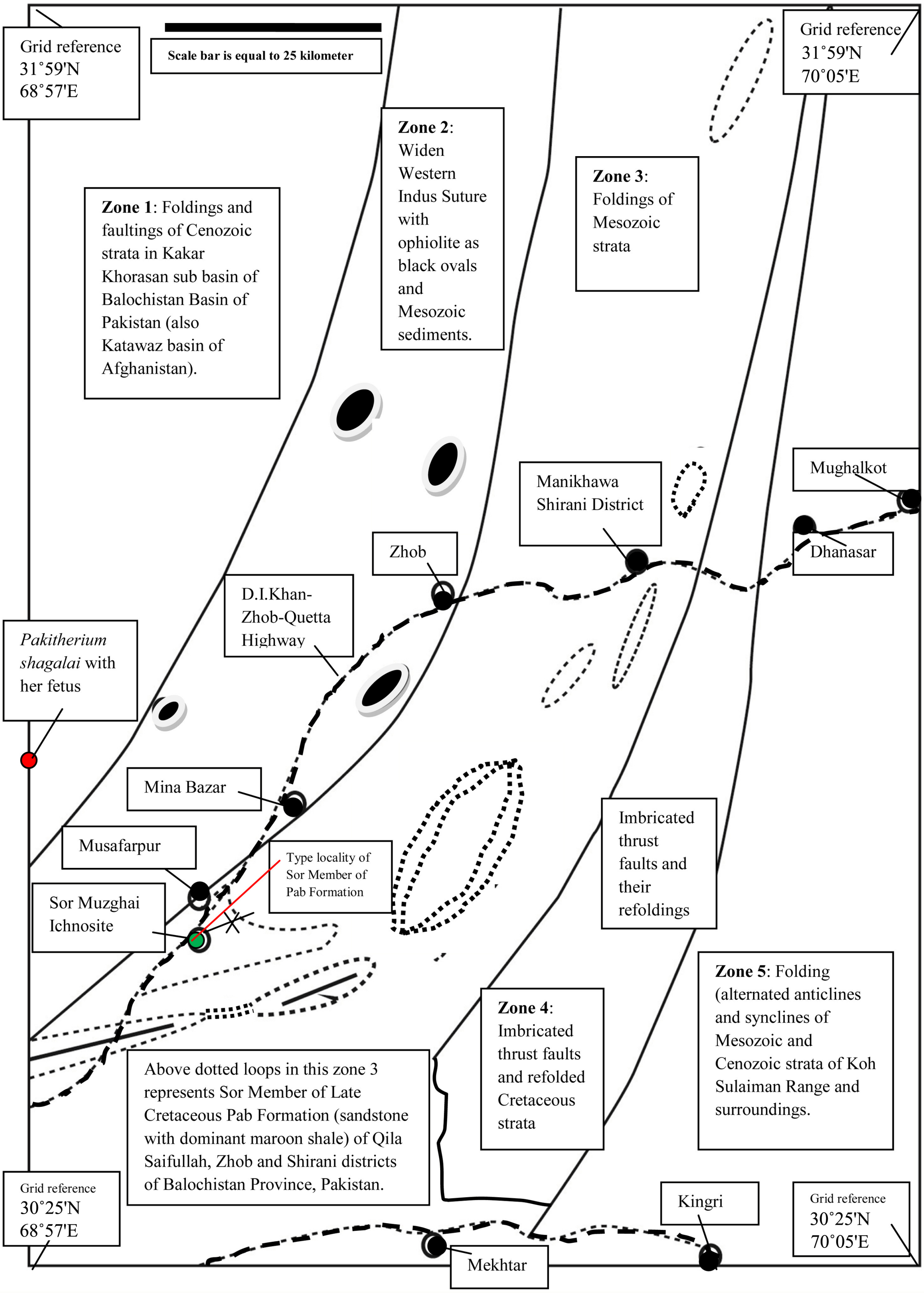

Figure 8. Structural geological map of Northern Sulaiman Foldbelt region of Balochistan, South Punjab and Khyber Pakhtunkhwa, Pakistan. Five major belts and zones are boarded by thick lines generally trending north east.

Katawaz basin. Second zone represents Western Indus Suture which hosts obducted ophiolite and sediments of Indus basin (eastern flank) and sediments of Balochistan basin in the west. Third zone represents the Mesozoic folded strata including Jurassic Loralai limestones and shale and rarely Early Cretaceous Parh Group (Sembar shale, Goru shale and marl/limestones and Parh limestones) and Late Cretaceous Fort Munro Group (Mughalkot shale, sandstone and limestones and Pab sandstone and shale and Vitakri maroon shale and sandstone). The Jurassic Loralai limestones and shale and Maastrichtian Pab sandstone and shale and Vitakri maroon shale and sandstone. Fourth zone is represented by imbricated thrust faults which are refolded again (**Figure 8**). Fifth zone represents folded strata (**Figure 8**). The prominent foldings (alternated anticlines and synclines) are observed in most of study area (**Figure 4**). The dominant plain and semiplain alluvium and eolian found in the eastern part of study area especially between D. I. Khan city to D. G. Khan city. Firstly the Choti Bala anticline (in the east) is observed which is located between Sakhi Sarwar and Choti Bala towns. This anticline is open and includes the Pliocene to Holocene sedimentary rocks like Sakhi Sarwar Group. Then westward Sakhi Sarwar syncline observed which is open and has low dips. Followed by Zinda Pir anticline [18] which is elongated belt trending north south. This anticline has Pachadhi and Poadhi peak forming flanks. This anticline has low to moderate dips. The oldest core formation is Early Paleocene Rakhi Gaj Formation which has minor exposures just on the vicinity of Zinda Pir Ziarat. Here the Rakhi Gaj sandstone and shale is capped by thick to massive limestones of Paleocene Dungan Formation with is 10km long and then plunged in the north and south. Then Eocene to Holocene strata followed plunging southward upto just east of Rakhi Munh and southwest of Sakhi Sarwar town and then Eocene to Pliocene strata started plunging northward upto Shamtala Baathi (west of Jhok Bodo village) (**Figure 7**) and Vihowa rud (southwest of Vihowa town) (**Figure 7**). The limb formations extend from Paleocene to Holocene strata. This Zinda Pir anticline is alternated by Barthi syncline which has same length like the Zinda Pir Ziarat anticline (**Figure 4** and **Figure 7**). This syncline represents low to moderate dips. The core younger formation is Dada conglomerate and Sakhi Sarwar Formation exposed well in the east of Rakhi Munh village. Followed by Fort Munro anticline (may be called anticlinorium) which extends from Sorra (northern plunge) to Mubarki, Hikbai (Yakbai), Gagan Thal, Khar-Fort Munro, Goran Thal (west of Choti chur and east of Nilani Toba), Chitri (west of Sakhi Borbux and east of Chacha), Daragal, Maarri and Giandari (southern plunge) (**Figure 4**). The oldest core Formation is Parh limestone and limb formation extends upto Sakhi Sarwar Group. This anticline is peak forming having maximum elevation in the area. This anticline is represented by low to moderate dips. Then the Manjhail-Pirgahanro syncline appears which has Early to Middle Eocene Drazinda Formation. This syncline plunges in the south just north of Chapar area and northern plunge occurred in the Pir Gahnro (Pir Gahno) and Luni (Kachiwanga) area. This syncline shared limbs with the Fort Munro anticline in the east and

Ranrkan-Hinglun (-Drug) anticline in the west. Then Rarkan-Hinglun-Drug anticline appears which hosts oldest core Formation as Parh limestones and Goru Formation exposed in the Hinglun Burg Pusht area (**Figure 5** and **Figure 7**). The eastern and also western limbs host formation upto Drazinda Formation. This anticline shares with Lakha Kach syncline in the west which again followed by Taghao anticline, eastern Chapar syncline, western Chapar anticline, Eastern Baghao syncline, mid Baghao anticline, west Baghao syncline, Kali Chapri-Mirri Wah anticline, Chuchandai-Kingri town syncline, Nosham anticline, Bahol syncline, Lunda anticline, Chamalang (Anokai syncline and Siah Koh anticline (**Figure 4** and **Figure 6**).

Following westward from central portion of Ranrkan-Hinglun-Drug anticline, the Andar Pur syncline appeared which hosts youngest Shaheed Ghat formation in the core axis. This Andar Pur syncline is sandwiched between the Ranrkan-Hinglun Burg Pusht-Drug anticline and Cheel Andar Pur-western Drug anticline. The Cheel Andar Pur-western Drug anticline hosts the oldest Goru shale and marl, and Parh limestones in the core (**Figure 5** and **Figure 7**). The eastern limb formations extend upto Shaheed Ghat Formation and the western limb extends upto Drazinda shale exposed just southwest of Kingri town. Following further westward from Cheel Andar Pur anticline, then Rara Sham syncline, Gandhera anticline, Kingri town syncline, western Kingri anticline, Khajuri syncline, Dhadhar-Alu Khan Kach anticline, Narwel syncline and Spinka Ghar anticline and then Murgha Kibzai imbricated thrust zone started (**Figures 4-8**). In northern part of Taunsa District area, the easternmost anticline is Zinda Pir anticline, then Barthi syncline and Ranrkan-Hinglun-Drug anticline. If we follow westward from Drug area of Ranrkan-Drug anticline, then repeated by Andar Pur syncline, Cheel Andar Pur-western Drug anticline, Rara Sham syncline, Tangi Sar anticline, then unnamed syncline, southern part of Shin Ghar anticline, unnamed syncline and Musakhel anticline and then Murgha Kibzai imbricated fault zone appear (**Figure 4** and **Figure 5** and **Figure 7** and **Figure 8**).

The Kingri anticline is represented by the oldest core Mughalkot shale and sandstone. The Kingri anticline joins Aram anticline in the north which hosts oldest Pab sandstone. Their eastern limb formations extend upto Drazinda Formation and western limb extends upto Shaheed Ghat shale. Followed by Khajuri syncline which hosts the oldest Shaheed Ghat shale in the core, then Dhadhar-Alu Khan Kach (Gharwandi) anticline, Narwal syncline and Spinka Ghar-western Alu Khan Kach anticline. Now we follow the folding structures from Aram to Gharwandi (Alu Khan Kach) To Khagoon Range to Murgha Kibzai area. In this line the Aram anticline followed by Khajuri syncline, Musakhel-Alu Khan Kach-Dhadhar anticline, western Alu Khan Kach syncline and Khagoon anticline. Then Murgha Kibzai imbricated thrust fault zone appeared (**Figure 4** and **Figure 5** and **Figure 7** and **Figure 8**).

Khajuri syncline is followed by Musakhel Bazar anticline. This is lengthy anticline extending from Dhadhar peak (in the south) to Alu Khan Kach to Musa Khel Bazar and Toi Sar (in the north). This anticline has low to moderate dips.

The oldest core formation is Goru and Parh formations. This Musakhel Bazar anticline is alternated by western Alu Khan Kach (Gharwandi) syncline and then by Khagoon anticline. The western Gharwandi syncline hosts the oldest Mughalkot and Pab formations in the northwestern vicinity of Alu Khan Kach. The Khagoon anticline hosts the Parh Limestones as the oldest Core formation. The dips are low to moderate. Further westward from Khagoon Range to Murgha Kibzai village, the intense imbricate thrusting of Cretaceous strata were observed which is also refolded. Then from Murgha Kibzai to western Indus Suture areas like Qila Saifullah to western Musafarpur-Mina Bazar-Sor Kach-Zhob, the alternated anticlines and synclines were observed.

From Vihowa to westward, the observed structures are Zinda Pir-Shamtala anticline, Barthi syncline, eastern Savi Ragha anticline, western Savi Ragha syncline, Shinghar anticline and then further westward from Toi Sar to Murgha Kibzai, the observed structure is imbricated thrust faults zone. From west of Chaudhwan or Darabin, the observed structures are Western Darabin-Domanda anticline, Darazinda-Shaikh Manda anticline, M-type Takht Sulaiman (peak forming) anticlinorium, then imbricated faults zone started, while here the imbricated zone is pinching (**Figure 7** and **Figure 8**).

3.2.2. Main Faults in the Northern Sulaiman Foldbelt, Shirani and Waziristan (South Punjab/Saraikistan, Balochistan and Khyber Pakhtunkhwa) Pakistan

The study area represents Ranrkan thrust fault, Rakhi-Kingri-Musa Khel strike slip fault (left lateral) (**Figure 4** and **Figure 5**) and Murgha Kibzai imbricated thrust faults and refolded zone. The Ranrkan-Hinglun Thrust fault is trending generally northeast-southwest and upthrusted more than 1 km [9]. Chacha-Rakhni-Kingri-Musakhel fault is a left lateral strike fault with relative movement 2-3km in the south [9], relatively movement near Kingri more than 3 km and diminishing in the northern part just west of Musakhel Bazar (**Figure 5**). Westward from Khagoon Range (Alu Khan Kach area) to west Takht Sulaiman, the intense imbricated thrust faults (more than 20 imbricated thrust faults) are observed. These imbricate faults are refolded later and also mineralized with barite in the Sembar shale and significant quartz crystals (window/fenestra and faden quartz) veinings and vugs in the sandstone and shale of Mughalkot Formation. Total imbricated faults are more than 20 thrusted faults. This imbricated zone is subdivided into two subzones, each zone represents more than 10 imbricated faults. This thrusted strata mostly belongs to Cretaceous strata dominantly Parh and Fort Munro Groups (**Figure 7** and **Figure 8**).

3.3. Economic Minerals of Northern Sulaiman Foldbelt, Shirani and Waziristan (South Punjab/Saraikistan, Balochistan and Khyber Pakhtunkhwa), Pakistan

The study area hosts many economic minerals and some trivial showings. Chromite, magnesite and asbestos were reported from Muslimbagh (**Figure 1**), Zhob (**Figure 1**) and Waziristan (**Figure 1**) ophiolitic complexes [6] [7] [34].

Soapstone showings in the ophiolitic rocks from Zhob valley like Gach Inziakai, Shinghar hill, Zamankar nala (Walgai Oba) and Bahram Khel localities [8] [9] [10] and the copper from Boya of North Waziristan, Sange Gar, Zizha, Shin Ghar and Otman near Jalat Killi of Zhob area, Nisai and Tor Ghar of Muslimbagh area [6] [7] [8] [9] [10]. The ophiolite associated massive sulphide from Boya, Mami Ragha and Spin Kamar was reported in Waziristan ophiolitic complex. Some copper minerals as gemstone were found from Muslimbagh, Zhob and Waziristan ophiolitic complexes. These ophiolitic complexes may host Manganese. The copper mineral in sediments are also reported in Rara Sham and other areas used for gemstones. Lead mineral galena PbS (**Figure 3**) may be associated with zinc, arsenic, copper, gold, silver, manganese and others are found in Waziristan. Further maroon to red oxide in Sata Post area (Taunsa District) and other places exposed on the flanks of D. G. Khan to Fort Munro road and red to yellow ochre found with Cretaceous coal of Alu Khan Kach, Kingri and Aram coal area (**Figure 5**).

The Muslimbagh, Zhob, Loralai, Musakhel, Shirani, and Waziristan areas (**Figure 1**) hosts many gemstones [35] [36] [37] like well developed window and faden quartz crystals, fluorite, chalcedony (chert, jasper, flint, agate, amethyst, etc), almandine garnet, tsavorite garnet, actinolite, natrolite/zeolite, marble, malachite, azurite, chrysocolla, epidote, rodingite (formed by rodingitization process-which are metasomatised calc-silicate rocks associated with serpentinites), calcite, etc. The reference [35] also reported many gemstones from the Muslimbagh area of Balochistan Province like natrolite, marble, serpentine, talc, quartz, chert, green chert, calcite, agate, amethyst, copper minerals (malachite, azurite, chrysocolla), jasper, flint, agate, amethyst, etc), almandine garnet, tsavorite garnet, actinolite, epidote.

Significant quartz (window/fenestra quartz having window and a few ribbons and faden quarts having thin thread/white milky line and also ribbons) vugs and veins are found in the Alu Khan Kach (Gharwandi) area (**Figure 5**) west of Allah Din house and eastern limb of Khagoon Range and anticline, Kingri Tehsil of Musakhel district, Zhob division. Windowed (fenestra) quartz includes window shape inside the crystal with inclusions while faden quartz is tabular which consists of white fuzzy line/thread/string/fiber/milky line sometimes curvy trail created by tectonic fracturing and then quickly cementing and healing and regrown. The quartz veins in sedimentary strata were found in Sulaiman and Balochistan basins both are under the territory of Balochistan Province. Quartz veins in igneous rocks are reported in Balochistan magmatic arc, western Indus suture (Khuzdar, Muslimbagh and Zhob areas) and northern Pakistan. These sedimentary quartz veins and vugs were first reported in Balochistan Province in 2011 (Page 284 of [16]). Later on these window and faden quartz (named as Kingri diamond) were also figured (Figure 1 page 262 of [38]; Figure 2(b) page 70 of [9]; Figure 4(b) page 148 of [10]) and reported as gem qualities (page 104 of [8]; page 15 of [37]; page 815 of [39]; page 929 of [36]). These quartz crystals are transparent to translucent rarely coated (thinly) by chlorite tinge. “Faden quartz study via fluid inclusion microthermometry (to know thermal history), X-ray computed tomography (clarity) and cathodoluminescence microscopy (differentiate between natural and artificial/synthetic gemstones; understand geological history) revealed quite stunning results with a very rich history (verbal communication with Estibalitz Ukar, University of Texas, USA during May 2022)". Quartz veins were found in sandstone and shale of Late Cretaceous Mughalkot Formation of Fort Munro Group. Tectonically Gharwandi locality is found in the eastern extremity of Murgha Kibzai imbricated thrust faults (**Figure 7** and **Figure 8**) which are refolded and again faulted. These intensely imbricated and refolded thrust faults are represented by the Cretaceous strata. Westward from imbricated faults, the folding of mostly Mesozoic with rare Cenozoic and uppermost Paleozoic strata are observed, and eastward from imbricated thrust faults, the major foldings of Cretaceous to Holocene strata were observed. The repeated thrusts and its refolding show strong tectonic intensity (in the area hosting window and faden quartz) which is responsible for fissuring and fracturing, then deposition of quartz as vugs in fissures and further breaking of quartz crystals by geodynamic and tectonic earth movements and then filling by fast cement accumulation and quick healing. Quartz formed in fissures but further opening of fissures/fractures via geodynamic and tectonic events will break the quartz, then quick healing and cementing was done by crystallizations of hydrothermal solutions or silica gel. Many geodynamic events of Indo-Pakistan subcontinent were printed from Late Cretaceous to so far. Further a few quartz (and fluorite) veins were being mined from the southwest of Mekhtar (**Figure 6**) as result of exploration for fluorite.

In Siahan-Makran Range of Balochistan basin under Panjgur and Kharan districts of Balochistan Province, the quartz veins/vugs in sedimentary strata were found in Eastern Waro (Survey of Pakistan toposheet 35M/16) and Siagari Shand area (Survey of Pakistan toposheet 31A/11) (page 929 of [36]; page 815 of [39]), and many other places quartz-carbonate veins including stibnite in the core. Eastern Waro locality was found in eastern plunge of Waro syncline and here network of thin quartz vugs/veins hosted in sandstones and shales of Oligocene Panjgur Formation. A major quartz vein (with 0.458ppm gold) was found in Siagari Shand area (southern slope of mountain; north of Sabzap) which is thick upto 2 m and long about half kilometer in Eocene Siahan shale and sandstone. Quartz crystals upto 1cm length is common. Siahan Range has enriched imbricated/repeated thrust faults which created high temperature and pressure for deposition of window and faden quartz. Gemstones and jewelry resources especially chert and jasper and others from older rocks and also from placer mollase Vihowa Group and rarely copper minerals were also reported from different areas [36].

Economic Eocene coal in Harnai-Khost-Sharig-Zard Alu belt and Duki-Anambar [40] [41] [42], Chamalang and possibly in Lunda, Surghari and Nosham areas [40] [41] [42] [43] [44] are found in Chamalang (Anokai) syncline, Lunda anticline and Bahlol syncline and Nosham thrusted anticline (**Figure 6**). The Eocene coal of Kingri (**Figure 5**) and Toi Nala (**Figure 7**) area of Musakhel district needs more study [45]. Many showings of coal are observed in the area west of Ziarat, Sor Kach Mina, Mekhtar, Shirani, etc. Many thin coal seams and carbonaceous shale are found in the Rakhi Munh, Khandor, Mahoi and Chitarwata areas. Kingri and Aram areas host large deposits (**Figure 5**) of mudy and sandy lignitic carbonaceous shale (not metallic which need miners commonly) found from the Latest Cretaceous Vitakri Formation. Many abandoned coal mines in the Rakhi Munh, Mahoi, Kingri and Aram areas are observed [40] [41] [42].

The huge gypsum deposits [46] [47] [48] [49] [50] are found in the limbs of Zinda Pir, Fort Munro and Hinglun-Rarkan (**Figure 4**), Kingri and southern Khan Muhammad Kot anticlines (**Figure 5**). A very small amount of gypsum is being used for preparation of gypsum powder (plaster of Paris) and also being used for cement preparation by D.G. Khan cement industry. There is only one cement industry in this large area and needs more installation of cement industry for the exploitation of mineral and large cement raw material resources (limestones, gypsum and shale/clays) and development of the area.

Significant fluorite deposits (50,000 tons) were reported in the Murgha Kibzai, Gadebar, Daman Ghar, Tor Thana, Wategam, Mekhtar, Balao, Mahiwal and other areas (**Figure 6**) of Loralai District, Balochistan [51] [52] [53]. The fluorite occurs as veins in the Jurassic Loralai limestones. This fluorite is found in veins and deposited by hydrothermal solutions [51] [52] [53]. Celestite small deposits and showings in the Baska and Drug formations are found in the Lal Khan village of Barkhan, eastern limb of Lakha Kach syncline and Sham localities (**Figure 4**) and other areas [52] [53] [54]. Small barite deposits were reported in the Sembar shale of Mekhtar and surrounding (blue line in **Figure 6**) areas [15] [16] [55].

Huge to large reserves of clays especially fuller's earths are observed in different formations of Chamalang, Kahan and Vihowa Groups especially on the limbs of tectonic anticlinal and synclinal structures (**Figure 4**). The clay deposits upto easily mineable depths 200 meters were estimated about 1 billion ton from eastern Sulaiman foldbelt. The clay was estimated 10 million tons upto 200 meter easily mineable depth in Zinda Pir anticline areas [56]. Low grade iron deposits (Fe_2O_3 14% - 21%) from Fort Munro and surroundings (**Figure 4**) were reported in Rakhi Gaj sandy ferruginous beds, and high grade ironstone (very small deposit) from Rakhi Gaj to Barthi areas of Dera Ghazi Khan and Taunsa districts were found in Chitarwata Formation [8] [9] [10] [15] [16]. Small deposits and showings of iron, ocher and industrial minerals and other commodities are found in different areas [57] [58]. Many strata such as green shale and green sandstone and others need exploration for agrominerals because Pakistan is an agricultural country [36] [59]. Silica sand from Chitarwata Formation was found in Zinda Pir anticline [15]. The millstone, quartzite and quartzose sandstone in Pab Formation of Rakhi Gaj, Rarkan and other areas [36] is very significant especially for steel industry. The occurrence of uranium and other radioactive minerals were found in the different localities of Dera Ghazi Khan and Taunsa districts (Saraikistan). Oligocene and Neogene fluvial strata of eastern and western limbs of Zinda Pir anticline encouraged to further explore uranium and other radioactive minerals in Neogene to Recent alluvium and placer deposits [60].

The huge construction materials are being exploited in the Sakhi Sarwar area (**Figure 4**) of Dera Ghazi Khan District. There are numerous crushing plants which are preparing different size of construction materials. These crusher plants supply the construction materials in the South Punjab and central Punjab. The construction material resources rocks are Dada conglomerate, Sakhi Sarwar Formation and alluvial terrace. Further source rocks from bed formations are Pirkoh, Habib Rahi, Drug, Dungan and Fort Munro limestones, Mughalkot marl and sandstones from Rakhi Gaj and Pab formations.

There are many anticlinal structures suitable for petroleum prospecting as shown in **Figures 3-8**. There are a few hot waters with gas springs such as Zinda Pir (**Figure 4**), Kinwa Vitakri (**Figure 4**), Garmaf (**Figure 7**), Mahiwal (**Figure 6**) and Karu (**Figure 6**) localities. The oilfield in Taunsa district (Dhodhak) and North Waziristan district are in production. The suitable resource rocks for petroleum are Wulgai shale, Loralai limestone and shale, Sembar shale, Goru shale and marl, Parh limestone, Mughalkot shale and limestone, Sangiali green shale and sandstone and brown limestone, Rakhi Gaj shale, Dungan limestone and shale, Shaheed Ghat shale, Toi shale and sandstone, Drug rubbly limestone, Habib Rahi limestone, Domanda shale, Pirkoh limestones and Darazinda shale. The suitable reservoir rocks for petroleum are Loralai limestone, Chiltan limestones, Goru marl/sandstone, Parh limestone, Mughalkot sandstone and limestone, Sangiali sandstone and limestone, Rakhi Gaj sandstone, Dungan limestone, Toi sandstone, Kingri sandstone, Drug rubbly limestone, Habib Rahi limestone and Pirkoh limestones (**Figure 2**). The eastern part of North Waziristan and South Waziristan (**Figure 3**) are represented by exposed folding of Neogene terrestrial sediments of Vihowa and Potwar group. These exposed anticline are significant for petroleum exploration and drilling because below the exposed terrestrial Neogene, the Mesozoic and Paleogene strata are mostly marine and also represent best reservoir rocks such as Pab, Dungan and Eocene limestones in the vicinity of Tank and Jandola and other eastern part of South Waziristan. Like this the eastern part of North Waziristan, the areas the exposed Neogene terrestrial deposits while subsurface below this the subsurface marine strata suitable for petroleum resource are Wulgai shale, Loralai limestone and shale, Sembar shale, Chichali shale, Kawagarh limestone, Hangu shale, Lockhart limestone, Panoba shale and Sakesar limestone (or may be called Habib Rahi and Pirkoh limestones). The best petroleum reservoir rocks are Loralai limestone, Kawagarh limestone, Hangu sandstone, Lockhart limestone and Sakesar limestone (or may be called Habib Rahi and Pirkoh limestones) are found which represents best oil resource rock and oil reservoir rocks.

There are significant surface and ground water resources. The surface water wasted as flood after rainfall so there is need to construct many smaller to medium sized dams (on many rud kohi/nalas/streams like Tochi, Domanda/Chaudhwan, Kaura, Vihowa, Sanghar, Luni, Sori Lund, Vidor, Mithwan, Sehan, Anambar, Lorali, Dhana Sar, Toi Nala, Mekhtar, etc.) for water storage which can be used for drinking and house usages and also for cultivation in the adjoining barren lands which help to overcome the shortage of wheat and other agricultural commodities.

3.4. Fossil of Miocene New Tomistominae (False Gharial), Gavialidae from Sakhi Sarwar Area, Dera Ghazi Khan, South Punjab, Pakistan

The names Gharial or Gavial, *Gharialis* or *Garialis* or *Gavialis* are primarily based on Ghara (earthen pot) in Hindi and also in Urdu and Saraiki languages mean drinking water storage earthen pot. The anterior snout with protuberance of external nare forms the shape of Ghara. The reference [61] provides some explanation for a discrepancy on names *Gavialis*, *Garialis* or *Gharialis*: "The French mode of writing this word, Gavial, appears to have originated in a misreading of the manuscript of some naturalist; the r and v being nearly similar in form. As Gharial is the correct native name, there seems no reason for perpetuating the misnomer." This difference has perpetuated in the vernacular use of the extant name with Gharial in English versus gavial in French but for some reason the Latinized genus name *Gavialis* has been retained since its first use by [62]. *The Gavialis gangeticus*-a living Gharial lives in a fresh water of India and Nepal. But a century ago its distribution was wider such as in Bangladesh, Bhutan and Pakistan where now possibly extinct and surely extinct now from Myanmar [63]. Recently a revision of genus *Gavialis* from India and Pakistan was taken by [64]. From India Gavials were known from Pliocene-Pleistocene strata like *Gavialis gangeticus* [65], *Gavialis hysudricus* [66] (revised *Gavialis gangeticus* by [64]) and *Gavialis leptodus* [67] (juvenile *Rhamphosuchus crassidens* by [64]). Gavials were known since a long from the land now Pakistan [66]. The *Gavialis lewisi* [68] was reported from the Pliocene strata of Dhok Pathan locality of Salt Range and *Gavialis browni* [69] was also reported from the Pliocene strata of Nathot locality of Salt Range, Punjab Province, Pakistan (North Indus or Upper Indus or Kohat-Potwar-Kotli basin; **Figure 1**), *Gavialis pachyrhynchus* [68] (revised cf. *Rhamphosuchus crassidens* by [64]) and *Gavialis curvirostris* [66] (revised *Rhamphosuchus crassidens* or new Tomistominae by [64]) were reported from the Miocene strata of Laki anticlinal hills, Sindh Province, Pakistan (South Indus or Lower Indus or Kirthar basin; **Figure 1**), and *Gavialis breviceps* [70] (revised *Rhamphosuchus crassidens* or new Tomistominae by [64]) from Oligocene-Miocene strata of Kumbi (Khumbi) area of possibly northern limb of Loti-Zin anticline (Figure 5 of [18]) of Dera Bugti district, Balochistan Province, Pakistan (middle Indus or Central Indus or Sulaiman basin; **Figure 1**).

Sakhibaghoon khizari is a first confirmed Miocene Tomistominae from Indo-Pakistan subcontinent while previously Miocene-Pleistocene Gavialinae gavilid were commonly reported from South Asian peninsula. Presently the Tomistominae crocodile is restricted to a single species, *Tomistoma schlegelii* (the "false Gharial"), and living in Southeast Asia [71]. However, it was once a much more diverse group with a near-global distribution [72] [73] [74]. Fossil remains referable to Tomistominae extend back to the early Eocene (Ypresian; 56 - 47.8 Ma) [72] [74] [75] [76] [77] [78]. *Sakhibaghoon khizari* seems to be derived Tomistominae longirostrine. The present discovery of *Sakhibaghoon khizari* in Miocene deposits of Pakistan expands the distribution of Tomistominae to Indo-Pakistan especially Pakistan. The present specimen of Gharial Gavialidae is also first in South Punjab which increased its distribution and also revealed connection with Taiwan, China, Thailand and also Europe (Eurasia or Laurasia) and Africa (Gondwana). Here we are describing a new fossil Gavial *Sakhibaghoon khizari* from the Miocene strata of Sakhi Sarwar area of Dera Ghazi Khan, South Punjab, Pakistan (middle Indus or Central Indus or Sulaiman basin; **Figure 1**).

Systematic paleontology of *Sakhibaghoon khizari*

Eusuchia [79]

Crocodilia [65] (sensu Clark in [80])

Gaviloidea [81]

Gavialidae [82]

Tomistominae [83]

Sakhibaghoon khizari new genus and new species

(**Figure 9** and **Figure 10**)

Holotype: PCGU-40/22 jaw fragment (**Figure 9** and **Figure 10**) housed in Department of Zoology, Ghazi University, Dera Ghazi Khan, South Punjab, Pakistan.

Type Locality, Horizon and Age: Type Locality is Pachadhin or Gharbin (Pachadhi Pahar or western ridge) at latitude 30˚04'51" North; and longitude 70˚15'44" East of Sakhi Sarwar area (**Figure 1** and **Figure 4**), Dera Ghazi Khan District, South Punjab, Pakistan. Stratigraphic horizon is terrestrial riverine fluvial sandstone with subordinate shale of Litra Formation of Vihowa Group. Its age is Miocene.

Etymology: Genus name *Sakhi* honors the host type locality Sakhi Sarwar and *baghoon* in Saraiki language meaning crocodile. Species name *Sakhibaghoon khizari*, honors the Prof. Samiullah Khizar, Ghazi University, Dera Ghazi Khan, South Punjab for his leading exploration of paleo zoological and paleontological fossil collections.

Diagnosis and Comparison: On basis of secondary plate it shows synapomorphy of crocodilian. Further the long and narrow rostrum is the synapomorphy of Gavialadae (longirostrine), while Alligatoridae have very broad rostrum and Crocodilidae has mediumly broad to deep/shallow and short rostrum. The anteroposteriorly long and narrow nasal (**Figure 9**) of *Sakhibaghoon khizari* is the synapomorphy of Tomistominae. *Sakhibaghoon khizari* differs from other Tomistominae in its possession of a unique combination of following characters:

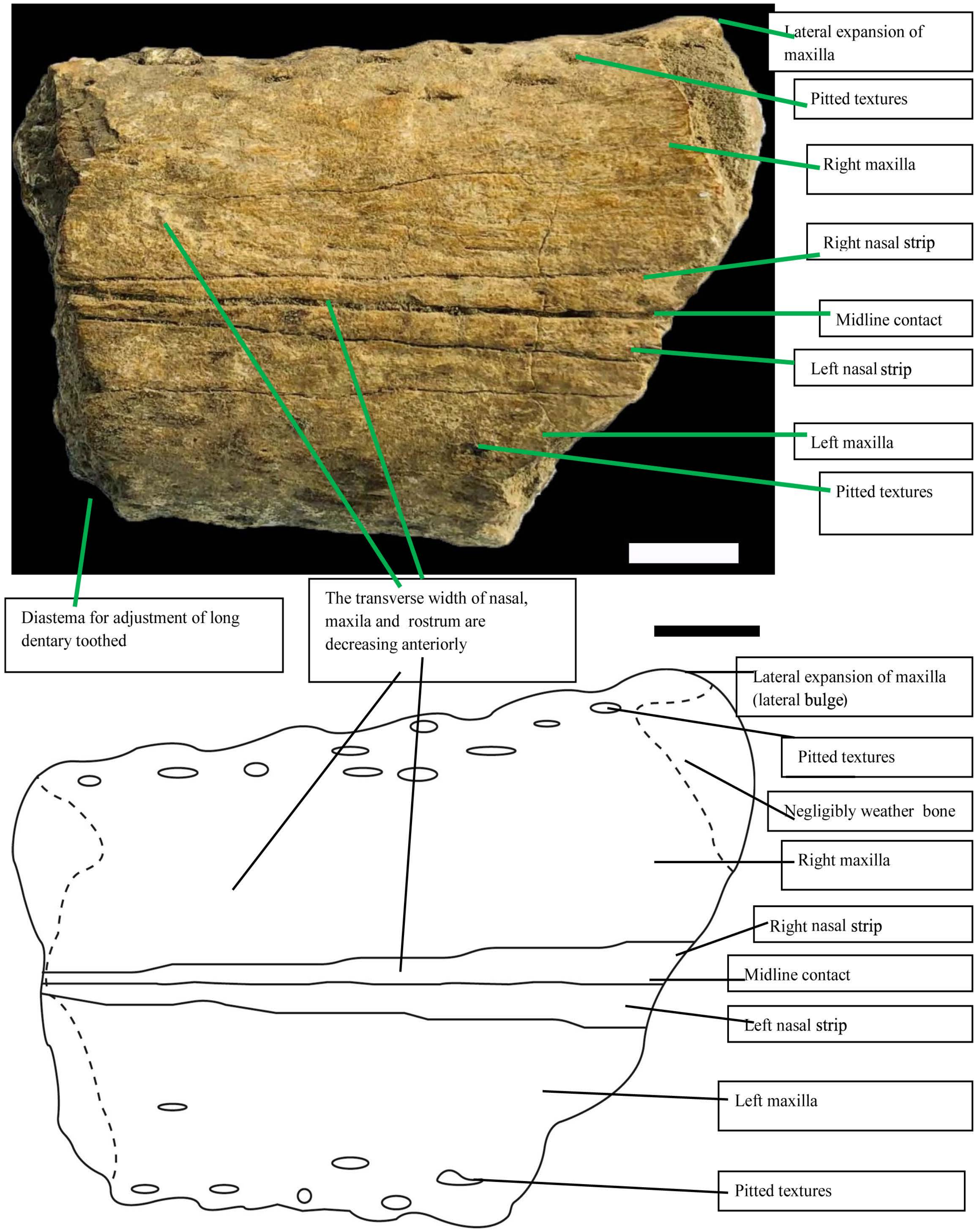

Figure 9. Middle rostrum (in dorsal view) of *Sakhibaghoon khizari* new genus and species, Tomistominae False Gharial found from the Miocene Litra Formation of Vihowa Group in Sakhi Sarwar area, Dera Ghazi Khan District, South Punjab, Pakistan. Scale bar is equal to 2 centimeter (cm).

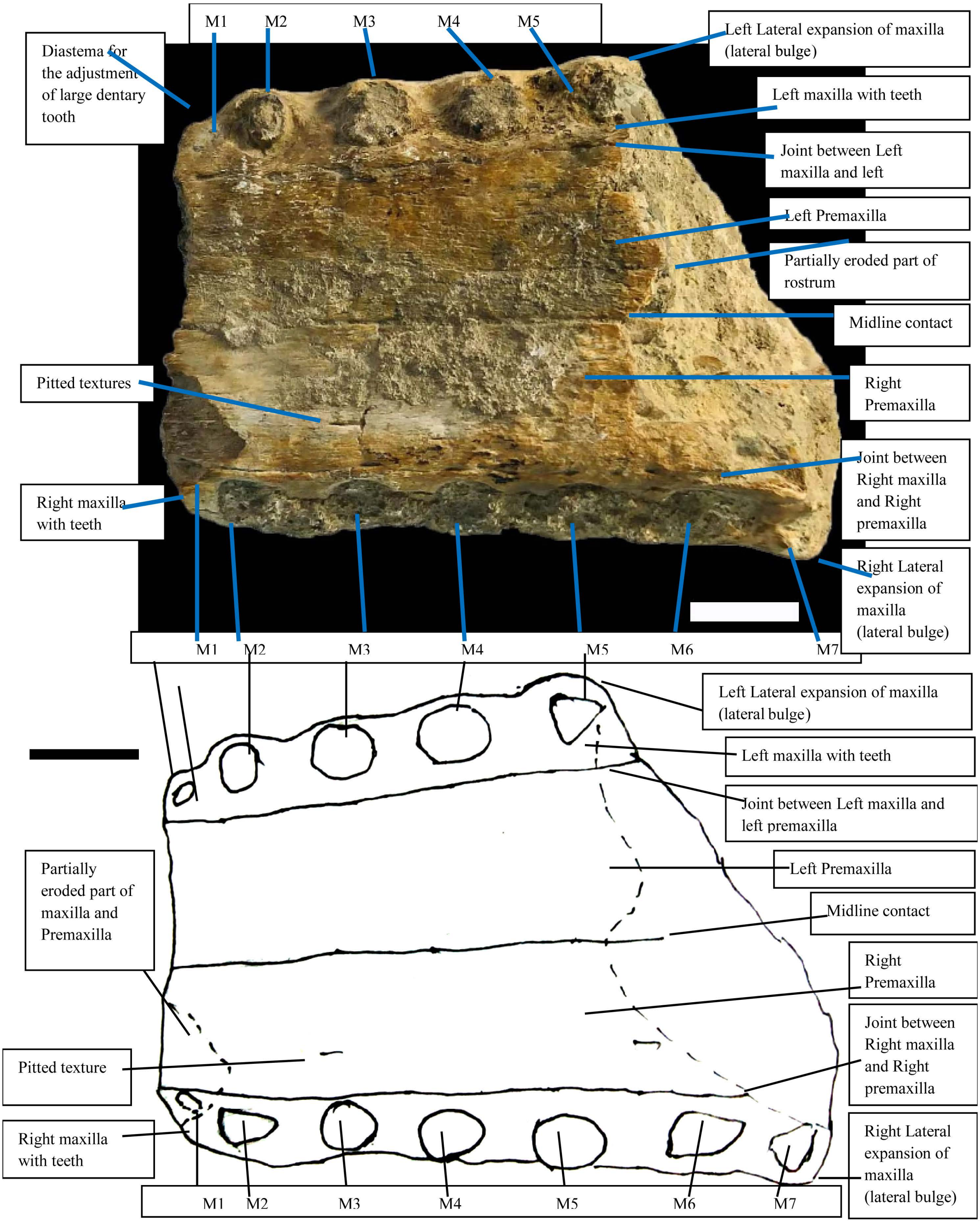

Figure 10. Middle rostrum (in ventral view) of *Sakhibaghoon khizari* new genus and species, Tomistominae False Gharial found from the Miocene Litra Formation of Vihowa Group in Sakhi Sarwar area, Dera Ghazi Khan District, South Punjab, Pakistan. Scale bar is equal to 2 centimeter (cm). Abbreviations: M1, 1st maxillary tooth; M2, 2nd maxillary tooth; M3, 3rd maxillary tooth; M4, 4th maxillary tooth; M5, 5th maxillary tooth; M6, 6th maxillary tooth; M7, 7th maxillary tooth.

1) a mediumly robust rostrum (**Figure 10**); 2) anteroposteriorly elongate posterior premaxillary processes (**Figure 10**); 3) a diastema at the junction of anterior maxilla with premaxilla (**Figure 9**) (**Figure 10**); 4) equal and wide separation of the 3rd - 6th maxillary teeth (**Figure 10**); 5) heterodont maxillary teeth including circular, subcircular, oval and triangular (**Figure 10**); (6) maxilla bearing teeth (**Figure 10**); 7) 1st maxillary tooth is relatively small and obliquely anteromedial to posterolateral elongated oriented and 2nd to 5th maxillary teeth with thick heterodont nature as 2nd transversely elongated, 3rd and 4th are rounded to subrounded and 5th maxillary tooth is triangular (**Figure 10**); 8) teeth of Miocene terrestrial fresh water riverine *Sakhibaghoon khizari* are relative thin in diameter than the teeth of Oligocene terrestrial fresh water riverine *Asifcroco retrai* which has relatively more thick teeth (almost twice in diameter); 9) teeth of *Sakhibaghoon khizari* are widely spaced (space between teeth is wide) while the teeth of *Asifcroco retrai* are close to each other and nearly contacted with each other, which represents *Asifcroco retrai* is a member of Crocodilidae Eusuchian reptile; 10) anteroposteriorly elongated nasal strip of *Sakhibaghoon khizari* in the mid jaw with its transverse width decreasing anteriorly (**Figure 9**) while this feature is not found in *Gavialis gangeticus* [65] from India and Pakistan, and *Gavialis bengawanicus* [84] from Thailand and Indonesia (Java); 11) transverse width of nasal strip of *Sakhibaghoon khizari* in the mid jaw is decreasing anteriorly (**Figure 9**) while in *Gavialosuchus eggenburgensis* [85] from Miocene of Europe this feature is increasing anteriorly; 12) transverse width of nasal strip of *Sakhibaghoon khizari* in the mid jaw is decreasing anteriorly (**Figure 9**) which is matching with *Maomingosuchus petrolica* (synonym, *Tomistoma petrolica* [86] from late Eocene of China [87], *Penghusuchus pani* [88] from Taiwan, *Toyotamaphimeia machikanensis* from Japan [89], "*Crocodilus*" *gaudensis* [90] updated as *Tomistoma gaudense* by [66] from Gozo Island of Malta [91], *Melitosaurus champsoides* [91] [92] from Gozo Island of Malta [91], *T. lyceense* ([93] [94] from Miocene of Italy [91], *T. calaritanum* [95] [96] [97] from Miocene of Italy [91], *Gavialosuchus eggenburgensis* [85] from Miocene of Austria [91], *Tomistoma lusitanica* [98] [99] from Portugal [91], and *Tomistoma dowsoni* [100] [101] from Egypt and Libya [91], *Kentisuchus astrei* a basal Tomistominae from Middle Eocene of France [74] but differentiated teeth pattern, arrangement and morphology; and (13), teeth of *Sakhibaghoon khizari* are circular to subcircular (**Figure 10**) while in *Penghusuchus pani* and *Toyotamaphimeia machikanensis* the teeth are circular.

Description of Cranial Elements: The *Sakhibaghoon khizari* fossil found as surface find (fragmentary) from the Miocene Litra Formation which consists of dominantly friable greenish grey sandstone and with minor muds or shale. The collected fossil represents the middle or central portion of rostrum/snout. This preserved rostrum represents ferruginous light brown coloration (**Figure 9** and **Figure 10**). This partial rostrum fragment includes articulated premaxillae, maxillae, teeth and nasal (**Figure 9** and **Figure 10**) which is being described as below.

Premaxilla: The middle portions of both fellows of premaxillae (**Figure 10**) are preserved which can be observed on ventral view of middle rostrum. The preserved anteroposterior length of left premaxilla in ventral view is measured 10 centimeter/cm (which is preserved medially from the level of 1st maxillary tooth to the level of 5th maxillary tooth of adjoining left maxilla). The preserved length of right premaxilla in ventral view is measured 13 cm (which is preserved medially from the level of 1st maxillary tooth to the level of 7th maxillary tooth of adjoining right maxilla). The transverse widths of left and right premaxillae are decreasing anteriorly (or increasing continuously proceeding posteriorly). The transverse width of preserved left premaxilla is slightly more than the width of right premaxilla in ventral view may be due to compression. The transverse width of left premaxilla in ventral view is measured 2.8 cm at the level of 1st maxillary tooth, 3 cm at the level of 3rd maxillary tooth, and 3.3 cm at the level of 5th maxillary tooth. The transverse width of preserved right premaxilla in ventral view is measured 2.6 cm at the level of 1st maxillary tooth, 2.8 cm at the level of 3rd maxillary tooth, 3.0 cm at the level of 5th maxillary tooth. The fellow of left and right premaxillae meets with each other via mid line contact or suture. The midline suture is slightly wavy to almost straight shown in ventral view. The midline contact has transverse width 1 mllimeter/mm and preserved length more than 8.7 cm. Premaxilla is wide and elongated strip observed just below the internal nasal cavity. Left premaxilla contacted with left maxilla via contact line or suture. Transverse width of slightly wavy suture line or contact line (between premaxilla and maxilla on both flanks) varies from 0.5 to 1 mm on ventral view. This suture contact line is medially convexed and laterally concave on teeth positions while on space it is straight or slightly convex laterally and concave medially. There are numerous anteroposteriorly fibrous lineations (parallel to subparallel) observed on the ventral view of both left and right premaxillae. Very rare pits are also observed in the premaxillae (ventral view). The dorsoventral width or depth of premaxillae seems to be thick and massive (**Figure 10**).

Maxilla: The anterior and mid portion of both the left and right maxilla (with articulated basal part of teeth) are preserved. The preserved anteroposterior length of left and right maxillae in ventral and also in dorsal view is measured 9.7 cm and 13 cm respectively. The transverse width of preserved left maxilla is 1.0 cm at the level of 1st maxillary tooth, 1.65 cm at the level of 2nd, 3rd and 4th maxillary tooth and 1.8 cm at the level of 5th maxillary tooth. The left maxilla is reduced at the level of 1st maxillary tooth showing a diastema (at the anterior contact of maxilla with premaxilla just posterior/back to external nare tuberosity or Ghara) (**Figure 9** and **Figure 10**). The left maxilla thickness increases (forms step) between 1st and 2nd maxillary teeth and maintains same thickness from 2nd maxillary tooth to 4th maxillary tooth (**Figure 10**), and further increases and forms step at the level of 5th maxillary tooth (**Figure 10**). The lateral or outer profile of left maxilla shows wavy profile which convexing laterally on teeth positions while convexing medially on spaces between teeth.

The transverse width of preserved right maxilla is 1.0 cm at the level of 1st maxillary tooth, 1.25 cm at the level of 2nd, 3rd, 4th, 5th and 6th maxillary tooth and 1.6 cm at the level of 7th maxillary tooth. Right maxilla is preserved between the level of 1st maxillary tooth and level of 7th maxillary tooth. The anteroposterior length of preserved right maxilla is 13 cm which is measured between the level of 1st maxillary tooth and level of 7th maxillary tooth. Ventrally left and right maxillae are separated with each other by both fellows of left and right premaxillae and midline contact or suture. Dorsally left and right maxillae are separated by left and right nasal strips and midline contact or suture. Further some marginal part of lateral portion of maxilla destroyed (at level of 2nd maxillary tooth to 7th maxillary tooth). There are numerous anteroposteriorly fibrous lineations (parallel to subparallel) observed on the dorsal view of both left and right maxillae. The dorsoventral width or depth of maxillae seems to be thick and massive (**Figure 9**). *Sakhibaghoon khizari* has rare pits on maxilla while *Tomistoma calariranum* has dominant pits.

Nasal: Although incomplete, the nasal is anteroposteriorly elongate given that they extend anteriorly from the level of 5th maxillary tooth to the level of 1st maxillary tooth. The nasal is characterised by a gradual mediolateral narrowing towards the preserved anterior end of the snout (**Figure 9**). It means the transverse width of left and also right nasal strip decreases continuously toward anteriorly or alternately its transverse width increase posteriorly. The left and right nasal strips are contacted with each other by a midline contact or mid line suture. The transverse width of this midline suture varies 1 mm to 1.25 mm. The preserved length of left nasal strip in dorsal view is 10.8 cm and preserved length of right nasal strip in dorsal view is 11 cm. The preserved width of left nasal strip at anterior portion (in dorsal view) is 2 mm and the preserved width of right nasal at preserved anterior portion (in dorsal view) is 3 mm. The preserved width of left nasal at preserved at mid portion (in dorsal view) is 4 mm and the preserved width of right nasal at preserved at mid portion (in dorsal view) is 4 mm. The preserved width of left nasal at preserved posterior portion (in dorsal view) is 7 mm and the preserved width of right nasal at anterior portion (in dorsal view) is 7 mm. The preserved length of mid line contact or suture is 11 cm. The midline contact or suture line is almost straight and negligibly wavy. The left nasal strip also contacted with left maxilla and right nasal strip also contacted with right maxilla by a contact or suture line of about 0.5 mm thick which is mostly straight with negligibly wide wavy. Nasal is rarely pitted and also thin fibrous lineation trending anteroposterior are observed. Left and right nasal strips are sandwiched between the left and right maxilla observed on dorsal view (**Figure 9**).

The nasal of *Sakhibaghoon khizari* is anteroposteriorly long, while this feature is not found in *Gavialis gangeticus* [65], *Gavialis hysudricus* [66], *Gavialis leptodus* and *Gavialis sp* from India [64] and *Gavialis browni* from Nathot Salt Range, Pakistan [69], *Gavialis bengawanicus* [84] from Thailand and Indonesia (Java). There are no overlap bones in *Sakhibaghoon khizari* and *Gavialis pa-*

chyrhynchus [66] from Laki Sadar anticline, Sindh, Pakistan. The data is not available regarding *Gavialis pachyrhynchus* [66] from Laki Sadar anticline, Sindh, Pakistan. The transverse width of long nasal of *Sakhibaghoon khizari* is gradually decreasing anteriorly (toward external protuberance of external nare).

Anteroposteriorly elongated nasal strip of *Sakhibaghoon khizari* in the mid jaw with its transverse width decreasing anteriorly while this feature is not found in *Gavialis gangeticus* [65] from India and Pakistan, and *Gavialis bengawanicus* [84] from Thailand and Indonesia (Java). Transverse width of nasal strip of *Sakhibaghoon khizari* in the mid jaw is decreasing anteriorly while in *Gavialosuchus eggenburgensis* [85] from Miocene of Europe this feature is increasing anteriorly. Transverse width of nasal strip of *Sakhibaghoon khizari* in the mid jaw is decreasing anteriorly which is matching with *Maomingosuchus petrolica* (synonym, *Tomistoma petrolica* [86]) from late Eocene of China [87], *Penghusuchus pani* [88] from Taiwan, *Toyotamaphimeia machikanensis* from Japan [89], "*Crocodilus*" *gaudensis* [90] updated as *Tomistoma gaudense* by [66] from Gozo Island of Malta [91], *Melitosaurus champsoides* from Gozo Island of Malta [91] [92], *T. lyceense* [93] [94] from Miocene of Italy, *T. calaritanum* [95] [96] [97] from Miocene of Italy, *Gavialosuchus eggenburgensis* from Miocene of Austria [85], *Tomistoma lusitanica* from Portugal [98] [99], and *Tomistoma dowsoni* from Egypt and Libya [100] [101], *Kentisuchus astrei* a basal Tomistominae from Middle Eocene of France [74] but differentiated teeth pattern, arrangement and morphology. *Sakhibaghoon khizari* has nasal which is decreasing in transverse width toward anteriorly like *Tomistoma calariranum* but pits are dominant in *Tomistoma calariranum* and rare in *Sakhibaghoon khizari.*

Dentition: Teeth are heterodont in size and shape. Cross sectional shapes of maxillary teeth at the preserved base are circular, subcircular, oval and triangular (**Figure 10**). Teeth are widely spaced. The space between maxillary 1st and 2nd teeth is 0.5 cm and space between 6th and 7th maxillary teeth is also 0.5 cm, while all other preserved teeth have about 1 cm spacing in between. The anteroposterior length and transverse width of 1st maxillary tooth of left maxilla is 0.6 cm and 0.3 cm, 2nd maxillary tooth is 0.7 cm and 0.8 cm, 3rd maxillary tooth is 1.1 cm and 1.1 cm, 4th maxillary tooth is 1.1 cm and 1.1 cm, and 5th maxillary tooth is 0.8 cm and 1.0 cm respectively. The lateral expansion of left maxilla at the level of 5th maxillary tooth is like the *Penghusuchus pani* from Taiwan, this expansion may increase upto 7th maxillary tooth. The anteroposterior length and transverse width of 1st maxillary tooth of right maxilla is 0.6 cm and 0.3 cm, 2nd maxillary tooth is 1.0 cm and 0.8 cm, 3rd maxillary tooth is 1.1 cm and 1.0 cm, 4th maxillary tooth is 1.1 cm and 1.1 cm, 5th maxillary tooth is 1.1 cm and 1.0 cm, 6th maxillary tooth is 1.3 cm and 1.0 cm, and 7th maxillary tooth is 0.9 cm and 0.7 cm respectively. The 7th maxillary tooth has expanded maxilla laterally/outside like the *Penghusuchus pani* from Taiwan, however, this lateral expansion is destroyed 5th and 6th maxillary teeth of right maxilla. The bases of teeth are well preserved on left maxilla while base of teeth on right maxilla are poorly preserved. The 1st

maxillary tooth is interpreted on the basis of occurring of diastema at the anterior contact of maxilla (with premaxilla). A few oval teeth (others are circular and subcircular, asymmetric D-shape) in *Sakhibaghoon khizari* matches with oval teeth of *Gavialis gangeticus.* Teeth of *Sakhibaghoon khizari* are heterodont like circular to subcircular, oval and triangular while in *Penghusuchus pani* and *Toyotamaphimeia machikanensis* the teeth are only circular (homodont). Teeth of *Sakhibaghoon khizari* are widely spaced (space between teeth is wide) while the teeth of *Asifcroco retrai* are close to each other and nearly contacted with each other which represents *Asifcroco retrai* is a member of Crocodilidae Eusuchian reptile. The teeth of Miocene terrestrial fresh water riverine *Sakhibaghoon khizari* are relative thin in diameter than the teeth of Oligocene terrestrial fresh water riverine *Asifcroco retrai* which has relatively more thick teeth (almost twice in diameter), which again represents that *Asifcroco retrai* is a large sized member of Crocodilidae Eusuchian reptile.

Recently reported vertebrates from Sulaiman foldbelt (Balochistan and South Punjab), Pakistan

Recently, (since 2000) the famous vertebrates were reported from the Mesozoic and Cenozoic strata of Sulaiman basin (middle Indus basin). In South Asian countries, the dinosaurs are only known from India and Pakistan. From India the dinosaurs are known since a long about close to 2 century [102] [103]. From Pakistan the dinosaurs are known since 2000 [104]. The latest Cretaceous Vitakri Formation (riverine alluvial) [24] [26] [105] of Fort Munro Group is exposed mostly in the Vitakri and its vicinity areas (**Figure 4**) which host the sauropods, theropods, mesoeucrocodiles, pterosaur, snake and bird [105]. The small, medium and large sized herbivorous titanosaurian sauropods were reported from Pakistan. The bone fossils of poripuchian titanosaurs (Sauropoda) comprised of *Gspsaurus pakistani* [105] [106] [107] [108], *Maojandino alami* [109], *Saraikimasoom vitakri* [105] [110] and *Nicksaurus razashahi* [109] of Gspsauridae, *Balochisaurus malkani* [109] and *Marisaurus jeffi* [109] of Balochisauridae and *Pakisaurus balochistani* [26] [105], *Anokhadino mirliaquati* [103], *Sulaimanisaurus gingerichi* [105] and *Khetranisaurus barkhani* [105] of Pakisauridae. The abelisaurian theropods comprised of *Vitakridrinda sulaimani* [105] [111] and *Vitakrisaurus saraiki* [105] [111] of Vitakrisauridae. The mesoeucrocodiles comprised of *Induszalim bala* [105] [111] and *Pabwehshi pakistanensis* [112] of Induszalimidae, *Mithasaraikistan ikniazi* [105] of Mithasaraikistanidae and *Sulaimanisuchus kinwai* [105] of Sulaimanisuchidae. The pterosaur-the flying reptiles represented by *Saraikisaurus minhui* [105] [111] of Saraikisauridae, paleobird represented by *Wasaibpanchi damani* [105] [109] of Wasaibpanchidae, and large paleosnake represented by *Wadanaang kohsulaimani* [105] of Madtsoiidae. A late Cretaceous fish *Kahamachli harrandlundi* was also reported from Dhaola Member of Pab Sandstone of Mat Khund area (**Figure 4**) of Kaha Maarri. Further the Maastrichtian Sor Member (**Figure 8**) of Pab sandstone of Sur Muzghai Musafarpur yielded ichnotaxa (**Figure 8**) based on tracks/trackways are *Pashtosau-*

roperus zhobi [109] [113] [114] of Ornithopaonia [109] (titanosaurian sauropod or ornithischian dinosaurs) and *Anmolpakhiperus alleni* [109] [114] of Pteropaonia [109] pterosaur, and Maarri area yielded ichnotaxon *Dgkhansauroperus maarri* [109] [114] [115] of Sauropaonia [109] titanosaurian sauropod. Besides these, the ichnotaxa reported from Kohat-Potwar-Kotli basin (North Indus/upper Indus basin) are *Malakhelisauroperus mianwali* [109] [114] [116] [117] Ornithopaonia [109] (titanosaurian sauropod or ornithischian dinosaurs), *Samanadrindoperus surghari* [109] [116] [117] Theropaonia [109] large sized theropod, and *Himalayadrinda potwari* [109] [116] [117] Theropaonia [109] small sized theropods, and from Kirthar basin (south Indus/lower Indus basin) are *Chiltansauroperus nicki* [109] Sauropaonia [109] sauropod. Before August 2021, these vertebrates were informal and unofficial by the rules of the ICZN, but all they formalized by the rules of the ICZN in August 2021 [105] and September 2021 [109].

The Cenozoic strata of the Sulaiman basin (middle Indus/Central Indus) yielded many vertebrates for a long time. But recently the Eocene strata yielded walking whales *Artiocetus clavis* [118], *Rodhocetus balochistanensis* [118] from the Kunvit Rakhni area (**Figure 4**) and swimming whale *Sulaimanitherium dhanotri* [109] [113] [114] [119] from Zamri Drug area (**Figure 7**) and horses/cyonid *Bolanicyon shahani* [109] [114], the Oligocene Chitarwata Formation yielded largest land rhinoceros *Buzdartherium gulkirao* [109] [114], and large eucrocodile *Asifcroco retrai* [109] [114] Crocodilidae from Gulki area (**Figure 7**), and the Miocene Litra sandstone yielded the large proboscidean *Gomphotherium buzdari* [109] [114] from Mahoi area (**Figure 7**). The Tertiary vertebrate (alluvial riverine) *Pakitherium shagalai* with her baby [109] [114] [119] was first time reported from Shagala area (**Figure 8**) of Balochistan Basin because previously it was considered marine flysh deposits. Besides vertebrates, the Mesozoic and Cenozoic strata yielded many invertebrates. Recently reported invertebrates [109] are arthropods *Nisaukankoil beakeri* [109] and *Phailawaghkankoil derabugti* [109] from Early Paleocene Rakhi Gaj sandstone and nautiloid *Pakiwheel vitakri* [109] from Early Paleocene Sangiali green shale and sandstone. Previously the reference [120] and others reported much mammalian fauna from the Sulaiman basin. The Cretaceous fauna of the Indo-Pakistan subcontinet show biogeugraphic link with Gondwana lands [102] [105] [109] [121].

4. Conclusion

The Northern Sulaiman Foldbelt, Shirani, North and South Waziristan (South Punjab/Saraikistan, Balochistan and Khyber Pakhtunkhwa) represents Permo-Triassic to Recent rocks, alternated anticlines and synclines with active faultings, cement resources, excellent water resources, construction stones, low-quality iron and muddy coal and possibly phosphate, and many other significant minerals like gemstone quality quartz crystals like the window and faden quartz crystals deposited by high-temperature hypothermal process. The area has large raw materials for cement resources. The area has large surface and groundwater. The new Tomistominae Gavialidae (False Gharial) *Sakhibaghoon khizari* fossil was found in the Miocene Litra Formation of Vihowa Group of Sakhi Sarwar area. This new Tomistominae is the first from the Indo-Pakistan subcontinent, especially from Pakistan. This specimen of Gavialidae is the first in South Punjab (Saraikistan) of Pakistan which increased distribution and also revealed a connection with Asia, Eurasia and Laurasia.

5. Recommendations

The Northern Sulaiman Foldbelt, Shirani, North and South Waziristan (South Punjab/Saraikistan, Balochistan and Khyber Pakhtunkhwa) has large raw material for cement resources which also needs to install many cement industries because now only one cement industry (D. G. Khan cement industry) is operations. The northern Sulaiman basin needs the installation of cement Industry because of its vast resources, its central location in Pakistan, etc. The construction of smaller and medium-sized dams on different rud kohi/nalas/streams/rivers is vital for the sustainable development of the area. The geological and paleontological exploration may reveal better results.

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Conflicts of Interest

Authors declare no conflicts of interest regarding the publication of this paper.

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