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PETROLOGY OF THE BIBAI VOLCANICS, NE BALUCHISTAN

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ABSTRACT

Throughout northeastern Baluchistan, the upper part of the Cretaceous Parh Formation contains evidence of volcanic activity in this region. Near Kach, northeast of Quetta a thick succession of Late Cretaceous volcanic rocks, referred to as Bibai volcanics may be seen. It is mainly composed of basaltic lavas at the base, followed by a thick succession of agglomerates, tuffs and volcanic ash that are interbedded with sand stone and conglomerates. The volcanics are interpreted to represent an island arc formed in the Zagros – Chitral convergence zone developed as a consequence of the northward drift of the Indian plate.

INTRODUCTION

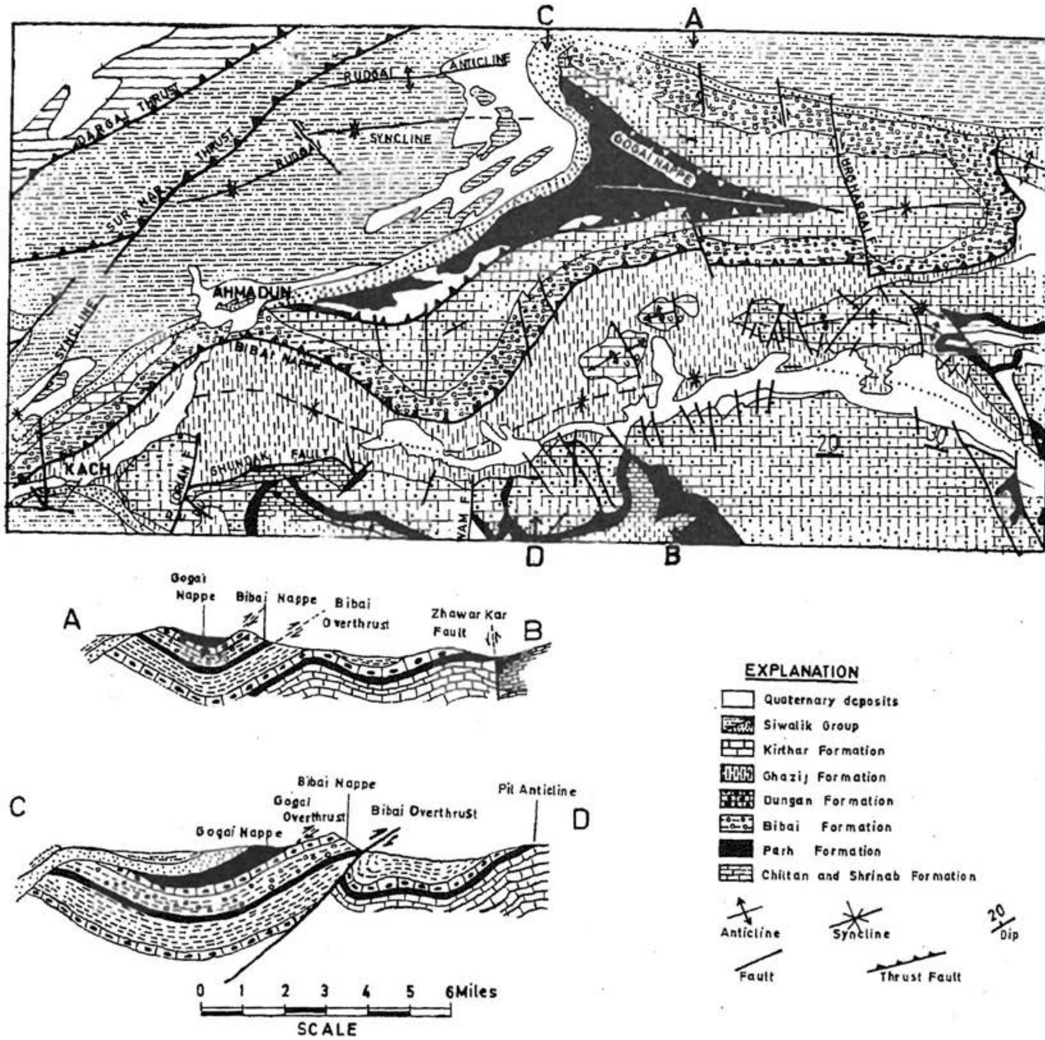
Stratigraphy and Structure

In northeastern Baluchistan the upper part of the Parh Formation (Cretaceous) shows evidence of widespread volcanic activity. The limestones in this formation contain volcanic ash, extensive laterite beds, some of which still retain tell-tale signs of having been altered from lava flows, and a widespread regional unconformity near the top. In the Kach area, about 45km NE of Quetta, a thick succession of volcanic ash, tuffs, agglomerates and basaltic lavas is seen. These rocks, earlier referred to as the Bibai Formation (Kazmi, 1955, 1979), overlie the Parh Formation and are overlain by the Dungan Formation (Fig. 1). In this paper the petrography of the Bibai volcanics and their bearing on the regional environment and tectonics is briefly discussed.

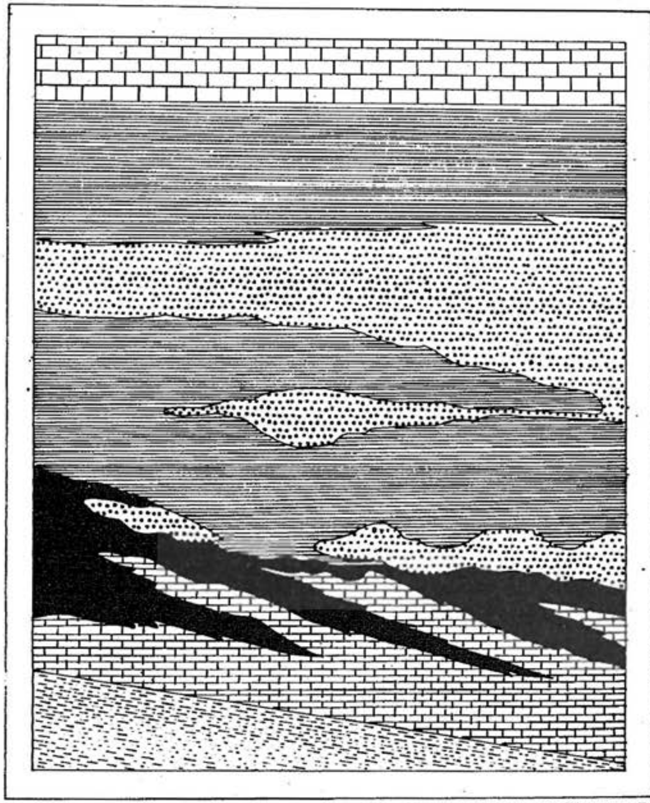
The following rock formations are exposed in the Kach area.

	— Unconformity —	
Siwalik Group		Mid. Miocene to Pliocene
Kirthar Formation		Mid. Eocene
Ghazij Formation		Early Eocene
Dungan Formation		Maestrichtian to Palaeocene
	— Unconformity —	
Bibai Formation		Campanian to Maestrichtian
Parh Formation		Barremian to Campanian
Sembar Formation		Neocomian
	— Unconformity —	
Chiltan Limestone		Mid. Jurassic

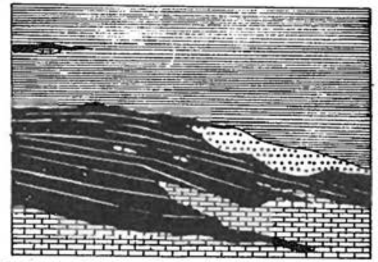
Fig. 1. Geological map of Kach area showing outcrop of Bibai volcanics. Geological cross-sections along lines A–B & C–D are given below.



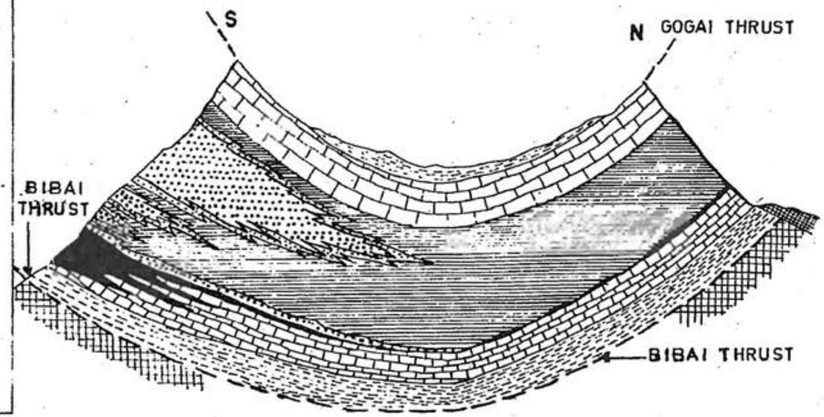
The Bibai Formation is comprised of two distinct lithostratigraphic zones; a lower zone which consists entirely of agglomerates, tuffs and lava flows and an upper zone which comprises ash beds, tuffs, sandstones, mudstones and conglomerates (Fig. 2). The lower zone is irregular and of variable thickness. It is best developed east of Ahmadun and wedges out westwards. It comprises of discontinuous wedges, lenses and patches of agglomerates and lava flows lying on the eroded surface of Parh limestone. Interbedded with the lavas are thin, isolated wedges of Parh limestone (Fig. 2). These lenses of Parh contain *Globotruncana lapparenti* and *G. linnei* indicating a Campanian age for the lavas. The upper part of the Bibai volcanics contains, amongst others, *Omphalocyclus macropora, Obitoides*



SECTION ALONG THE STRIKE SHOWING THE LITHOLOGY AND STRUCTURE OF THE BIBAI FORMATION



SECTION(ALONG THE STRIKE) NEAR SHNA WAR SHOWING THE RELATION BETWEEN THE LAVA FLOWS AND PARH LIMESTONE



DIAGRAMMATIC SECTION ACROSS THE SARU GHAR – MAZHU GHAR RANGES, SHOWING THE STRUCTURE AND LITHOLGGY OF THE BIBAI FORMATION

EXPLANATION

- SIWALIK GROUP
- GHAZIJ FORMATION
- DUNGAN LIMESTON

- Finegrained Sandstone and Siltstone
- Tuffs, Ash bed and Mudstone
- Boulder conglomerates
- Pillow Lavas, Agglomerates

} BIBAI FORMATION

- Porcellainous Limestone
- Mudstone and Marls.

} PARH LIMESTONE

Fig. 2. DIAGRAMMATIC SECTIONS SHOWING STRUCTURE AND LITHOLOGY OF THE BIBAI FORMATION

sp., and *Baculites binodosus* which suggest a Maestrichtian age. The Bibai volcanics may be, therefore, correlated with the Moghal Kot Formation (Williams, 1959) and Fort Monroe Formation (Shah, 1978).

Structurally the Kach area forms part of the alochthonous zone which is traversed by a number of thrust faults, including the Gogai and Bibai nappes (Kazmi, 1979). In this region outcrops of Bibai Formation form a thrust sheet (Bibai nappe) which overlies the Ghazij and at places the Dungan Formation (Figs. 1 and 2).

PETROGRAPHY

The Lava Flows

The lavas consist of several flows of basalts. They are fine-grained, dark greenish-grey to black in colour, amygdaloidal or porphyritic and commonly exhibit flow structure. In texture they vary from perlitic, trachytic to hyalophitic or hyalopilitic. The primary minerals are iron oxides, olivine, augite, titaniferous augite, aegirine augite, enstatite and labradorite. The secondary constituents occur mainly as vesicular infillings or alteration products and comprise celadonite, chlorophaeite, palagonite, lussatite, chalcedony, calcite, zeolite, serpentine and iddingsite. A brief description of some of these is given below.

Iron Oxide. Iron oxide in the form of minute magnetite and ilmenite grains is abundant in all the lava flows. Thin sections of specimens from the chilled margins of the flows, however, rarely show any iron oxide which probably has not crystallized out from the dense brownish black glass or has been masked by it. Ilmenite is rarer than magnetite and has been more commonly noted in flows rich in plagioclase and poor in pyroxene content. This may be due to the entry of titanium in titaniferous augite in pyroxene-rich rocks, whereas in the plagioclase-rich varieties the titanium has been accommodated in ilmenite.

Magnetite is more abundant than ilmenite. It occurs as minute euhedra, anhedra or as irregularly shapped granules disseminated in the groundmass. Inclusions of magnetite occur in the plagioclase and pyroxene. Magnetite crystals also cut across or corrode the pyroxene crystals.

Olivine. Only a few lava flows contain olivine. It occurs as corroded phenocrysts pointing to reaction with melt. The olivine also shows secondary alteration. Where alteration has gone to an extreme, only skeletons of the original crystals are seen. Serpentine psuedomorphs after olivine are common. Iddingsite psuedomorphs also occur but are relatively rare. Iddingsite is seen as skeletal crystals of a deep orange to rich reddish-brown tint, strongly pleochroic, with a well marked cleavage and lamellar structure.

Augite. Augite is the most common pyroxene in these basalts. It occurs both as large euhedral to subhedral phenocrysts and also as minute microlites or globulites in the groundmass. It frequently shows poikilitic texture, containing inclusions of iron ore.

Titaniferous augite. Some lava flows are entirely composed of dark minerals with little or no plagioclase within the groundmass. Such rocks contain abundant titaniferous augite which forms large euhedral phenocrysts, with rectangular, eight sided or polygonal outline, brownish in colour, strongly pleochroic and frequently twinned. These crystals have high extinction angles (350° – 45°), moderate birefringence and contain inclusions of magnetite.

Aegirine augite. Zoning is quite common in these augites and in some sections hour-glass zoning may be seen. Some phenocrysts contain an inner zone of aegirine or aegirine-augite, green in colour, pleochroic, with extinction from almost parallel to 35°. The outer zone consists of enstatite or augite but rarely of titaniferous augite.

Enstatite. In some of the lava flows enstatite is the more common pyroxene and occurs as fine colourless euhedral phenocrysts. Almost all the enstatite crystals examined are found to have been altered to antigorite along cleavages and joints.

Plagioclase. It occurs as phenocrysts upto 1cm in size and also as minute laths and microlites in the groundmass. Albite twinning is common and carlsbad and pericline twins are rare. Measurements on the albite lamellae give extinction angles upto 35° in the phenocrysts, corresponding to a labradorite composition of about An_{59}.

The large crystals are not homogeneous in their internal structure. They contain irregular isotropic to subisotropic patches, formed by palagonite which is highly fibrous and transparent, with refractive index lower than labradorite. Often a phenocryst may be full of this substance and there is little or no trace of twinning. The smaller crystals are often in the form of mere skeletons.

Secondary minerals. The minerals of later origin are all alteration products derived in part from the original constituents and occur as amoebiform masses in the groundmass or as linings and infillings to the vesicles and geodes. They include green, brown and colourless varieties of glass (celadonite, chlorophaeite and palagonite), lussatite, chalcedony, calcite and zeolites.

Secondary material in thin sections is colourless, pale coloured or brightly coloured, and forms small irregular grains, spherulites, amoebiform patches or thin bands lining the vesicles. It is derived from the primary glass, pyroxene, plagioclase or iron oxide due to devitrification or hydration and replacement. In general the secondary product after glass in the Bibai basalts may be referred to as palagonite; its yellow-brown variety has been considered as a distinct mineral-chlorophaeite (Fermor, 1925). In thin sections chlorophaeite is seen as irregular grains of rich orange-yellow colour dispersed in the groundmass, as brownish yellow to yellowish brown concentric layers lining the vesicles, or as radiate spherulites, with an outer dark brownish layer, an intermediate yellowish brown radiate zone and a central isotropic zone (which is often absent).

The green mineral lining and infilling the vesicles in the Bibai basalts is probably celadonite rather than delessite, because it does not show the straw colour characteristic of delessite (Fermor, 1925). It is pleochroic from light to dark green and occurs in the groundmass as large irregular patches with concentric fibrous layers completely filling or lining the vesicles. Celadonite and chlorophaeite also occur as psuedomorphs after pyroxenes with an outer rim of dark brown palagonite, an intermediate zone of orange – yellow chlorophaeite and inner dark green sub-isotropic zone of celadonite.

Lussatite in the Bibai basalts is in light brown to colourless fibers partially or completely filling the cavities. Analcime is found in basalts relatively free from chlorophaeite and celadonite (Fig. 3). Chalcedony and calcite are the other secondary constituents found in the Bibai basalts and occur mainly as vesicular infillings.

Tuffs and Associated Rocks

Overlying the lavas and agglomerates of the lower zone of the Bibai volcanics, there is a great thickness of boulder conglomerates, interbedded with ash beds and tuffs. The ash varies in colour from violet to greenish grey to light grey. It is fine-grained (siltstone size), but some beds are coarser grained with grains upto 1mm and grade into coarse tuff. Occasionally these beds contain small lapilli, 5mm in size.

Tuffs. The tuffs, in the upper part of this zone gradually become mixed with varying amounts of non-volcanic terrigenous material and develop current bedding. The tuffs in the lower part of the zone are dark greenish-grey to blackish-grey, closely laminated, hard, and compact. The "agrillaceous tuffs", on the other hand, are soft and powdery and have been weathered into mud, silt or fine, loose sand. Near Ahmadun and eastward, the tuffs are interbedded with thick lenses of boulder conglomerates. Westward of Ahmadun, the conglomerates gradually disappear and instead, at the same horizon, there are relatively more persistent beds of coarse gritty sandstones interbedded with argillaceous tuffs or soft mudstone containing ash. The sandstones contain large rounded grains of quartz, chalcedony and calcite, abundant ash, fossil debris and foraminifera, together with rare grains of pyroxene, hornblende and iron oxide (Fig. 3).

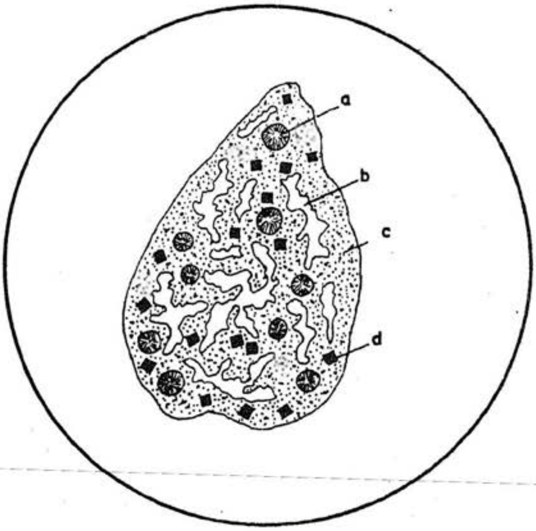
Conglomerates. The conglomerates attain a maximum thickness of about 350 meter near the Wam Pass. When traced laterally they have been reduced to thin irregular lenses, which are in fact the remnants of burried, infilled channels (Fig. 2). The conglomerates contain large rounded pebbles and boulders ranging from 3 to 40cm in size. The degree of roundness attained by these conglomerates is light to dark grey graywacke type, consisting of fine to coarse, angular to subangular fragments of ash, pyroxene, calcite and chalcedony, set in a cryptocrystalline base of calcite or glass. The latter constitutes upto 75 per cent of the matrix. In some instances, the groundmass of the matrix is entirely glassy, in others entirely calcitic, but commonly mixed, calcitic and glassy.

Under the microscope the ash particles in the matrix are seen as rounded, brown minute specs of iron oxide. These are set in a base of brown palagonite, irregular transparent patches, or spherulites of devitrified clear glass (colourless palagonite) within the brownish palagonite (Fig. 3). The pyroxenes are largely in

BIBAI BASALT SHOWING PHENOCRYSTS OF LABRADORITE AND VESICLE LINED WITH ANALCIME AND INFILLED WITH CALCITE (X 20)

BIBAI BASALT SHOWING A LARGE VESICLE LINED WITH RADIATE SPHERULITES OF CHLOROPHAEITE AND INFILLED WITH CLEAR PALAGONITE (BLACK). THE SMALLER VESICLE IS INFILLED WITH LUSSATITE. (UNDER CROSS NICOLS, X 20)

BIBAI MUDSTONE WITH CLASTIC DEBRIS (QUARTZ, CHALCEDONY, PYROXENES, HORNBLENDE, IRON OXIDE) FOSSIL DEBRIS AND ABUNDANT ASH.(X 10)



AN ASH GRAIN FROM MATRIX OF VOLCANIC CONGLOMERATE. (a) SPHERULITE OF PALAGONITE (b) CLEAR PALAGONITE; (c) BROWN PALAGONITE WITH SPECKS OF IRON; (d) IRON ORE. (X 100)

Fig. 3. BIBAI VOLCANICS AS SEEN IN THIN SECTION.

the form of anhedral to subhedral grains or broken corroded laths of augite. There are dense rounded grains of chalcedony with irregular or poorly defined edges.

With the exception of rare pebbles of Parh limestone, all the pebbles and boulders in these conglomerates are those of tuffs, agglomerates, basalts or andesites. The presence of andesite boulders is interesting, because andesite has not been noted to occur in association with the basalts of the lower zone of this series. The andesite boulders probably represent higher flows of the lower zone which were eroded away. These boulders are rich brown in colour with large lath-shaped phenocrysts of plagioclase ranging from An_{28} to An_{50} in composition. There are also small subhedral crystals of pigeonite. The groundmass is in the form of a fine network of plagioclase, iron ore and glass. The rock is often amygdaloidal, with the vesicles filled with calcite, chalcedony or analcime. It shows ophitic or pilotaxitic texture and common flow structure.

DISCUSSION

The Bibai rocks indicate significant volcanic activity in the northeastern Baluchistan towards the close of the Cretaceous (Campanian to Maestrichtian). Initially during Campanian the volcanic activity was submarine (pillow structure, interfingering with marine Parh limestone), followed by a subaerial phase (volcanic ash containing lapilli etc.) during the Maestrichtian. Similar events appear to have taken place in southern Baluchistan (Bela area) during the late Cretaceous and there is considerable analogy between the Bibai volcanics and the Porali volcanics of the Bela area (Allemann, 1979; HSC, 1960).

The great thickness and exceptional roundness of the Bibai volcanic conglomerates suggest presence of a large volcanic island. This is yet another evidence for the presence of one or more island arcs which came into existence during late Cretaceous along the margins of the northward drifting components of the dismembered Gondwanaland (Takin, 1972; Gansser, 1974; DeJong and Subhani, 1979). By the Maestrichtian most of the older part of the Tethys lying between Gondwanaland and Eurasia had been consumed and its remnants now contained chipped off fragments of Gondwanaland (microcontinents) and one or more island arcs separated by marginal seas (Stocklin, 1974; Powell, 1979). This remnant of the Tethys has also been referred to as the Zagros – Chitral convergence zone by Powell. By the late Maestrichtian the northward drifting components of Gondwanaland (Arabia and India) had collided with this zone resulting in the obduction of ophiolitic masses (Oman, Bela, Zhob, etc.) and formation of wide zones of extensive thrust slices such as those seen near Kach.

The northward tapering structure of the Bibai volcanics near Kach indicates that the Bibai nappe was initially located on the northern slopes of the volcanic island chain. South of Kach there is no sign or trace of any ancient source of volcanic activity. On the contrary the area south of Kach comprises the autochthonous zone. It is therefore inferred that the Bibai nappe has undergone considerable southward tectonic transport, probably of the order of several tens of kilometers.

The Zhob valley obducted masses of ophiolites emplaced during the late Paleocene (Allemann, 1979), lie only at a short distance northeast of the Bibai nappe. The Bibai nappe and the Zhob ophiolites are both located in the same wide belt of imbricate structure (referred to as Balla Dhor – Zhob – Kurram ophiolite belt and scuppen zone by Kazmi (1982) that runs through north-eastern Baluchistan. It may be therefore inferred that this nappe may have formed at the same time or slightly before the emplacement of the Zhob ophiolites. It is likely that the Zhob ophiolites may have initially constituted the "foundation" of the Bibai island arc and part of the adjacent oceanic crust.

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