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Nilawahan Rift, a Permian event in Salt Range, Pakistan

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ABSTRACT: *New data on a volcanic glass beds interbedded with Warcha Sandstone of Nilawahan Group in Eastern Salt Range is presented. Major, trace and rare earth element data on these volcanic rocks clearly points towards highly alkaline nature of the volcanicity. Nilawahan group of Salt Range and associated alkaline volcanic rocks suggest that these rocks were deposited/extruded in a rift system which was developed during the permian rifting of Gondwanaland. This rift is proposed to be designated as NILAWAHAN RIFT. Nilawahan Rift was a low volcanicity failed rift (aulcogene) of the Gondwana Rift belt with a nearly NS orientation in a Gondwanic configuration. The northern parts of the rift recorded marine transgression as evidenced by permian limestone and interbedded basaltic sills and dykes in Khyber Agency. In Salt Range rift related deposits are dominated by fluvial to glacio-fluvial sediments.*

INTRODUCTION

The well-known Precambrian evaporite deposits of the Salt Range attest to a continental palaeogeography of the region. Palaeozoic era in the area, however, witnessed marine transgression and the development of epicontinental seas as represented by sandstones and dolomites of its Cambrian stratigraphy. Ordovican, Silurian, Devonian and Carboniferous are stratigraphically not represented in the Salt Range. During these periods marine rocks were deposited in the northern regions of Pakistan such as Khyber Agency, Hazara, Chitral and Nowshera. An extended period of non-deposition prevailed from upper Cambrian to Permian in Salt Range. During the Permian the area started to receive glacio-fluviatile detritus starting from Tobra Formation of Nilawahan Group. Towards the upper part of Lower Permian (Sardhai Formation) marine limestones and shales deposition in the sedimentary sequences mark once again the development of shallow epicontinental seas.

A thin bed of glassy rocks interbedded within Nilawahan Group discussed herein interpreted to represent volcanicity during the development of rift structures which resulted in the fragmentation of Gondwanaland. Nilawahan rift was essentially parallel to the NE edge of Gondwanaland whose Northern parts extended into an ocean represented by permian basic volcanics interbedded with permian limestones in Khyber Agency (Shah, 1977). The southern end of the rift now represented by the fluviatile deposits of Nilawahan Group in the Salt Range attest to a failing of rifting which could not penetrate further south towards the interior of the Gondwanaland. Coarse detritus including pebbles and boulders of pink granites in Tobra Formation attest to the existence of an uplifted part of the Indian craton in the south. A late

Palaeozoic to early Mesozoic extrusion of highly under-saturated alkaline glass in the Salt Range correlates favourably with alkaline magmatism in North Pakistan and Kashmir, and on a global scale with the rifting of Gondwanaland.

STRATIGRAPHY

A generalized geological map of the Salt Range depicting the distribution of upper Palaeozoic rocks is shown in Figure 1. These rocks are the subject of discussion in this paper. A brief summery of the Precambrian/Palaeozoic stratigraphy of the Salt Range is reproduced below from Shah (1977).

Salt Range Formation

The Salt Range Formation is divided into three members. Billianwala Salt Member is the lowest member of the Salt Range Formation. Ferrugenous red marl, with thick seams of salt upto 650 meters or more in thickness, constitutes this member.

The middle member designated as Bhandar Kas Gypsum Member consists of massive gypsum beds with dolomite and clays. This member is about 80 meter or more in thickness.

The Upper Sahwal Marl Member (3 to 100 m thick) consists of bright red marl beds with irregular gypsum, dolomite beds, and Khewra Trap. The lower part of this member is represented by dull red marl with salt seams and upto 10 meters thick gypsum beds. It may be up to 40 meters or more in thickness.

The formation represented evaporite sedimentation in an enclosed basin under highly arid conditions.

Jhelum Group

The Salt Range Formation is stratigraphically overlain by the Jhelum Group which is further subdivided in to the following formations: Khisor Formation, Baghanwala Formation, Jhelum Formation, Kussak Formation and Khewra Sandstone.

Lithological variation in these formation once again suggests the continuation of arid conditions in the region as dolomite and gypsum repeatedly appear in the succession. Thick sandstone and shale deposits of this formation, however, suggest basin subsidence causing the formation of shallow epicontinental seas.

Nilawahan Group

A long period of non-deposition prevailed in the area before the deposition of sediments of the Nilawahan Group. This group includes the following formations: Sardhai Formation, Warchha Sandstone, Dandot Formation and Tobra Formation.

The base of the Nilawahan Group includes glacial to glaciofluvial Tobra Formation followed by fluvial sedimentation in Dandot and Warchha formations. The overlying Sardhai Formation records the marine conditions, especially in Khisor Range.

Volcanism in Warchha Sandstone

Butt et al. (1994) described a glass bed in Warchha Sandstone of Nilawahan Group in eastern Salt Range. It occurs as 10-30 cm thick concordant bed of vitric tuff/flow near Pidh, Watli and Saloi villages shown in Figure 1, (NGR 455080 to 458085 on toposheet No. 43 D/4, 338143 and 202409 on toposheet No. 43 H/2). The observed strike length of this bed is estimated to be about 4 km. The samples used in this study were collected from the vicinity of Saloi and Watli.

Petrography and major element geochemistry of the volcanic glass led Butt et al. (1994) to interpret these volcanics as syn-sedimentary and possibly related to a Permian rifting event. This paper presents further data on major trace and rare earth elements to define the tectonic environments of the volcanic rock.

A summary of petrography of these rocks is reproduced herein from Butt et al. (1994). These

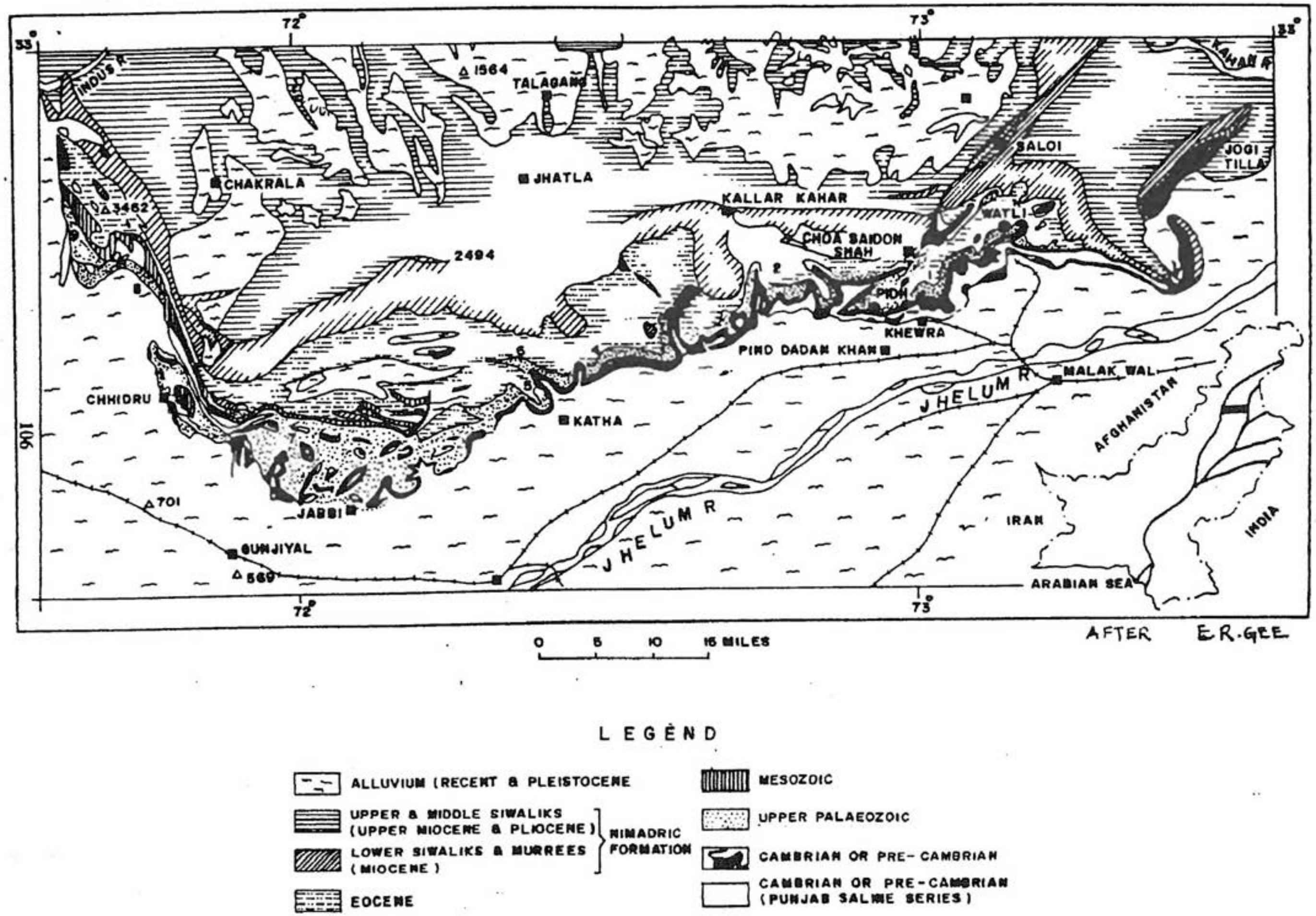

Fig. 1. Geological map of the Punjab Salt Range.

consist of an unaltered palagonitic brown glass. A weak fluoidal texture is accentuated by the presence of microscopically unidentifiable lath shaped microlites. The glass shows no evidence of either spherulitic or perlitic devitrification. Neither is there any texture to suggest gaseous saturation to form bubbles and their subsequent collapse to produce shard-like textures so characteristic of ash flow tuffs and pyroclastics. Small areas of recrystallized calcite has, however, been interpreted to be devitrified carbonated glass (Butt et al., 1994). Other minerals include xenocrysts of detrital quartz, feldspar, biotite, muscovite, chlorite and opaque iron oxide and their alteration products. Some evidence of early crystallization of magnetite and its subsequent alteration products was also observed.

Butt et al. (1994), on the basis of petrography and major element geochemistry argued about the alkaline nature of these volcanic rocks. They suggested that the rocks were carbonatitic to nephelinitic glassy flows. Further geochemical data on major, trace and rare earth elements was produced during this study. Data on four selected samples from these glasses interbedded with Warchha Sandstones in eastern Salt Range is presented in Table 1.

The chemical composition of these vitric lava flows shows that they are low in SiO_2, Al_2O_3 and alkalies and very high in CaO. The average CaO content is 22wt.%. It is interesting to note that this CaO is in glass as there are no other minerals in the rock to account for it. Since these rocks consist of 75-80% glass and only 20-25% xenocrystic minerals, their chemical composition can be taken to represent the composition of the magma/lava. A comparison with published data suggests that these glasses range in composition from nephelinitic to melilitic to extrusive calcio-carbonatites (Butt et al., 1994).

On the basis of REE data presented in Figure 2, these glassy rocks fall into two distinct groups. One group shows a lower enrichment in light rare earth elements and a tendency for only a slight depletion in heavy rare earth elements. The other group shows a strong enrichment in LREE and an equally strong depletion trend in HREE (Fig. 2). The first group also shows higher SiO_2, Al_2O_3, Fe_2O_3, MgO and alkalies whereas it is lower in CaO and CO_2 content. Rare earth elemental values obtained for both the types, however, suggest a mantle related origin of these lavas. REE pattern of the first group are comparable to the calculated patterns for carbonatites which would be in equilibrium with nephelinitic magmas (Twyman & Gittins, 1987). The second group shows REE pattern identical to those calculated for nephelinitic to phonolitic magmas (Twyman & Gittins, 1987).

Spider diagram involving trace elements is shown in Figure 3. A feature common to all these rocks is a strong negative strontium anomaly. These patterns are broadly identical to melanephelinites from Tertiary carbonatitic complexes in East Africa and olivine nephelinite of the Kenya Rift Valley (LeBas, 1987). A feature common to all nephelinites is their enrichment in K, Th, Nb and LREE which points towards their mantle origin (LeBas, 1987). Data for volcanic glasses in the eastern Salt Range presented in Figures 2 and 3, therefore, suggest a mantle origin for these lavas.

DISCUSSION AND CONCLUSION

Carbonatite genesis

The discovery of a carbonatitic glassy flow has some important bearing on carbonatite genesis. Two petrogenetic schemes are being debated in the literature about the development of carbonatites. According to one of the schemes alkali carbonatite magma of the type erupted as lavas in Tanzanian Oldoinyo Lengai volcano is

TABLE 1. CHEMICAL ANALYSES OF GLASSY ROCK FROM EASTERN SALT RANGE

Sample No.	601	602	603	604		601	602	603	604
SiO_2	39.78	30.60	44.76	45.01	Ho	4.3	2.3	1.8	0.73
TiO_2	0.33	0.35	0.43	0.51	In	0.11	0.06	0.21	0.17
Al_2O_3	6.54	5.88	9.33	9.74	Lu	0.21	0.28	0.24	0.24
Fe_2O_3	4.76	5.13	8.87	9.31	Mo	1.2	0.8	1.1	2.10
FeO	0.20	0.56	0.79	0.87	Nd	170	55	176	119
MnO	0.20	0.41	0.31	0.27	Rb	31	—	—	39.6
MgO	0.63	0.55	4.13	4.76	Sb	1.9	1.5	1.4	1.2
CaO	25.34	26.70	18.22	17.02	Sc	0.69	7.3	4.7	8.15
Na_2O	1.88	2.02	2.43	2.02	Se	0.92	0.56	2.7	0.31
K_2O	1.35	1.02	1.72	1.06	Sn	4.1	4.6	5.5	6.5
P_2O_5	0.56	0.62	0.81	0.83	Ta	3.2	5.9	5.3	1.8
CO_2	16.12	19.83	5.55	4.37	Tb	3.14	1.5	3.4	2.62
H_2O	2.76	6.05	2.66	4.43	Th	3.6	10.6	43.2	32.4
Total	100.45	99.78	100.01	100.02	Yb	1.5	2.6	3.4	3.6
					Zn	51	115	128	96
Ba	553	270	247	210	Zr	320	364	433	536
Ce	137	79	492	428	La	9.9	23.6	281.2	155.4
Co	3.4	6.9	12.5	42.3	Gd	11.1	4.4	8.7	3.6
Cr	65	90	59	66	Sr	152	220	310	39
Cs	1.3	2.9	2.8	2.2	Ag	0.2	0.21	0.4	0.85
Eu	0.5	1.4	5.5	1.9	Sm	3.9	9.2	23.1	63.7
Ga	17.4	10.9	15.7	15.2	Er	2.3	3.2	0.95	4.4
Hf	3.3	5.0	4.7	6.60					

considered to be the parental liquid produced by immiscible separation from a nephelinitic magma (LeBas, 1981; Woolley, 1982). During cooling the alkalic carbonatite magma loses alkalies and gives rise to calcite-dolomite carbonatites. The other scheme envisages immiscible separation of a mildly alkalic olivine sovite magma from olivine nephelinite magma. The former undergoes fractional crystallization to produce carbonatites through separation of alkali poor anhydrous minerals (Twyman & Gittin, 1987).

Petrographic and field evidence presented herein suggests that the glassy rocks of the Salt Range were relatively anhydrous and that the eruption was rather quiescent. A complete lack

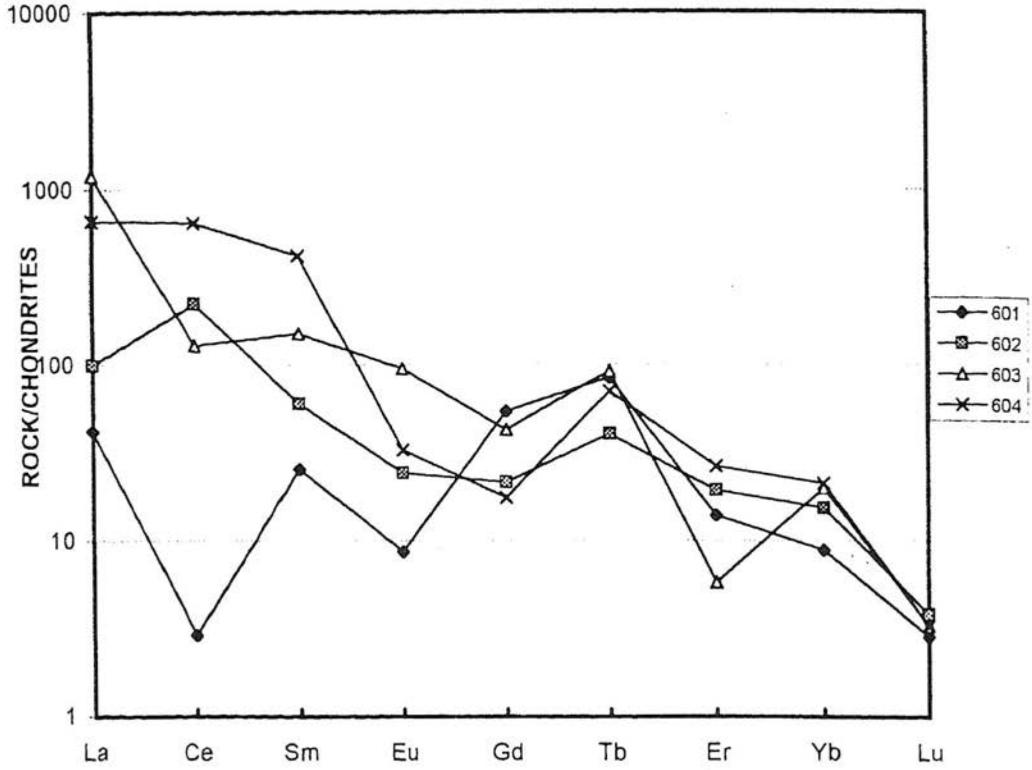

Fig. 2. Chonderite normalized REE distribution for glassy rocks of the Salt Range.

of bubbles in the glass and a general absence of pyroclastic material associated with these beds are a clear manifestation of the above. Similarly, the sandstones underlying the glassy beds also show no evidence of metasomatism. Nephelinitic lavas from carbonatitic provinces generally do not contain CO_2 (LeBas, 1987). This may be due to their residence in the lower crustal magma reservoir and a rather complete immiscible separation of carbonatite magmas. If the tectonic conditions during the ascent from mantle of carbonated parent magma do not allow a residence in the lower crust, a rather dry, low alkali parent magma can erupt as carbonatitic-nephelinite. The glassy rocks of the Salt Range are considered to be such a magma which did not get sufficient time to separate into two immiscible silicate and carbonate fractions. If this interpretation of glassy rocks to represent carbonated nephelinitic magmas tapped directly from the mantle is accepted, it provides some constraints on the possible petrogenetic schemes for the generation of carbonatites.

Since the parental carbonated nephelinitic magma appears to be rather dry, it appears unlikely that the carbonate fraction separated from such a magma will be enriched in alkalies and votalites to the extent envisaged in the petrogenetic scheme of LeBas (1981) and Woolley (1982).

Alternative petrogenetic scheme proposed by Twyman and Gittins (1987) envisages a rather dry, midly alkalic olivine sovite magma to sepa-

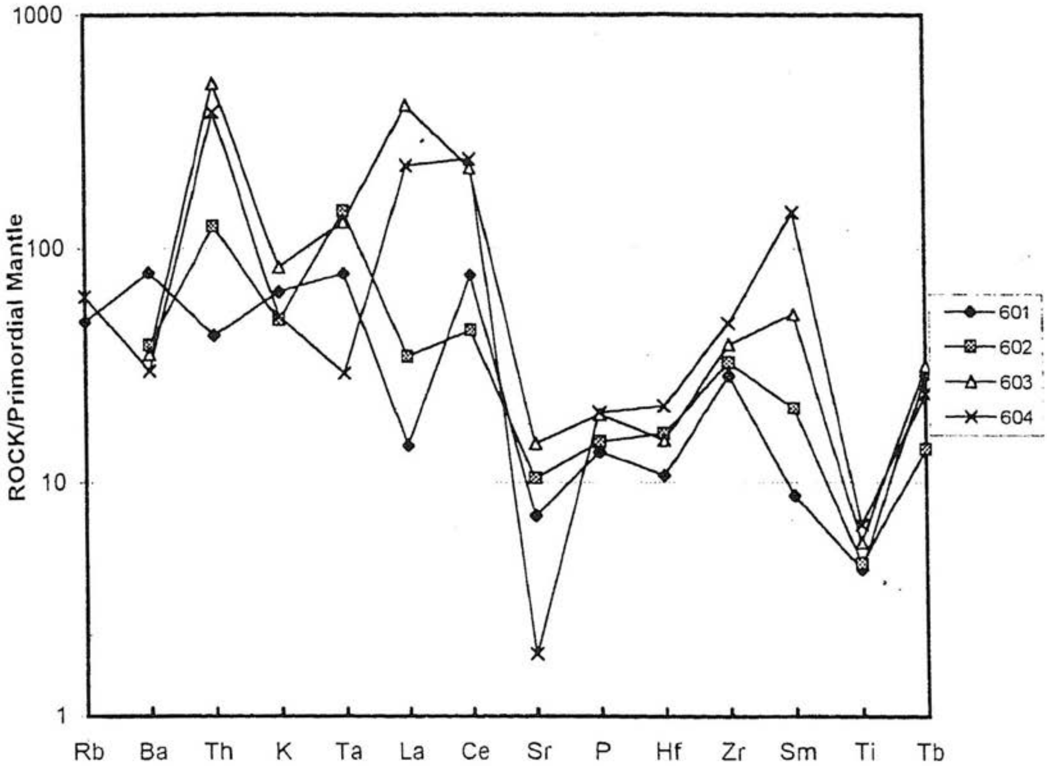

Fig. 3. Primordial mantle-normalized trace element abundances of glassy rocks of the Salt Range.

rate from parental carbonated nephelinite magma. If one considers the glassy rock of the Salt Range to be such a magma, a carbonate fraction separated from such a magma through immiscibility will closely approximate in its alkali content to a mildly alkaline olivine sovite liquid. Highly carbonated glasses from the Salt Range contain 3% total alkalies. An immiscible separation of carbonate rich liquid from nephelinite magma has been calculated by Twyman and Gittins (1987) to contain anywhere from 8 to 18% total alkalies. Since the Salt Range glass is interpreted to be a carbonated nephelinite magma, its immiscible separation is likely to yield a mildly alkaline olivine sovite magma rather than a highly alkaline carbonate magma of the type erupted at Oldoinyo Lengai volcano in Tanzania.

TECTONIC IMPLICATIONS

Butt et al. (1984) and this study have presented a limited amount of geological and geochemical data suggesting that the glasses within the fluviatile sandstones of Warchha Formation represent alkaline lavas originated in the mantle. Deep mentle sources appear to have been tapped during the Permian times in the Salt Range area. The other igneous material in the area are "Khewrite" dykes and sills (Faruqi, 1986) which have also been interpreted to have formed by crystallization from an alkaline (ultrapotassic) magma related to mantle processes (Jan & Faruqi 1995). Geochemical data suggest the lavas under discussion to be of nephelinitic to nephelinite-carbonatite in composition. Glasses containing as much a 30 wt.% P_2O_5 have also been collected from this area (Zafar Pers. Commun.). Tectonic environments which are likely to host such igneous activity are major rift systems. A lower Permian age of these lavas and possibly also of Khewrite compares favourable with the time of rifting of Gondwanaland.

By this time the Arravali Range had already risen into a high mountain chain geographically south of the area now represented by the Salt Range. Considering the thickness of Nilawahan Group, it appears appropriate to suggest that a major rift was developed towards the close of the Carboniferous time. This rift is proposed to be designated as "NILAWAHAN RIFT". The distal parts of the rift (now represented by eastern Salt Range) received detritus from elevated Aravalli Range of the Indian Craton. Palaeotopography of the Permian times, which caused a northwest transport of material eroded from the Arravali Ranges, appears to have been influenced not only by the high altitude of Arravali Range but also due to the formation of a wide graben which constituted a broad basin wherein the glaciofluviatile to fluviatile sediments of the Nilawahan Group were deposited. Permian marine sediments hosting basic volcanics and dyke material in Khyber Agency (Shah, 1977) attest to the fact that the northern parts of Nilawahan rift developed marine conditions. This may have provided a route for marine transgression towards the interior of the Indian continent which deposited post Permian carbonates in the Salt Range.

In the absence of further evidence of marine volcanics in Salt Range area, it is interpreted that the Nilawahan rift failed leading to the break-up of India from Gondwanaland.

Suba Raju et al. (1978) interpreted that younger rift zones inherited the previous rift structures of the Indian craton or adjusted to them by producing en echelon faults and formation of new grabens within the original graben. Since alkaline plutonic rocks have also been reported from the axial belt and north Pakistan, it is possible that a reactivated cratonic rift structure may have been responsible for their emplacement. It may, therefore, be conjectured that Precambrian rift system of cratonic India (Naqvi & Rogers, 1987) may well have extended within the basement upto the Salt Range, the axial belt and N. Pakistan. This would also indicate the possibility that the alkaline rocks in north Pakistan, the axial belt and the proposed "NILAWAHAN RIFT" may owe its origin to an extension of the same Precambrian rift system. Continuous tectonic activity during Permian rifting is also evidenced by a cyclic nature of fluviatile sediments of Nilawahan Rift. The base of each cycle is represented by a conglomerate suggesting a tectonic rejuvination.

Alternatively, Khewra traps may represent an older volcanic event. These rocks have recently been interpreted as ultrapotassic rocks (Jan & Faruqi, 1995). Earlier works have considered it to be a volcanic rock erupted in shallow lacustrin environment (Martin, 1956), whereas Faruqi (1986) described these to be intrusive dykes and sills. Jan and Faruqi (1995), however argued that its discordant relationship may be due to salt tectonics. If a volcanic nature of these rocks is accepted and if their occurrence below Cambrian strata is valid, the possibility of a Cambrian volcanic event related to initiation of rifting during that time and its continuation up to Permian can not be totally ruled out.

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