CHAPTER VII

MINERALOGY AND GEOCHEMICAL ANALYSIS

GENERAL

In the last chapter detailed petrography has been discussed, dealing with microfacies studies of different clastic and carbonate sediments. In the present chapter, detailed investigations pertaining to X-ray diffractometry, heavy mineralogy, major, and minor oxides and trace element analysis have been carried out which in turn help in depicting the provenance, climatic conditions and in identifying the different sedimentary cycles during the time of deposition, as well as different diagenetic events of Jurassic sediments.

X-RAY MINERALOGY

The samples for both clastic and carbonate sediments were processed as per conventional techniques according to Caroll, D.(1970). The processed samples were examined on Philips X-ray diffractometer model PW-1710, with Nickel filtered Copper radiation using an electrically controlled linear recorder with an accelerating potential of 40KV and current of 30 MA, CPS 5000 and times constant one second. The detailed X-ray analysis method has been discussed in chapter III.

About 35 representative samples of different lithotypes were analysed for X-ray mineralogy and results were presented in Table VII .1. Only representative x-ray diffractograms of various lithotypes of each

TABLE : VII.1 MINERALS DISTRIBUTION IN BULK SAMPLES ANALYSED BY X-RAY DIFFRACTOMETRY IN JURASSIC SEDIMENTS, JAISALMER BASIN, WESTERN RAJASTHAN

FORMATION	MEMBER	SAMPLE No	MINERALS DISTRIBUTION: Quartz	Calcite	Dolomite	Feldspar	Kaolinite	Illite	Montmorillonite	Gypsum	Goethite	Hematite	GROSS MICRO FACIES	CHARACTERISTIC FEATURE
BHADASAR	MOKAL	MBR-1	x x x	x x								x	Quartz arenite	
		MBR-3	x x x	x x								x	-do-	
	KOLAR	MBR-5	x x x	x x	x		TR					TR	Quartz wacke	
		MBR-5A	x x x	x	x		TR					TR	Quartz arenite	
	DUNGAR	MBR-8	x x	x x	x x x							x	Oolitic Quartz wacke	
BAISAKHI	RUPSI	BR-13	x x	x x x	x		TR						Bioclastic	
		BR-15	x x x	x x			TR						Quartz wacke	
	LUDHARWA	BRL-3	x x	x x	TR		TR						Quartz wacke	
		BRL-5	x x x				x	TR					Quartz wacke	
	BAISAKHI	BB-7	x x	x x x	TR		x	TR					Bioclastic claystone	
		BB-8	x x x	x x			x	TR				TR	Ferr.. quartz wacke	

FORM ATION	MEMBER	SAMPLE No	QUARTZ	Calc-lite	Dolo-mite	Feld-spar	Kao-linite	Ill-ite	Chlo rite	Mont-mori-llonite	Gyp-sum	Goe-thite	Hema tite	MICRO FACIES	GROSS CHARACTER-ISTIC FEAT-URE
JAISALMER	KULDHAR	BJ-1	x	x x	x								x	Wackestone	
		BJ-2	x	x x x										-do-	
		BJ-10	x	x x x	TR									Bio wackestone stone	
		K-4	TR	x x x	TR								x	Oolitic Pack-stone	
	BADABAG	BJ-8	x x x	x	x		x				x			Quartz arenite	
		BJ-7	x x	x x x	x		x	x						Algal wacke-stone	
	FORT	F-2	x x x			x			TR					Quartz arenite	
		F-7	x	x x x										Bioclastic wackestone	
		TJ-5	x x	x x										Cal. quartz wacke	
	JOYAN	TH-20	x x	x x										Pelletal quartz wacke	
		TH-14	x x	x x										Quartz wacke	
	HAMIRA	TH-2	x x	x x	TR									Quartz wacke	Presence of zoned dolomite crystals
		TH-5	x x x	x x	x x									Quartz wacke	
		TH-6	x x	x x x			TR	P						-do-	

FORM	MEMBER	SAMPLE	MINERALS DISTRIBUTION											GROSS MICRO FACIES	CHARACT-ERISTIC FEATURE
			Quartz	Calc-ite	Dolo-mite	Feld-spar	Kao-linite	Ill-ite	Chlo-rite	Mont-mori-llonite	Gyp-sum	Goe-thite	Hema tite		
LATHI	THAIYAT	TL-2	x x x	x	TR		TR		TR					Quartz wacke	
		TL-4	x x x											-do-	
		WL-3	x x x											Siltstone	
		WL-4	x x x			x	TR							Siltstone	
	ODANIA	AL-3	x x				TR							Quartz wacke	
		AL-8	x x x	x			TR						P	Quartz Wacke	
		AL-7	x x	x			x x							Quartz Wacke	
		L-3	x x x	x x			x x	TR				P		Quartz wacke	
		L-12	x x x	x x			x	TR						Quartz Wacke	

INDEX :

X X X ABUNDANT — TR TRACE

X X FAIR — P PRESENT

x COMMON

member has been given (Fig. VII.1 to VII.3). The mineralogical details of various lithotypes of each formation are discussed in the proceeding paragraphs.

LATHI FORMATION

Clay mineral analysis carried out as 2 micron clay fraction separated from sandstone samples of this formation reveals presence of mainly kaolinite (90-95%)and illite (5-10%)in Thaiyat Member. The bulk sample analysis of sandstone run upto 60° reveals presence of minor amount of calcite and dolomite apart from quartz, kaolinite, illite and traces of chlorite (Fig VII.1). Presence of calcite and dolomite within the sandstone reveals that there was some influx of saline water during deposition of the sandstone.

Exogenetic modification to quartz arenite and subarkose under more acidic conditions are often similar and spectacular. Variation generally only occurs where abundant rock fragments were deposited or where the detrital sediments were finer grained.

Quartz overgrowth, porefilling kaolinite, altered muscovite and dissolved feldspar grains are clearly seen from quartz arenites of Lathi Formation. Both the quartz and kaolinite might have precipitated directly from ground water. Additional silica and alumina released during dissolution of feldspar grains might have contributed to these authigenic phase (Curtis & Spears 1968; Berner & Holden, 1979). Similar observation has been noted in samples of Lathi Formation where the sands become reddish in colour by plants and as a result leached by acid, causing removal of feldspars and detrital micas while kaolinite precipitates in underlying muds. The dissolution of feldspar grains,

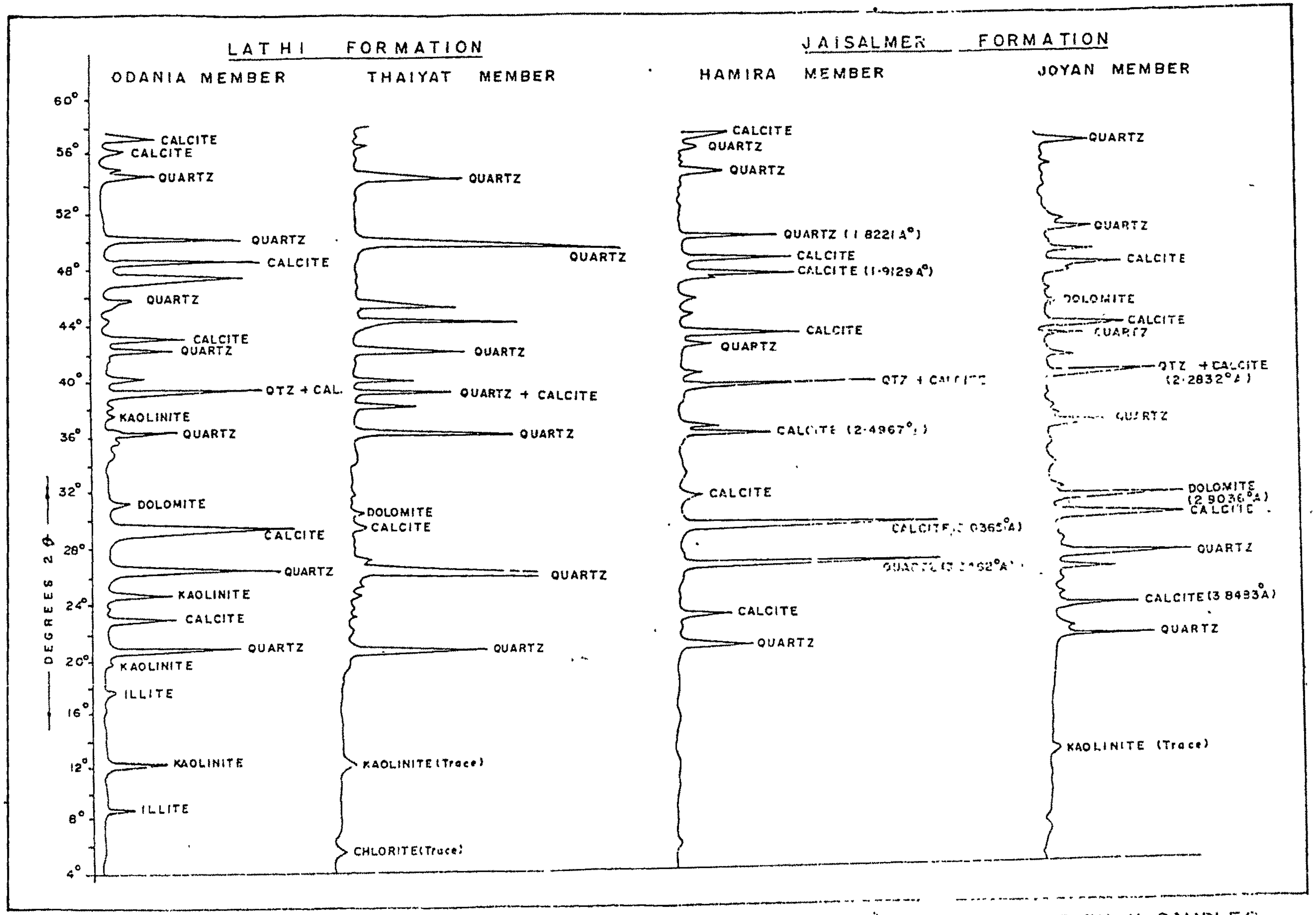


FIG.VII-1. REPRESENTATIVE X-RAY POWDER DIFFRACTION PATTERNS OF < 2μ FRACTION OF BULK SAMPLES OF CLASTIC SECTION OF LATHI AND JAISALMER FORMATIONS [illegible] JAISALMER BASIN, WESTERN RAJASTHAN.

as well as alteration of muscovite may be explained by their relative instability in acidic condition (Fanning & Keramides 1977, Huang 1977, Lin & Clemency 1981). Similarly silica relatively insoluble at low pH with the result is readily precipitated. (Blatt, 1966)

JAISALMER FORMATION

X-ray analysis of representative samples of Jaisalmer Formation covering their respective members were carried out. The insoluble residue of the carbonate section comprises mainly quartz and kaolinite (Table VII.2). The powder pack analysis (4-60°) of samples reveals presence of calcite and quartz as the main constituents in the carbonate rock of Jaisalmer Formation (Fig. VII.3). Minor proportion of dolomite has also been observed in a few samples of Hamira and Joyan members, (Fig. VII 2). This indicates the fresh water influx after the deposition of the sediments. The analysis of the sandstone samples of Fort and Badabg members indicate the presence of quartz being the common constituent with minor proportion of plagioclase (Fig. VII.2). From the XRD analysis it is evident that the carbonate sections of the Jaisalmer Formation are mainly constituting of calcite with minor proportion of quartz (Fig. VII.3), indicating the deposition of these sediments in very shallow marine to nearshore environments.

BAISAKHI FORMATION

XRD analysis of selected sample run form 4°-60°, indicates the presence of quartz, kaolinite, calcite, dolomite with traces of degraded illite and chlorite in finer clastic dominated Baisakhi Formation. The presence of

Table VII.2 Distribution of Insoluble Residues in vertical profile of carbonate section, Jaisalmer Formation.

Sl No.	Sample No	Wt of Sample	Wt after Treatment	% of (I.R)	REMARKS (General characteristics)
1.	TH-10	25 gm	9.8785	39.514	-Insoluble residues are predominantly chert, quartz, kaolinite, and chlorite
2.	TH-14	25 gm	11.6806	46.722	
3.	TH-2	25 gm	12.1028	48.411	
4.	TH-6	25 gm	17.0247	68.099	
5.	TH-11	25 gm	15.8817	63.536	-Quartz grains are basically of two types 1) One with cracks and fracture 2) and another with gas and minerals inclusion without cracks.
6.	TH-9	25 gm	8.6563	34.625	
7.	K-4	25 gm	1.7611	7.044	
8.	BG-2	25 gm	1.2361	4.944	
9.	K-2	25 gm	9.8464	39.386	
10.	F-5	25 gm	1.7742	7.0968	
10.A	K-11	20 gm	1.7611	8.8055	
11.	TH-20	25 gm	10.930.3	43.721	-Quartz are dominating minerals showing asymmetrical variation in vertical profiles
12.	BG-11	25 gm	16.7029	66.812	
13.	F-2	25 gm	24.6628	98.651	
14.	TH-8	25 gm	15.7835	63.134	
15.	F-1	25 gm	24.6945	98.778	
16.	K-1	25 gm	6.8532	27.412	
17.	TH-15	20 gm	1.1175	5.587	
19.	K-8	20 gm	5.4685	27.3425	
20.	BG-10	20 gm	9.5314	47.657	
21.	TH-5	20 gm	13.5496	67.748	
22.	F-3	20 gm	1.5168	7.584	
23.	F-7	20 gm	0.5182	2.591	

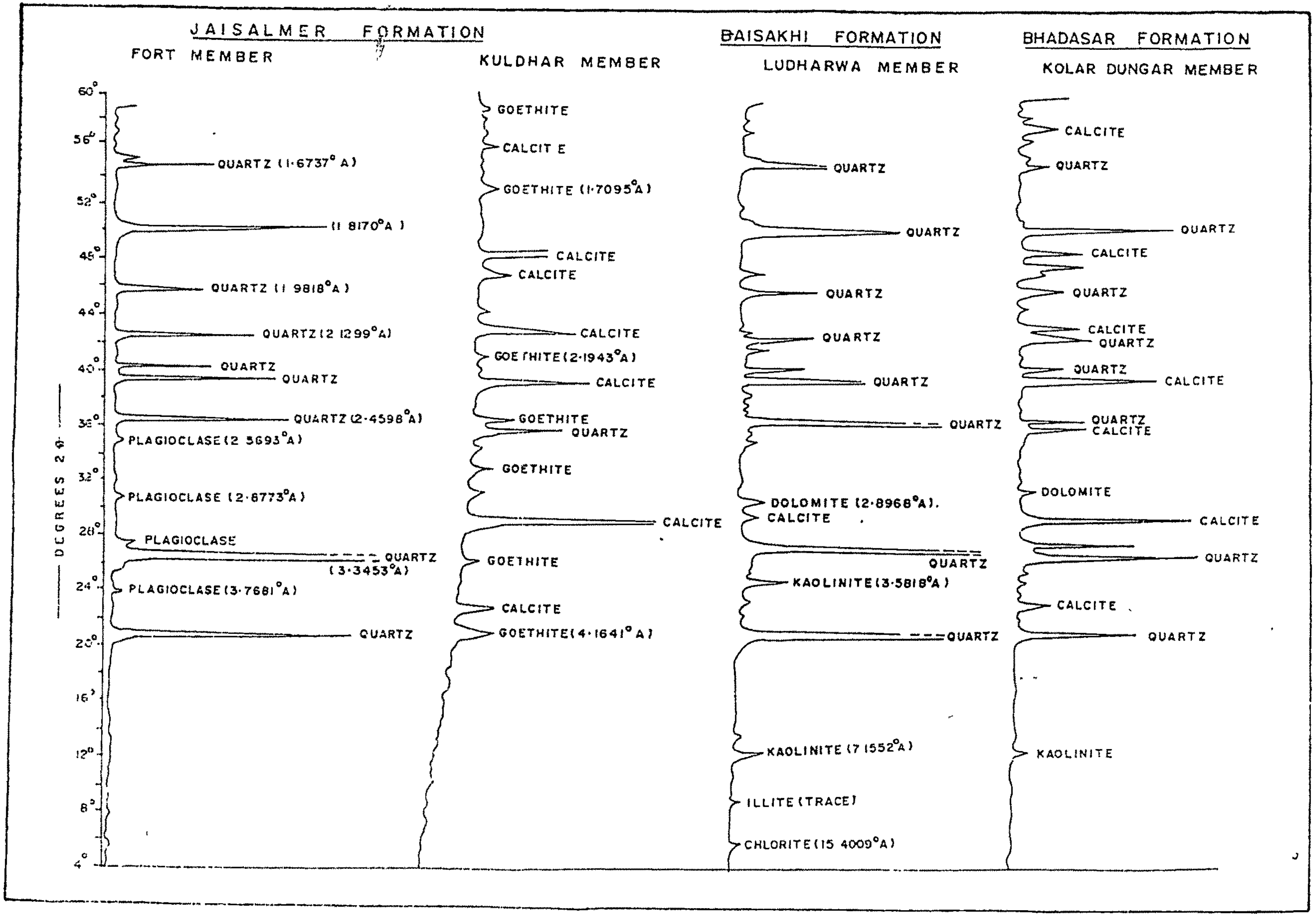


FIG. VII-2: REPRESENTATIVE X-RAY POWDER DIFFRACTION PATTERNS OF $<2\mu$ · FRACTION OF BLUK SAMPLES OF CLASTIC SECTION OF JAISALMER, BAISAKHI AND BHADASAR FORMATION, JURASSIC SEDIMENTS, JAISALMER BASIN, WESTERN RAJASTHAN.

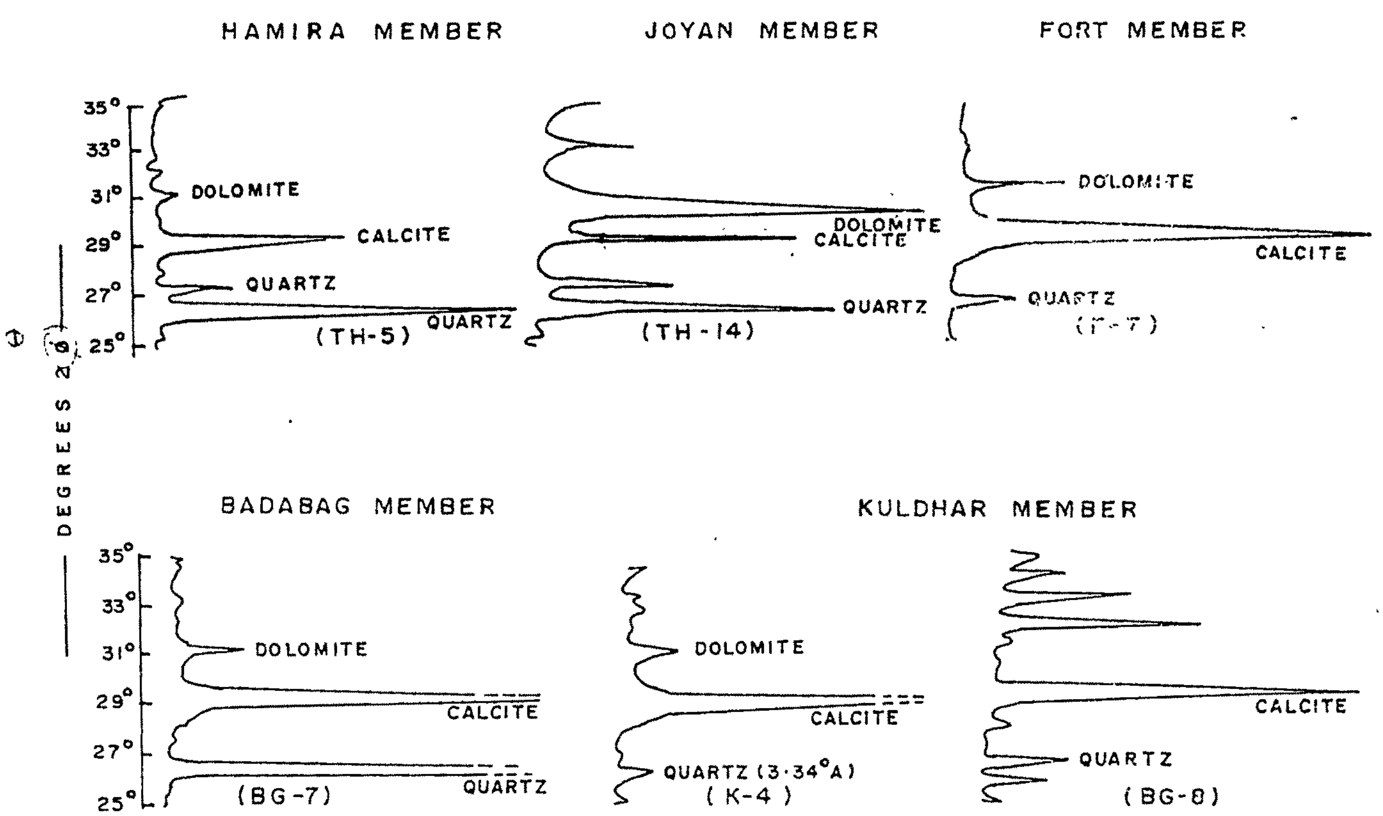


FIG. VII,3. REPRESENTATIVE X-RAY POWDER DIFFRACTION PATTERN OF THE <2 mm FRACTION OF CARBONATE SEDIMENTS OF DIFFERENT MEMBERS OF JAISALMER FORMATION, JAISALMER BASIN, WESTERN RAJASTHAN.

degraded illite along with chlorite suggest marine diagenesis during deposition of sediments.

BHADASAR FORMATION

XRD analysis of representative samples from sediments of Bhadasar Formation reveals presence of mainly quartz, and calcite with minor amount of kaolinite and dolomite. In sediments of upper member of this formation (Mokal Member), persistent occurrence of hematite minerals were observed along with major occurrence of quartz, calcite, dolomite and kaolinite. The occurrence of kaolinite in these sediments may be due to alteration of plagioclase felspar. The hematite mineral is formed in the oxidising condition after the recrystallisation of calcite. The petrographic study also suggests the similar observation and it has been clearly seen that the ferruginous cement has been formed after the calcite cement, hence calcite cement predates the ferruginous cement.

HEAVY MINERAL ANALYSIS

Heavy mineral analysis of 45 selected samples from clastic sequence have been carried out to depict the provenance supplying the detritus to the depositional site and to identify the tectonic episode. The heavy mineral assemblage observed in clastic sequence of different formations of Jurassic sediments are presented in Table VII.3. The findings of heavy minerals study has been discussed formation wise in preceeding paragraphs.

LATHI FORMATION

Heavy mineral assemblage in Odania Member of Lathi Formation are

TABLE : VII. 3 HEAVY MINERAL ASSEMBLAGE OF CLASTIC SEQUENCE

OF JURASSIC SEDIMENTS, JAISALMER BASIN, WESTERN RAJASTHAN

FORMATION	MEMBER	SAMPLE	RUTILE	ZIRCON	TOURMALINE	GARNET	BIOTITE	APATITE	STAUROLITE	KYANITE	EPIDOTE	HORN-BLENDE	SPHENE	ZOISITE	SILLIMANITE	HYPER-STHENE	NON-OPAQUE %	OPAQUE %	
			HEAVY MINERAL % WITHOUT OPAQUES.																
BHADA-SAR	MOKAL	MBR-3	10	20	30	40											4.67	95.33	Poor yield
	KOLAR-DUNGAR	MBR-5	10	10	30	50											5.0	95.0	Poor yield
BAISAKHI		BR-18	-	-	-	-	-	-	-								0	100	-Dominance of Opaques
	RUPSI	BR-10	-	-	-	11.11	-	-	-					22.22			8.26	91.74	-Limonite, Chlorite present
		BRP-3	-	-	33.33	66.66	-	-	-								6.25	93.75	-Chlorite present
		BRP-2	1.16	1.16	18.60	61.63	2.33	-	10.47		4.65						19.72	80.28	
	LUDH-ARWA	BRL-5	11.21	1.86	29.90	19.65	0.93	1.87	20.56	3.74		5.61	2.80			1.87	50.00	50.00	
		BRL-3	1.61	1.08	20.43	53.23	1.08		19.35			2.69					55.36	44.64	Spinel 0.54%
	BAIS-AKHI	BB-1	3.25	4.07	18.70	36.59		0.81	11.38	9.76		10.16			2.03		73.00	27.00	Hypersthene 3.25%
		BB-6	1.75	1.75	4.39	87.72			4.39								49.78	50.22	
		BB-8		11.11	22.22	44.44			22.22								5.66	94.34	Poor yield
		BJ-4		11.11	11.11	33.33			33.33			11.11					5.66	94.34	
JAISALMER		BJ-1	2.08	3.13	9.38	27.08			10.42	6.25	10.42	22.92				3.13	32.43	67.57	
	JOYAN	J-2	-	-	-	55.55	22.22		22.22	-	-	-					2.91	97.09	Poor yield
		J-1	-	2.27	38.64	45.45	2.27		11.36	-	-	-					20.09	79.91	
		J-1A	-	1.74	6.96	62.61	-		14.78	3.48	-	8.70				1.74	46.94	53.06	
		TH-17	-	-	-	-	-		-	-	-	-				-	0	100	Flooding of opaques.
		TH-12	-	-	-	-	-		-	-	-	-				-	0	100	-- do --
	HAMIRA	TH-10	-	11.33	5.33	86.66			6.66								51.72	48.28	
		TH-5	-	2.56	0.51	95.90			1.03								63.93	36.07	
		TH-4	1.64	4.92	40.98	32.79			18.03			1.64				40.66	40.66	59.33	
LATHI	THAIYAT	TL-3				100											0.99	99.01	Flooding of opaques
		TL-4															0	100	
		WL-4															0	100	-do-
		WL-5		14.29	14.29	42.86			28.59								21.88	78.13	

HEAVY MINERALS % WITHOUT OPAQUES.

FORMATION	MEMBER	SAMPLE	RUTILE	ZIRCON	TOURMALINE	GARNET	BIOTITE	APATITE	STAUROLITE	KYANITE	EPIDOTE	HORNBLENDE	SPHENE	ZOISITE	SILLIMANITE	HYPERSTHENE	NON-OPAQUE %	OPAQUE %	REMARKS
LATHI	ODANIA	AL-2	-	-	43.48	-	88.69		21.74			13.04	-	-		13.04	16.43	83.57	
		AL-6	3.17	7.94	30.16	23.81	-		26.98			1.59	3.17	3.17		-	23.95	76.05	
		AL-10	-	-	40	-	-		-			60	-	-	-		2.55	97.48	
		L-12	-	-	-	-	-		-			-	-				0	100	Flooding of opaques

dominated by opaques (83-100%). Among the non-opaques, dominant minerals are tourmaline, staurolite, garnet, with sporadic occurrence of hypersthene, hornblende, zircon, sphene and zoisite (Fig VII.4). Dominance of opaques, tourmaline, staurolite and garnet are indicative of mafic igneous and metamorphic provenance.

Heavy mineral assemblage observed in Thaiyat Member is also more or less similar to the heavy mineral observed in Odania Member. In Thaiyat Member, the heavy mineral assemblage is dominated by opaoues (78-100%) with garnet, staurolite, tourmaline and zircon. This heavy minerals association leads to a dominantly mafic igneous and metamorphic provenance mixed with volcanic rocks.

JAISALMER FORMATION

Heavy minerals study of basal part of Jaisalmer Formation (i.e Hamira and Joyan members) which are dominantly clastic sequence reveals presence of opaques (36-100%) and non opaques comprising tourmaline, garnet, staurolite, zircon, hornblende with rare occurrence of kyanite, hypersthene, and rutile. (Fig VII.4).

The Heavy mineral suites observed in the sediments of basal part of Jaisalmer Formation is suggestive of igneous and metamorphic provenances. Further presence of rounded tourmaline, zircon and garnet suggest the reworking of the sediments. In other words the sediments have been derived from pre existing sedimentary rocks.

BAISAKHI FORMATION

Heavy mineral study of lower part of Baisakhi Formation i.e. Baisakhi

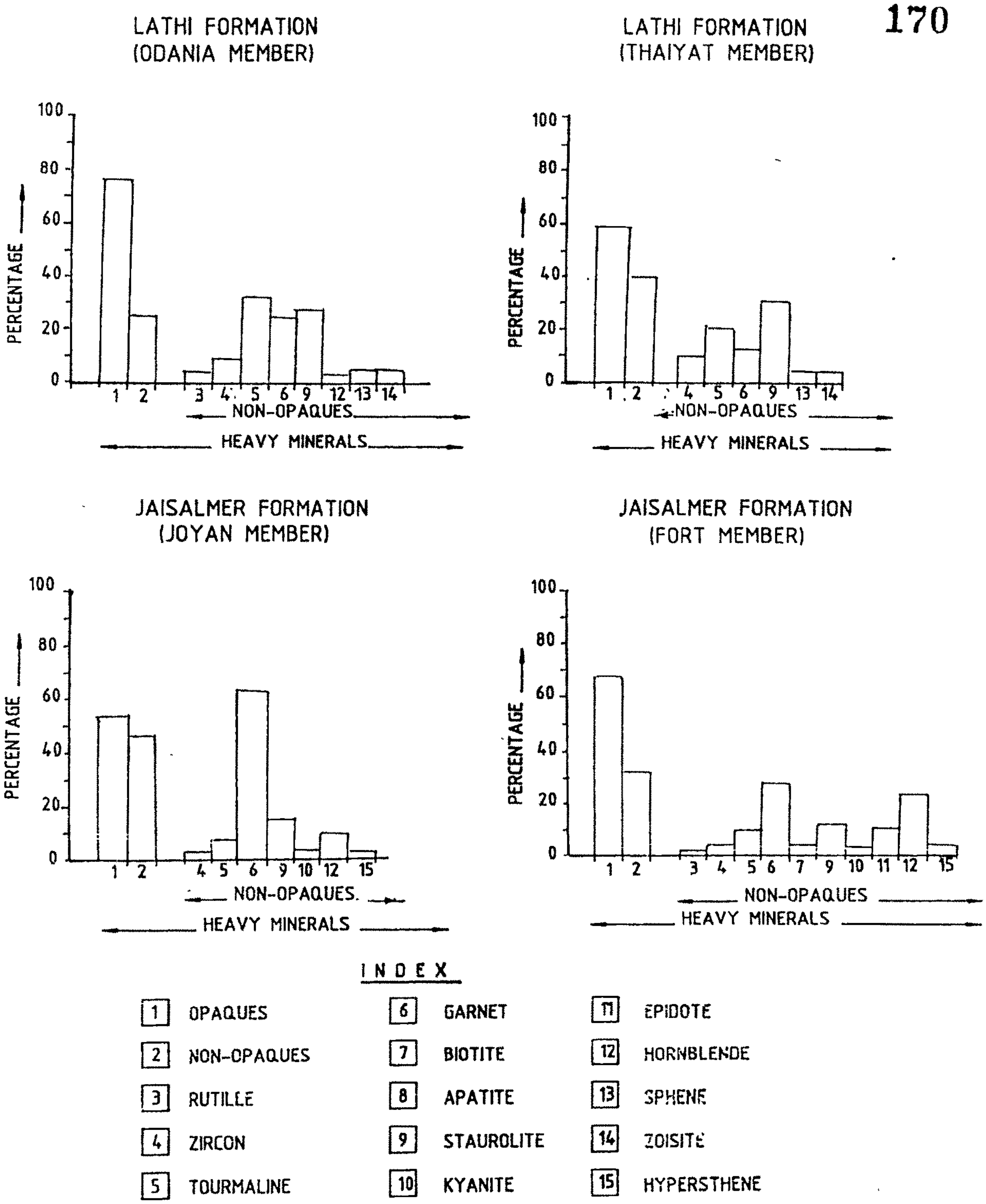


FIG. VII.4 HISTOGRAM OF DISTRIBUTION OF HEAVY MINERALS IN LATHI, JAISALMER AND BAISAKHI FORMATIONS.

Member is mainly represented by opaques (95-100%) with rare occurrence of non opaques. The non opaques constitute tourmaline, garnet, staurolite and zircon (Fig VII 5). The presence of a major constituents of opaques within the sediments of Baisakhi Member is governed by the finer nature of sediments which is mainly shale sequence and stability of the heavy minerals. Under such condition the ultra stable minerals (Opaques) can persist within the sediments. The overlying sequence of Baisakhi Formation (Rupsi Member) is mainly represented by flooding of opaques (80-100%). Among the non opaques dominant minerals, garnet and tourmaline were observed with minor proportion of staurolite, kyanite and apatite. The dominance of opaques within the sediments of Rupsi Member as well as rounded tourmaline and garnet suggest a mixed reworked sedimentary and volcanic provenance.

BHADASAR FORMATION

The heavy mineral assemblage (Table VII.3) of Bhadasar Formation (both Kolar Dungar and Mokal members) is characterised by dominance of opaques (95-100% Fig VII.5). Among the non-opaques the heavy minerals recorded are garnet, tourmaline, zircon and rutile. The dominance of opaque minerals within the sediments of Bhadasar Formation with minor association of non-opaques mainly garnet, tourmaline, zircon and rutile suggest a volcanic provenance mixed with acidic igneous (granitic) source.

GEOCHEMICAL STUDY

Various kinds of chemical processes that take place in solution within the sediments, especially the processes that influence pH, Eh and salinity are

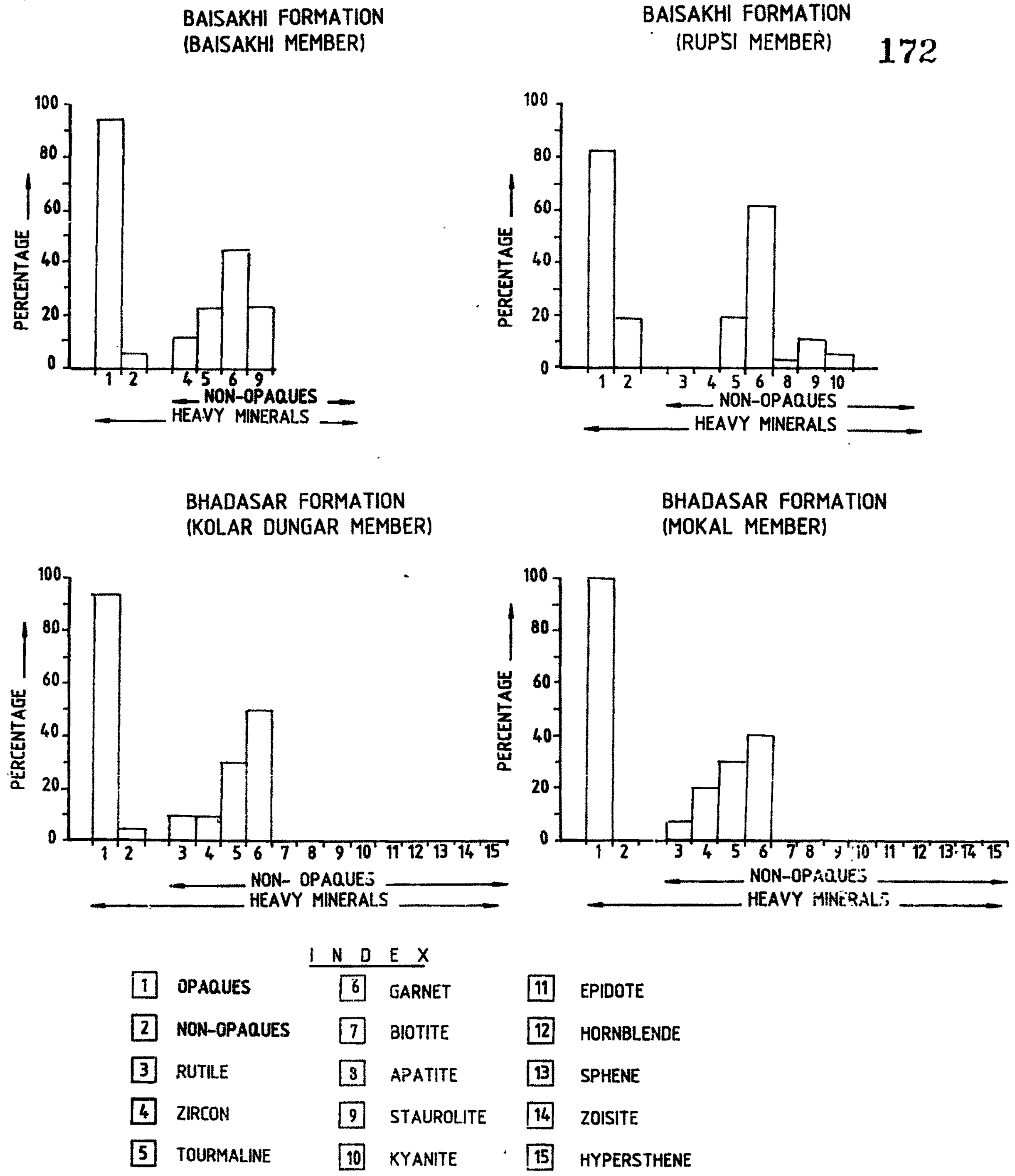


FIG. VII.5 HISTOGRAM OF DISTRIBUTION OF HEAVY MINERALS IN BAISAKHI AND BHADASAR FORMATIONS reflected in the minerals precipitation, or the minerals which are stable in that particular environment. Based on the various major and minor oxides along with trace elements, the chemical parameters are discussed. Such studies has been done by various workers (Mason 1949; Krumbiens & Garrels, 1952; Sloss, 1953; Chilingar, 1955; Degens et. al. 1957, Curtis, 1964; Moore & Denner, 1969; Condie, 1967, Perry, 1972; Blatt et. al. 1972; Singh et. al 1990). At the same time geochemical data has been utilised while dealing with diagenesis of sediments in the preceeding chapter where petrographic studies has also been incorporated.

METHODOLOGY

In the evaluation of geochemical behaviour of the major and minor or trace elements, proper sampling is important. In the present study, sampling has been done by grid methods and a detailed petrographic study of each sample has been carried out. Representative samples have been collected from each lithotypes from the complete observed sequence and were analysed for both major and trace elements.

The selected major and trace element were determined by X-ray Fluorescence Spectrometer and U.V Spectrophotometer. The detail Geochemical analysis methods has been discussed in chapter III

PRESENTATION OF ANALYTICAL DATA

The chemical analysis data have been put to several statistical tests each leading to its own mode of presentation and interpretation, the same data at times are thus liable to yield different types of results. Thus it seems to be more important in this concern that a proper choice of the methods of the presentation of the analytical data are selected. Sedimentary rocks particularly present their own problems which are essentially different than those of igneous and metamorphic rock. Keeping all these in view in the present study the method of presenting the analytical data as weight percent oxide and as percent cations has been adopted. The oxide data is calculated to 100 excluding the anions (OH), CO_2, S and C. The resultant data is converted into cation.

GRAPHICAL PRESENTATION

Unlike the igneous rocks which form one series from acid to ultrabasic, the sedimentary rocks do not form any such series so that the method of graphical presentation with silica as abscissa does not satisfy the full requirements. On the other hand the variations in the sedimentary rocks are usually with age and also lateral. In the present case therefore the analysis have been plotted with reference to the respective formations in the stratigraphic sequence. In doing so, an attempt has been made to present more realistic picture of chemical variations of major oxides for individual sample data (Fig. VII.6, VII.7) for average data (Fig.VII.6A, VII.7A), Besides, the chemical characteristics of each respective formation triangular diagram with a pieces of the triangle which forms common mineralogical or chemical variants are also drawn (Fig. VII.8 to VII.11).

The variations of Trace Elements in the individual formations covering both clastic and carbonate sediments are also presented (Fig. VII.12 and VII.13), which are responsible for modification in the early stage of deposition and subsequent diagenesis of the respective sedimentary formations. These diagrams are very helping in interpretations in the present work..

Table. VII.4 Chemical Analysis (Wt %) of clastic sequence of Lathi Formation.

MAJOR OXIDES	LATHI FORMATION				OVERALL AVERAGE
	THAIYAT	ODANIA			
	LT-2	A -8	L-12	AVERAGE	
SiO_2	85.37	83.99	49.41	66.70	36.03
Al_2O_3	5.71	7.32	6.68	7.00	6.35
TiO_2	0.62	0.60	0.74	0.67	0.64
Fe_2O_3	2.72	3.14	6.78	4.96	3.84
MnO	0.02	0.06	0.10	0.12	0.07
MgO	1.67	1.74	3.04	2.39	2.30
CaO	0.30	0.40	29.97	15.18	7.59
P_2O_5	0.29	0.29	1.01	0.65	0.47
Na_2O	1.28	1.34	2.46	1.90	1.59
K_2O	1.39	0.54	0.47	0.51	0.95
Total	99.37	99.42	100.66	100.08	99.72
Fe_2O_3+MgO	4.39	4.88	9.82	7.35	5.87
K_2O/Na_2O	1.09	0.40	0.19	0.27	0.68
Al_2O_3/SiO_2	0.07	0.09	0.13	0.10	0.18

Table VII. 5 Chemical Analysis (Wt.%) of Clastic Sequence of Jaisalmer Formation

MAJOR OXIDES/ RATIO	JAISALMER FORMATION								OVERALL AVERAGE
	FORT	JOYAN			HAMIRA				
	F-2	TH-20	TH-14	AVERAGE	TH-5	TH-6	TH-11	AVERAGE	
SiO_2	71.45	45.85	44.63	45.24	72.10	65.37	72.68	70.05	62.25
Al_2O_3	9.16	8.50	8.64	8.57	5.78	5.61	5.31	5.57	7.77
TiO_2	0.90	0.75	0.71	0.75	0.64	0.62	0.58	0.63	0.76
Fe_2O_3	4.26	5.50	5.60	5.55	3.98	2.93	2.92	3.28	4.36
MnO	0.10	0.15	0.18	0.17	0.07	0.05	0.07	0.06	0.11
MgO	1.80	2.40	2.43	2.42	2.47	2.36	2.33	2.39	2.20
CaO	4.50	30.85	32.98	31.91	10.83	18.96	12.01	13.93	16.78
P_2O_5	1.20	0.78	0.68	0.73	0.65	0.65	0.65	0.65	0.86
Na_2O	3.85	2.01	1.98	2.00	2.09	1.95	1.90	1.98	2.61
K_2O	0.17	1.15	1.19	1.17	0.55	0.61	0.64	0.60	0.65
Total	97.49	97.94	99.02	98.49	99.16	99.11	99.09	99.14	98.37
Fe_2O_3+MgO	8.16	7.90	8.03	7.97	6.45	5.29	2.25	5.67	7.27
K_2O/Na_2O	0.04	0.57	0.60	0.58	0.26	0.31	0.34	0.30	0.31
Al_2O_3/SiO_2	0.13	0.18	0.19	[illegible]	0.08	0.89	0.07	0.08	0.12

Table VII. 6 Chemical Analysis (Wt %) of clastic sequence of Baisakhi and Bhadasar formations

MAJOR OXIDES/ RATIO	BHADASAR				BAISAKHI						OVERALL AVERAGE
	KOLAR DUNGAR				RUPSI				LUDHARWA	BAISAKHI	
	MBR-3	MBR-5	MBR-8	AVERAGE	BR-5	BR-13	BR-14	AVERAGE	BRL-3	BB-7	
SiO_2	55.05	45.01	48.29	49.45	37.67	31.26	31.78	33.57	80.62	30.38	48.50
Al_2O_3	6.38	5.34	5.53	5.75	7.60	11.64	9.33	9.52	6.85	9.39	7.88
TiO_2	0.84	0.99	0.72	0.85	0.77	0.74	0.85	0.78	0.63	0.78	0.76
Fe_2O_3	19.00	29.23	29.36	25.86	17.19	9.67	16.75	14.54	5.05	3.44	12.22
MnO	0 .25	0.16	0.54	0.32	0.13	0.12	0.20	0.15	0.01	0.08	0.14
MgO	3.16	3.06	2.34	2.85	2.78	2.80	2.72	2.77	1.80	3.36	2.70
CaO	10.80	11 .95	9.35	10.70	29.26	38.80	33.83	34.00	0.60	46.60	22.97
P_2O_5	0.50	0.54	0.40	0.48	0.63	0.82	0.68	0.71	0.34	1.14	0.67
Na_2O	2.25	2.44	184	2.18	2.15	2.25	2.17	2.22	1.38	2.00	1.95
K_2O	0.94	0.94	0.95	0.94	0.88	0.81	0.82	0.84	2.05	0.75	1.15
Total	99.17	99.66	99.32	99.39	99.16	98.91	99.13	99.10	99.33	97.92	98.94
Fe_2O_3 +MgO	42.16	42.29	21.70	35.38	39.97	12.47	27.47	26.64	4.85	6.80	18.42
K_2O/Na_2O	0.42	0.38	0.52	0.44	0.39	0.36	0.38	0.38	1.48	0.38	0.67
Al_2O_3 / SiO_2	0.12	0.12	0.11	0.12	0.20	0.37	0.29	0.28	0.08	0.31	0.16

Table VII. 7 Chemical Analysis (Wt.%) of Carbonate sequence of Jaisalmer Formation

OXIDES	JAISALMER FORMATION									OVERALL AVERAGE OF JAISALMER LIMESTONE
	KULDHAR				BADABAG				FORT	
	K-4	K-8	K-8A	AVERAGE	BG-2	BG-7	BG-10	AVERAGE	F-7	
SiO_2	12.47	15.08	20.51	16.02	23.57	17.67	32.17	24.47	12.37	17.62
Al_2O_3	6.72	6.27	7.25	6.75	9.73	6.11	4.09	6.64	7.15	6.85
TiO_2	0.95	0.88	0.79	0.87	0.91	0.97	0.68	0.85	0.98	0.90
Fe_2O_3	5.96	13.31	12.83	10.70	5.12	4.00	3.11	4.08	4.26	6.35
MnO	0.13	0.20	0.17	0.17	0.17	0.12	0.08	0.12	0.11	0.13
MgO	4.25	3.08	3.18	3.50	4.23	4.59	3.06	3.96	4.92	4.13
CaO	63.11	54.76	51.56	56.48	49.76	59.18	52.90	53.95	62.85	57.76
P_2O_5	1.33	1.09	1.01	1.14	1.38	1.63	0.90	1.30	1.55	1.33
Na_2O	3.54	3.03	2.58	3.05	3.36	3.81	2.44	2.99	4.10	3.38
K_2O	0.24	0.52	0.97	0.58	0.25	0.20	0.32	0.26	0.16	0.33
Total	98.70	98.22	100.85	99.01	98.48	98.28	99.75	98.84	98.45	98.77

Table VII. 8 Elemental Analysis of Clastic sequence of Lathi Formation

ELEMENTS	LATHI				OVERALL AVERAGE
	THAIYAT	ODANIA			
	LT-2	AL-8	L-12	AVERAGE	
Si	39.86	39.22	23.07	31.14	35.50
Al	3.02	3.88	3.54	3.71	3.36
Fe^{+3}	1.90	2.19	4.74	3.46	2.68
Ca	0.21	0.28	21.41	10.84	55.25
Mg	1.01	1.05	1.84	1.44	1.22
Na	0.95	0.99	1.82	1.40	1.17
K	1.15	0.45	0.39	0.42	0.78
Mn	0.01	0.05	0.15	0.10	0.05
Ti	0.37	0.38	0.44	0.41	0.39
P	0.12	0.12	0.30	0.21	1.16

Table VII. 9 Elemental Analysis of Clastic Sequence of Jaisalmer Formation

ELEMENTS	JAISALMER								OVERALL AVERAGE
	FORT	JOYAN			HAMIRA				
	F-2	TH-20	TH-14	AVERAGE	TH-5	TH-6	TH-11	AVERAGE	
Si	33.36	21.41	20.84	21.12	33.67	30.52	33.94	32.71	26.91
Al	4.85	4.50	4.58	4.54	3.06	2.97	2.81	2.95	3.67
Fe^{+3}	2.98	3.84	3.91	3.87	2.78	2.04	2.04	2.29	3.08
Ca	3.21	22.04	23.56	22.80	7.74	13.55	12.01	3.94	13.37
Mg	1.84	1.45	1.47	1.46	1.49	1.42	1.41	1.44	1.45
Na	2.86	1.49	1.47	1.48	1.55	1.45	1.41	1.47	1.47
K	0.14	0.95	0.99	0.97	0.46	0.50	0.53	0.50	0.73
Mn	0.08	0.11	0.14	0.12	0.05	0.04	0.05	0.05	0.08
Ti	o.54	0.45	0.42	0.43	0.38	0.37	0.35	0.37	0.40
P	o.48	0.31	0.27	0.29	0.26	0.26	0.26	0.26	0.27

Table V II.10 Elemental Analysis of Clastic Sequence of Baisakhi and Bhadasar formations

ELEMENTS	BHADASAR				BAISAKHI						OVERALL AVERAGE
	KOLAR DUNGAR				RUPSI				LUDHARWA	BAISAKHI	
	MBR-3	MBR-5	MBR-8	AVERAGE	BR-5	BR-13	BR-14	AVERAGE	BRL-3	BB-7	
Si	25.71	21.02	22.55	23.09	17.59	14.60	14.84	15.[illegible]8	37.65	14.19	22.65
Al	3.38	2.83	2.93	3.05	4.02	6.16	4.94	5.04	3.31	4.97	4.09
Fe^{+3}	13.28	20.44	20.53	18.08	12.02	6.76	11.72	10.17	5.05	2.40	8.92
Ca	7.72	8.54	6.68	7.65	20.91	27.72	24.17	24.27	0.43	33.30	16.41
Mg	1.91	1.85	1.41	1.72	1.68	1.69	1.64	1.67	1.09	2.03	1.63
Na	1.67	1.81	1.36	1.61	1.67	1.67	1.61	1.65	1.02	1.48	1.44
K	0.78	0.78	0.79	0.78	0.73	0.67	0.68	0.69	1.70	0.62	0.99
Mn	0.19	0.12	0.42	0.24	0.10	0.09	0.15	0.08	0.07	0.06	0.13
Ti	0.50	0.59	0.43	0.51	0.46	0.44	0.51	0.47	0.38	0.47	0.46
P	0.20	0.22	0.16	0.19	0.25	0.33	0.27	0.28	0.14	0.46	0.27

Table VII.11 Elemental Analysis of Carbonate sequence of Jaisalmer Formation

ELEMENTS	JAISALMER FORMATION									Overall Average
	KULDHAR				BADABAG				FORT	
	K-4	K-8	K-8A	AV	BG-2	BG-7	BG-10	AV	F-7	
Si	5.82	7.04	9.58	7.48	11.01	8.25	15.02	11.43	5.78	8.23
Al	4.62	4.91	5.96	5.16	7.80	5.89	2.17	5.28	4.85	5.09
Fe^{+3}	4.17	9.30	7.57	7.01	2.18	2.80	2.17	2.38	2.98	4.13
Ca	45.09	39.13	40.35	35.56	42.28	37.79	37.79	38.42	44.90	40.22
Mg	2.57	1.12	1.92	1.87	2.55	2.77	1.85	2.39	2.97	2.41
Na	2.63	2.25	1.91	2.26	2.49	2.83	1.81	2.37	3.04	2.55
K	0.20	0.43	0.80	0.48	0.21	0.16	0.32	0.23	0.13	0.28
Mn	0.10	0.15	0.13	0.13	0.13	0.09	0.06	0.09	0.08	0.10
Ti	0.57	0.52	0.47	0.52	0.54	0.58	0.41	0.51	0.58	0.54
P	0.54	0.44	0.41	0.46	0.56	0.66	0.36	0.53	0.62	0.54

Table VII.12 Trace Element Analysis (ppm) of clastic sequence of Lathi Formation

Elements	LATHI FORMATION				Overall Average
	THAIYAT	ODANIA			
	LT-2	AL-8	L-12	AVERAGE	
S	0.14	0.12	0.74	0.43	0.29
V	49	38	87	62.5	56
Cr	90	90	91	90.5	90
Co	16	14	14	14	15
Ni	59	59	66	62.5	61
Ga	27	22	18	20	24
Rb	11	5	38	20.5	16
Sr	79	81	410	245.5	162
B	62	55	88	75	67

Table VII.13 Trace Element Analysis (ppm) of clastics sequences of Jaisalmer Formation

Elements	JAISALMER FORMATION								Overall Average
	FORT	JOYAN			HAMIRA				
	F-2	TH-20	TH-14	AVERAGE	TH-15	TH-6	TH-11	AVERAGE	
S	1.01	0.56	0.47	0.52	0.43	0.39	0.40	0.41	0.65
V	75.00	75.00	79.00	77.00	57.00	53.00	46.00	52.00	68.00
Cr	85.00	90.00	91.00	90.50	90.00	90.00	90.00	90.00	360.00
Co	40.00	22.00	19.00	20.50	22.00	22.00	31.00	25.00	29.00
Ni	58.00	53.00	53.00	53.00	56.00	53.00	54.00	54.30	55.00
Ga	15.00	15.00	18.00	16.50	18.00	19.00	21.00	19.30	17.00
Rb	42.00	35.00	27.00	31.00	27.00	29.00	22.00	26.00	33.00
Sr	490.00	420.00	398.00	409.00	231.00	244.00	239.00	238.00	379.00
B	93.00	102.00	105.00	104.00	98.00	95.00	83.00	92.00	96.00

Table VII.14 Trace Element Analysis (ppm) of clastic sequence of Baisakhi and Badasar formations.

Elements	BHADASAR				BAISAKHI						OVERALL AVERAGE
	KOLAR DUNGAR				RUPSI				LUDHARWA BAISAKHI		
	MBR-3	MBR-5	MBR-8	Average	BR-5	BR-13	BR-14	AVERAGE	BRL-3	BB-7	
S	0.20	0.25	0.17	0.21	0.33	0.57	0.37	0.42	0.15	0.77	0.39
V	115	113	57	95	248	375	147	257	48	64	116
Cr	93	92	90	92	95	104	91	97	90	91	93
Co	40	44	12	32	54	10	26	30	11	25	25
Ni	40	56	43	53	52	36	48	52	61	54	55
Ga	13	13	14	13	11	15	12	13	26	18	18
Rb	3	3		2	15	27	11	18	14	39	18
Sr	12	9	66	29	209		126		154	154	223
B	80	77	76	78	80	92	85	86	60	78	76

Table VII.15 TOTAL ROCK PARTITION VALUES IN ppm (Chester, 1965)

Elements/ratio	Reef facies	Non-Reef facies	CARBONATE SEQUENCE (JAISALMER FORMATION)
Co	5	5	10-42
Ni	30	30	52-56
V	10	10	62-158
Cr	40	40	88-97
Cr/Ni	.1	1	1.62-1.76
Ni/V	2	2	0.35-0.89

Table VII. 16 Trace Element Analysis (ppm) of Carbonate sequence of Jaisalmer Formation

TRACE ELEMENTS/ RATIO	JAISALMER LIMESTONE									OVERALL AVERAGE
	KULDHAR				BADABAG				FORT	
	K-4	K-8	K-8A	AVERAGE	BG-2	BG-7	BG-10	AVERAGE	F-7	
V	62	77	78	72.3	105	80	158	114.3	65	83.87
Cr	90	90	91	90.3	89	90	97	92.0	88	90.10
Co	35	10	10	18.3	36	33	27	32.0	42	30.76
Ni	55	55	56	55.3	53	53	55	53.6	52	53.63
Ga	17	13	14	14.6	14	15	19	16.6	13	14.53
Rb	49	34	29	37.3	54	54	76	61.3	49	49.20
Sr	454	371	367	397.3	524	589	562	558.3	536	497.20
B	84	80	85	83.0	90	105	95	96.6	76	85.20
S	0.83	0.70	0.64	0.72	1.02	1.15	0.67	0.95	1.07	0.91
Cr/Ni	1.64	1.64	1.62	1.63	1.68	1.70	1.76	1.71	1.69	1.67
Ni/V	0.89	0.71	0.72	0.77	0.50	0.66	0.35	0.50	0.80	0.69

PRESENTATION OF RESULTS

The results of the analysis have been tabulated and given in the following paper in this chapter. The original oxide of various lithotypes are given in Tables VII.4, VII.5, VII.6 and VII.7; Constitutents (Wt.% cations) are given in Tables VII.8, VII.9, VII.10, & VII.11. The trace element data have been presented in parts per million (ppm) in Table VII.12. VII.13, VII.14, & VII.16, The total rock partition values in ppm has been shown for carbonate sequence of Jaisalmer Formation according to Chester, 1965) in Table VII.15.

THE BEHAVIOUR OF MAJOR AND TRACE ELEMENTS

In the present study, an attempt has been made to study the distribution behaviour of the major and trace elements with their significance to the provenance, diagenetic changes and depositional environments. For the description of the elemental analysis the Jurassic sediments under investigation has been grouped mainly as.

1. Clastic sequence: including sandstone of Lathi, Jaisalmer, Baisakhi and Bhadasar formations. The main microfacies are quartz arenite, oolitic quartzwacke, bioclastic quartz wacke, and calcareous quartz wacke etc.

2. Carbonate sequence : represent mainly Jaisalmer Formation. The main microfacies are bioclastic and oolitic packstone, wackestone, pelletal grainstone, wackestone etc.

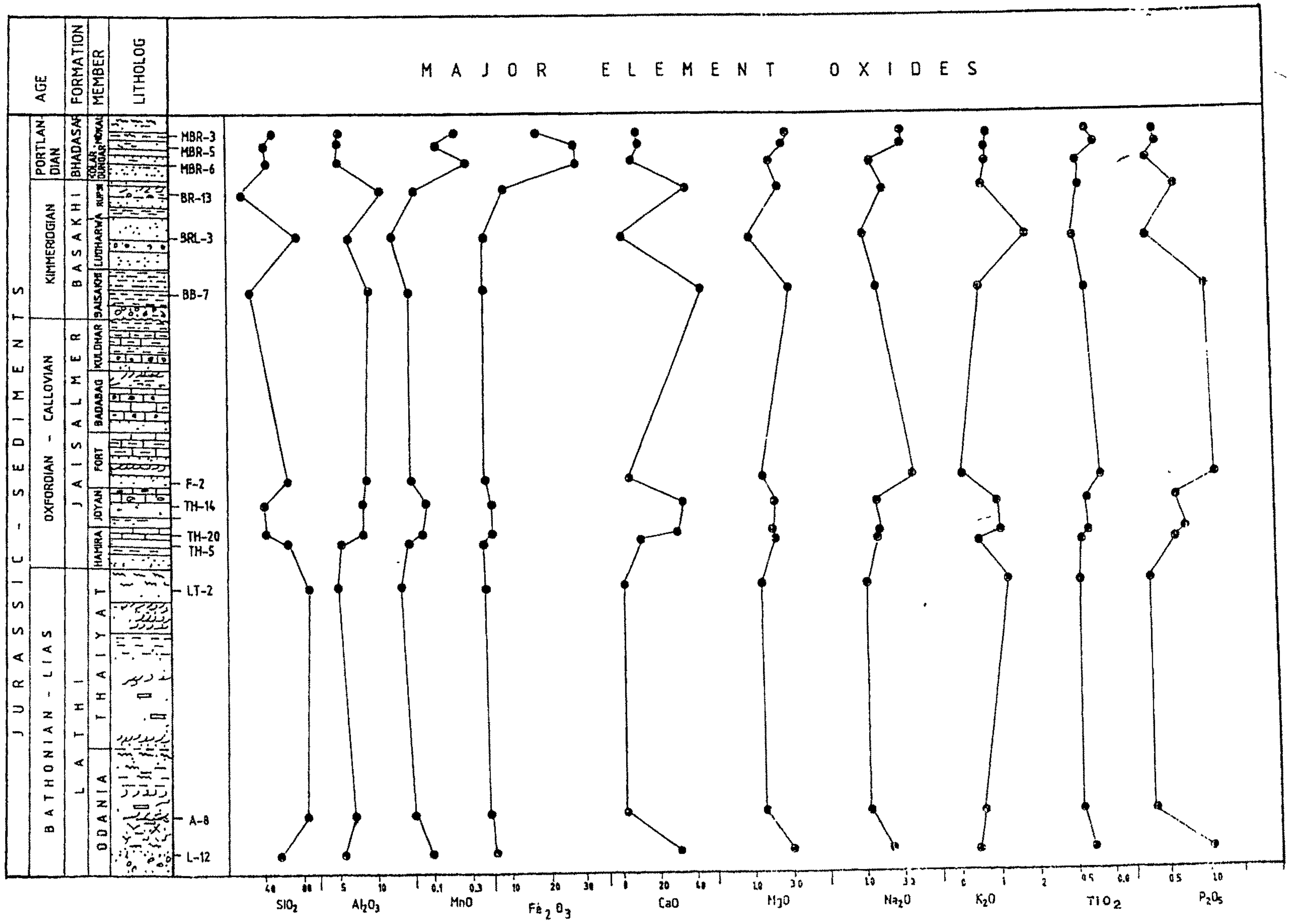


FIG. VII-6 VARIATION DIAGRAM OF THE MAJOR ELEMENT OXIDES IN CLASTIC SEQUENCE OF JAISALMER FORMATION.

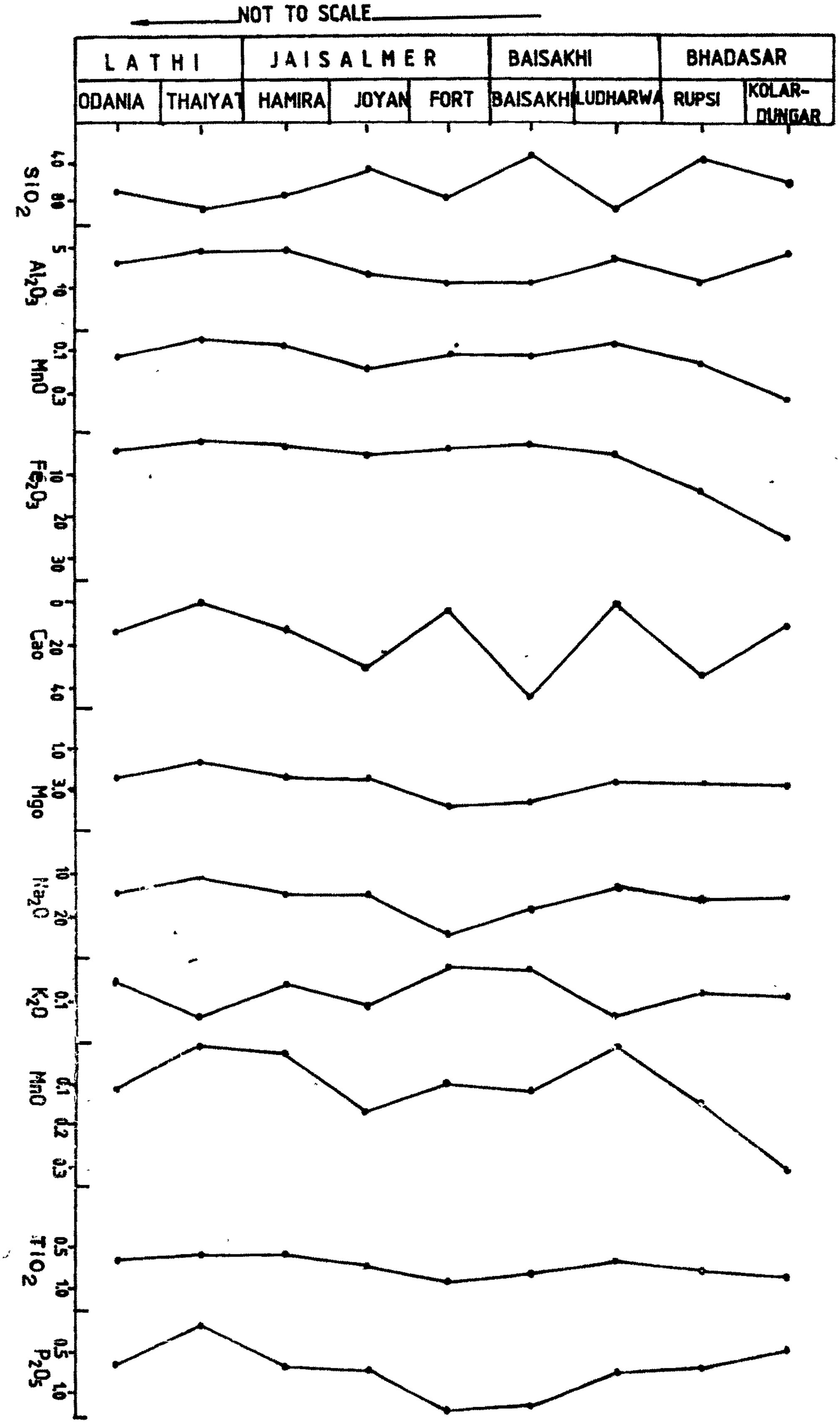


FIG. VII 6A VARIATION DIAGRAM OF THE AVERAGE MAJOR ELEMENT OXIDES IN CLASTIC SEQUENCE OF JURASSIC SEDIMENTS.

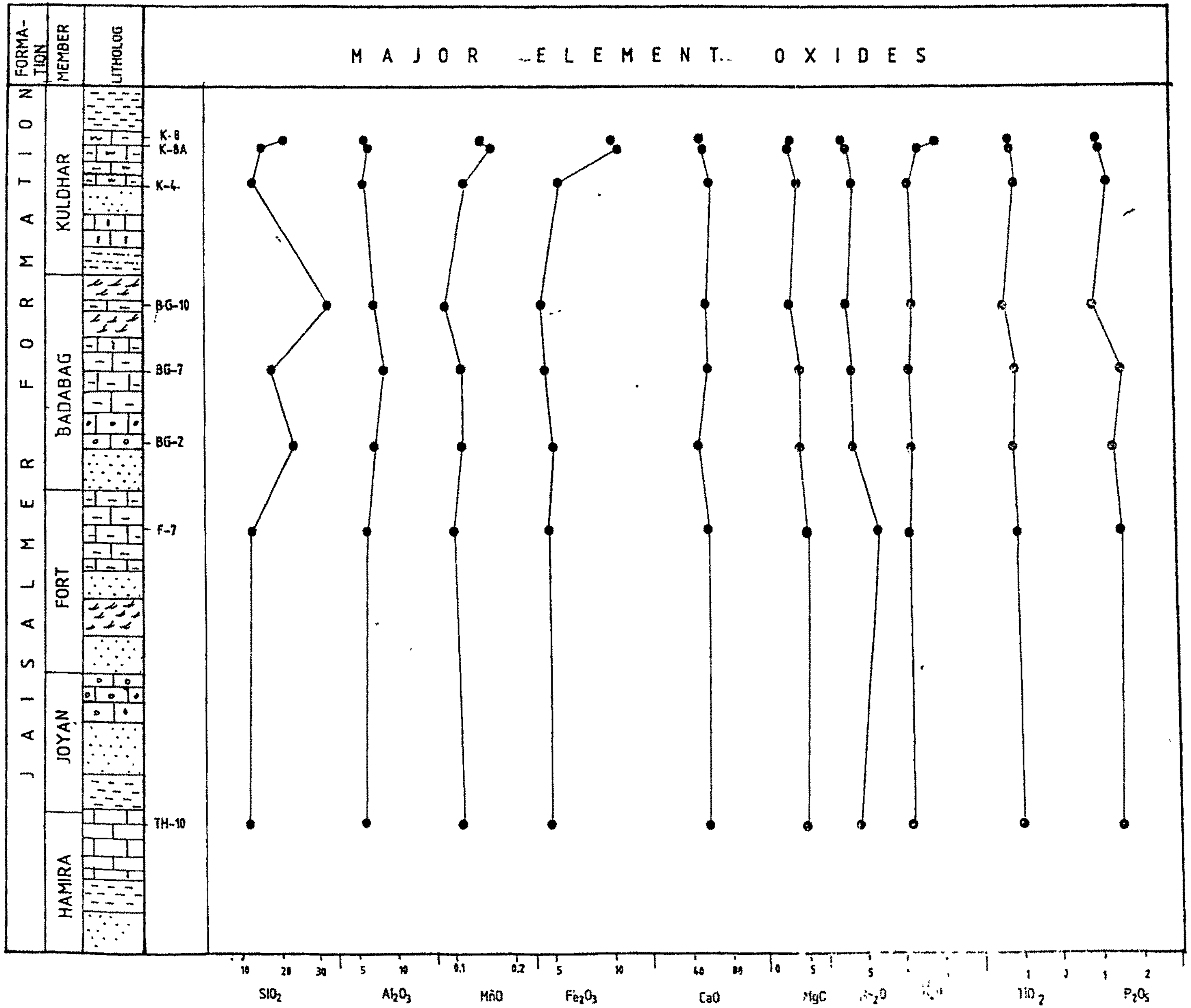


FIG.-VII-7 VARIATION DIAGRAM OF THE MAJOR ELEMENT OXIDES IN CARBONATE SECTION OF JAISALMER FORMATION.

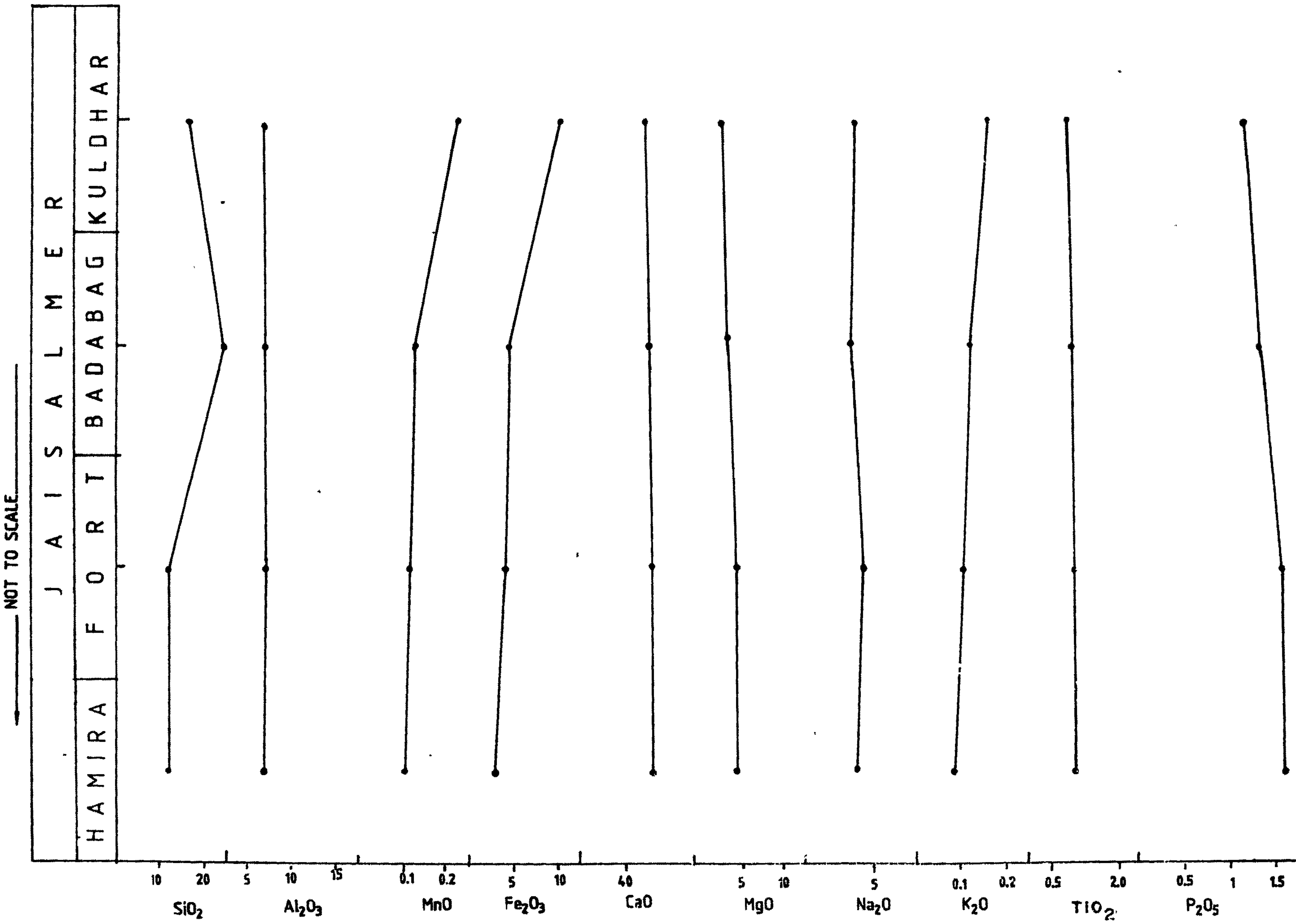


FIG. VII-7A VARIATION DIAGRAM OF THE AVERAGE MAJOR ELEMENT OXIDES IN CARBONATE SECTION OF JAISALMER FORMATION.

THE MAJOR ELEMENTS

For better understanding of the distribution of major and trace elements, the Jurassic sediments as whole has been taken into account as per their lithological characters. The clastic as well as carbonate sediments has been dealt separately for better illustration.

(a) Clastic sediments

The chemical analysis of clastic sediments of Lathi, Jaisalmer, Baisakhi and Bhadasar formations are presented in Table. VII.4 to VII.6.

Silica

It can be seen from the data that the SiO_2 percentage in sandstones of Baisakhi and Bhadasar formations varies between 30 to 80%. In general, the upper, Rupsi and lower Baisakhi members of Baisakhi Formation are poor in SiO_2 (30-37%) suggesting marine influence during their sedimentation. The maximum concentration of SiO_2 is observed in middle Ludharwa Member of Baisakhi Formation whereas in the Kolar Dungar member clastics are characterised by SiO_2 ranging between 45 to 55%. The distribution pattern of SiO_2 from bottom to top in Bhadasar Formation, show dominance of continental environment.

The average SiO_2 content is relatively high in the clastic rocks of upper Fort and Lower Hamira members (65-72%) of Lower Jaisalmer Formation whereas the middle Joyan Member rocks contain low SiO_2 percentage (44-46%).

The sandstones of Lathi Formation are in general rich in SiO_2

(55-85%). However the considerably low SiO_2 % (49%) is observed in the sediments of Odania Member, of Lathi Formation which contains bioclasts as well as calcareous matrix.

The asymmetrical distribution of silica content in the vertical profile of Jurassic sediments, suggest periodic occurrence of transgressive and regressive phase. However, the influence of marine transgressive phase was more pronounced and are represented by several marine bands in the sequence. The substantially low SiO_2 content in Joyan Member of Jaisalmer Formation and Baisakhi and Rupsi members of Baisakhi Formation with the predominance of argillaceous facies related with the transgressive phase. The Kolar Dungar Member shows an upward increase in quartz content.

The Si-Al-Fe ratio plot (Fig VII.8) after More and Dennen,(1970), for the clastic rocks indicates that the clastic sediments of Baisakhi and Bhadasar formations cover in the zone of shale. The clay sample of Ludharwa Member of Baisakhi Formation plots in the field of subgrey wacke.

The sandstones of Jaisalmer and Lathi Formations mostly cover in the zone of sandstone and sub greywacke. Thus the sandstones of Baisakhi and Bhadasar formations show the abnormal behaviour which may be due to the presence of high ferruginous matrix together with predominance of clay matix.

Alumina

The alumina content in the clastic rocks of Jurassic sequence is

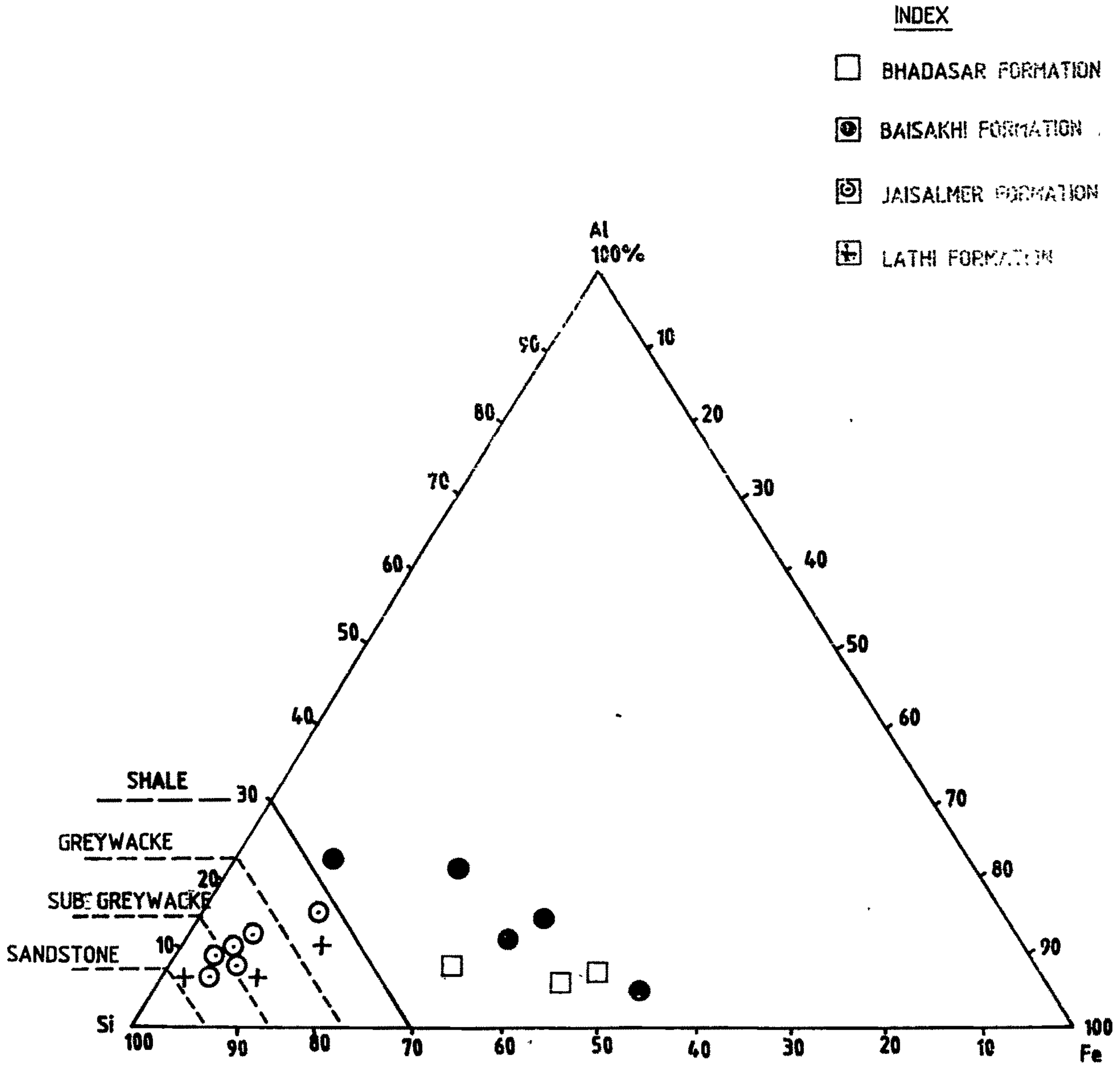
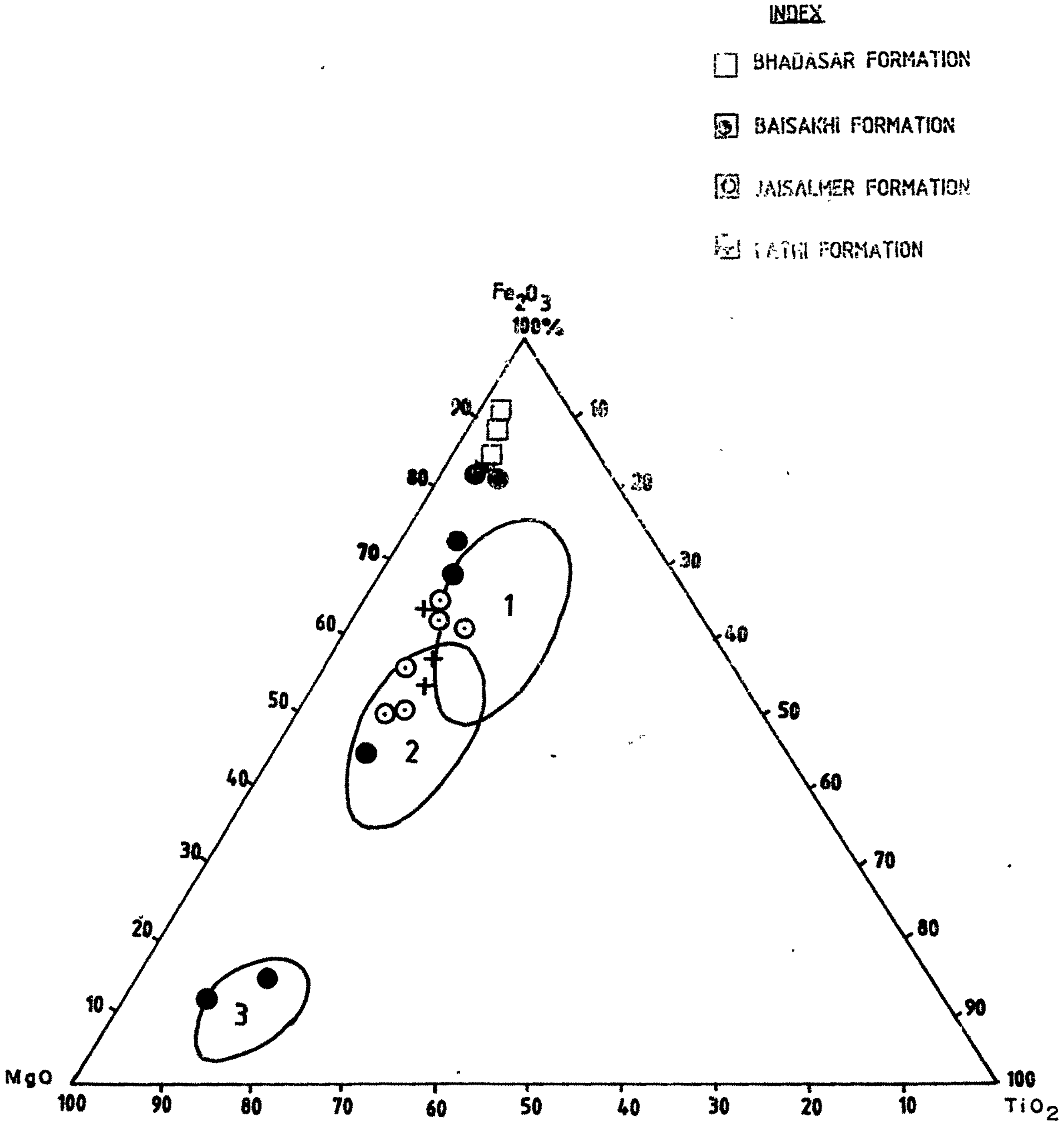


FIG. VII.8 : TERNARY PLOTS OF Si-AL-Fe RATIO OF CLASTIC SEQUENCE OF JURASSIC SEDIMENTS, (After Moore & Dennen, 1969).



SOURCE OF SEDIMENTS
(1) GRANITE & QUARTZ MONZONITES, (2) QUARTZ-DIORITE AND GRANODIORITE, (3) BASALT.

FIG. VII.9 : Fe_2O_3-Mgo-TiO_2 DIAGRAM OF CLASTIC SEQUENCE OF JURASSIC SEDIMENTS, (After Cordie, 1967).

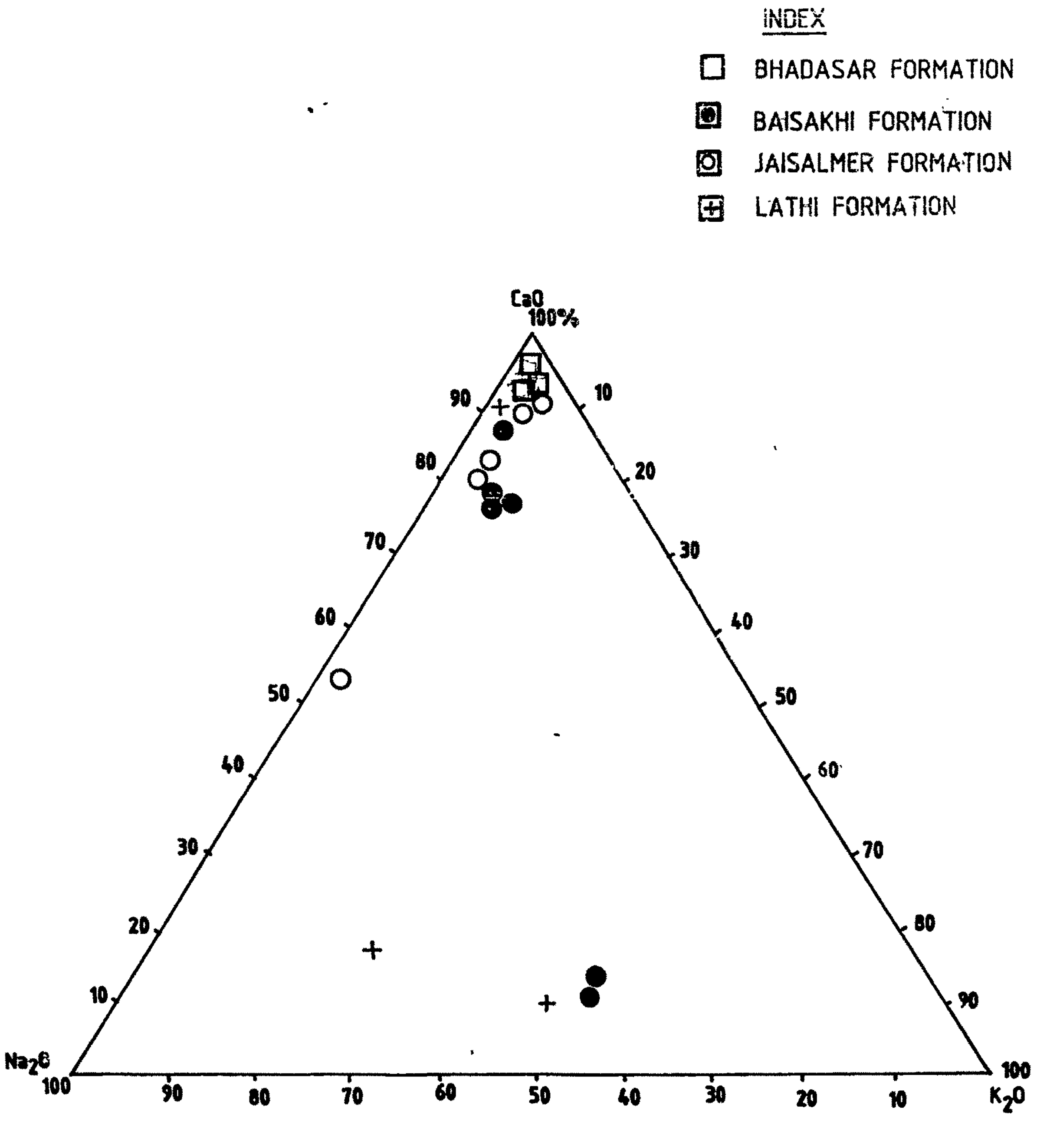


FIG. VII.10, CaO-Na_2-K_2O DIAGRAM FOR CLASTIC SEQUENCE OF JURASSIC SEDIMENTS (After Singh et. al, 1990), considerably high and varies in between 5 to 11%. The Al_2O_3/SiO_2 ratio ranges from 0.07 to 0.29 and does not show a much systematic variation. However the significantly high value (0.28) of Al_2O_3/SiO_2 in Rupsi Member of Baisakhi Formation may be due to different sedimentary provenances.

There is a well established correlation between Al/Ti ratio and provenance (Boston, 1970). A high ratio of nearly 20 suggests a terrigenous source , while weathering products of average marine rock should have low Al/Ti ratio. In the clastic rocks of present study, this ratio is between 4.80 to 10.00 with an exceptionally high value of 14 in sample BR-13 of Rupsi Member of Baisakhi Formation. The Al/Ti ratio in Kolar Dungar Member rock of Bhadasar Formation is relatively low (4.8 to 6.8) and suggests that they have dominant constituents derived from the weathering of older sedimentary rocks of marine origin. The clastics of other members show the value of this ratio around 8 to 10 and indicate the mixed provenance of igneous and metamaphic as well as sedimentary rocks.

The sandstone containing more than 5% Al_2O_3, in their composition, and when plotted in the triangular diagram (Fig.VII .II) of Blatt et. al. 1972) show their deposition in tectonically controlled basin. In the triangular diagram Fe_2O_3 + MgO-Na_2O-K_2O (Fig VII.11) the clastic rocks of the present study occupy Eugeosynclinal field excepting a few points falling close to the demarcation boundary of exogeosynclinal field. This indicates that sedimentation of Jurassic rocks occured in tectonic set up where volcanic rocks occured in the filling strata and where igneous batholiths were intruded during orogeny.

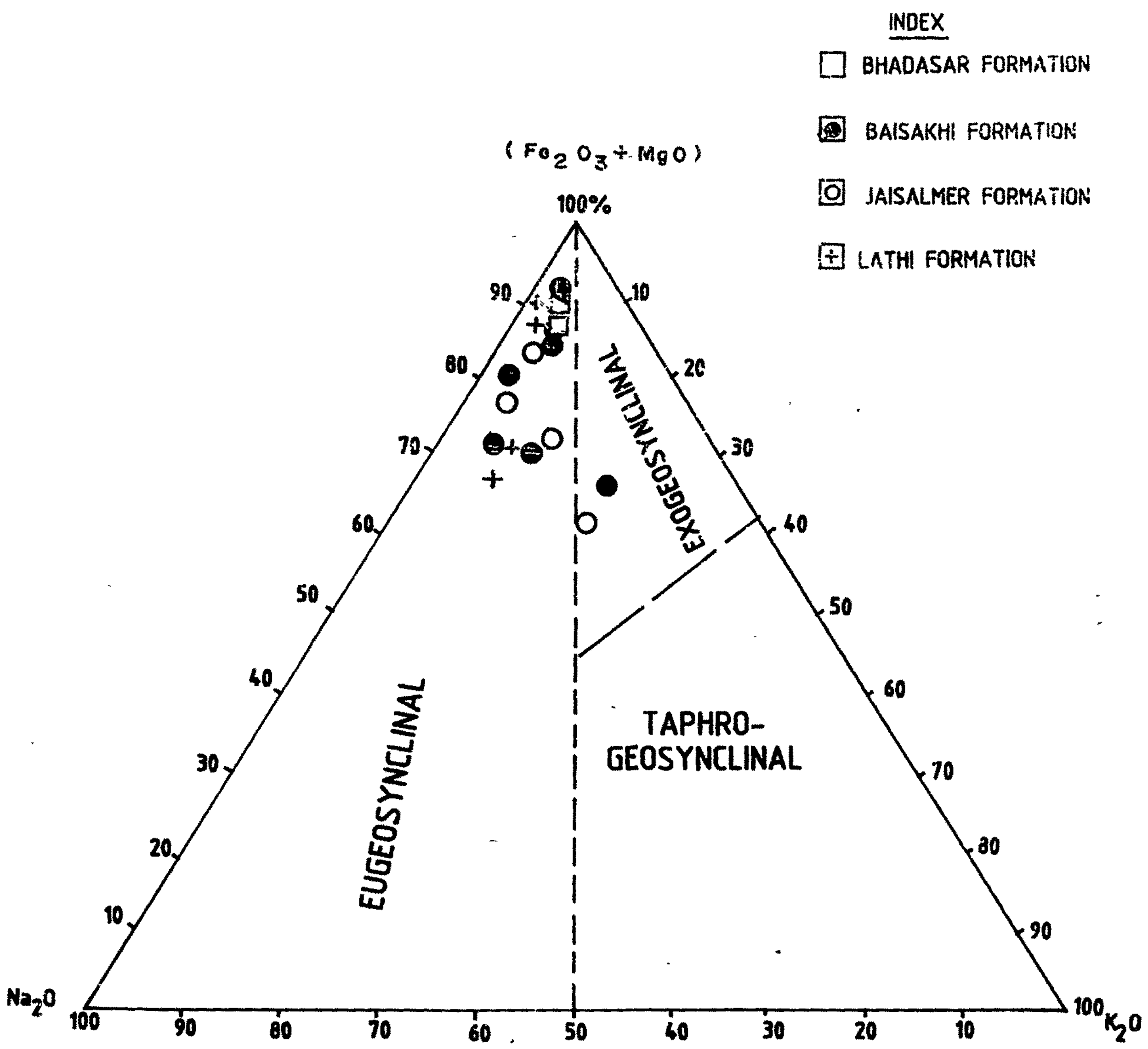


FIG. VII.11 : CHEMICAL COMPOSITION OF CLASTIC SEQUENCE IN RELATION TO TECTONIC SETTING. (After Blatt et. al; 1972),

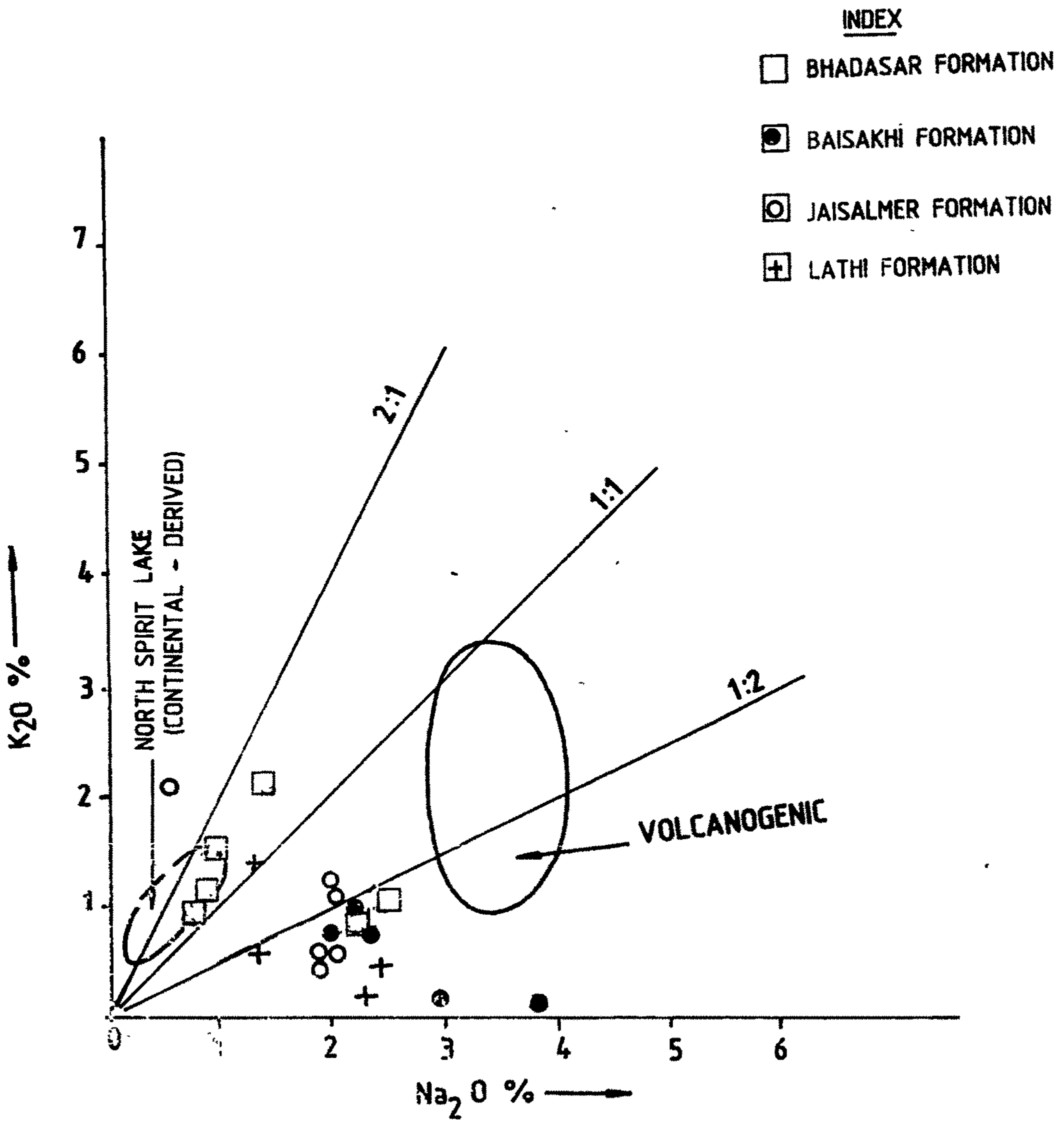


FIG. VII.12 : Na_2O Vs K_2O PLOT FOR CLASTIC SEQUENCE OF JURASSIC SEDIMENTS.

Iron

The iron content in the clastic rocks is represented by Fe_2O_3. The content of Fe_2O_3 throughout the section is far from constant, as is evident from Table VII.4 to VII.6. The Fe_2O_3 content varies from 2.72% in Thaiyat Member rock of Lathi Formation to 29.36% in the rock of Kolar Dungar Member of Bhadasar Formation. In general the occurrence of Fe_2O_3 shows a minor variation in rocks of Lathi Formation to Ludharwa Member of Baisakhi Formation whereas a continuous increase in rocks of Rupsi Member of upper Baisakhi Formation to overlying Kolar Dungar clastics of Bhadasar Formation. The variation seems to be influenced by the abundance of ferruginous minerals as well as carbonate contents, in these sediments.

Manganese

The behaviour of manganese shows almost similar trend with the variation of iron content and is very well illustrated by Fig. VII.6 & VII.7. where both the MnO and Fe_2O_3 are shown plotted through the Jurassic section. Increase in the manganese and iron contents correspond with increase in the amount of diagenetic minerals. The increase in content of MnO in the clastic sediments of Rupsi Member of Baisakhi and Kolar Dungar Member of Bhadasar Formation indicates that some manganese was incorporated in the sediment from solution. The considerably low content of MnO in the clastic rocks of other Jurassic section (i.e in Lathi & Jaisalmer Formations and Baisakhi, and Ludharwa members of Baisakhi Formation) suggests that inclusion of diagenetic minerals are virtually absent in these sediments and the manganese content of the detrital sediments at the time of sedimentation was low. Although the variation of iron and manganese are similar, some difference is observed in the variation of manganese/iron ratio (Table. VII.8, to Vii.10). The Mn^{++}/Fe^{+++} ratios is in general quite low in Baisakhi and Bhadasar clastics whereas sandstones of Jaisalmer and Lathi Formation show the ratio between 0.018-0.032. However in samples of Thaiyat Member of Lathi Formation this ratio is quite low (0.005). The possible explanation for this behaviour is that, compared to manganese, there was more iron in the detrital fraction during the deposition of Baisakhi and Bhadasar clastics as well as Thaiyat Member of Lathi Formation.

Calcium

The inspection of the table of analysis of clastic sediment of Jurassic section (Table. VII4 to VII.6) shows that the concentration of calcium content is considerably high almost in the clastics throughout the section. The concentration of CaO is maximum (46.60%) in Baisakhi Member of Baisakhi Formation followed by Rupsi Member. In general the behaviour of CaO shows the increasing trend in Lathi sediments to Joyan Member of Jaisalmer Formation followed by both decreasing and increasing trend corresponding to major transgressive and regressive phases of depositional conditions.

The plotting of (Fig VII.10) chemical composition of Jurassic clastics within the ternary diagram CaO-Na_2O-K_2O helps to distinguish the clastics of different formations. Contrary to the other ternary diagrams, the plots of Jurassic sandstones in the triangular diagram (Fe_2O_3-MgO-TiO_2 Fig VII.9 after Condie, 1967) suggest volcanic source i.e basalt and andesite. Only a few samples of Lathi Formation and Ludharwa Member of Baisakhi Formation suggest a granitic source. The relatively very high content of CaO due to the presence of calcareous clay and bioclasts is responsible for occupying the field of basalt and suggest volcanic rocks as a probable source of these clastics. However as supported by the other trangular plot (Fe_2O_3-MgO-TiO_2, Fig.VII.9). The provenance for these clastics are considered to be granite/granodiorite as well as pre-existing calcareous sedimentary source.

Magnesium

The distribution of maganesium follows the similar trend as of calcium in the sediments of Lathi and upto Joyan Member of Jaisalmer Formation . The MgO content in these clastics varies in between 1.67 to 3.36% with a relatively high concentration in the sandstones of Baisakhi and Bhadasar formations. It is observed that almost for all the samples including those where abundant calcite is present, the range of magnesium values is limited. This behaviour of magnesium concentration rather suggests the association of magnesium predominantly with the clay minerals.

Sodium and Potassium

The Na_2O and K_2O contents show systematic variation with the more Na_2O and coresponding less K_2O excepting in the Ludharwa Member of Baisakhi Formation where K_2O content is higher (2.05%) than Na_2O (1.38%). The concentration of Na_2O and K_2O varies from 1.38 to 3.85% and 0.17 to 2.05% respectively. An antipathetic relationship between the distribution of sodium and potassium is apparent from the Fig VII.6A & VII.7A and this suggest that the sodium and potassium does not have a common loss. The relatively high and low concentration of K_2O in Ludharwa Member of Baisakhi Formation and Fort Member of Jaisalmer Formation may correspond to the dominance as well as less occurrence of K-feldspar as well as its derivative kaolinite; the distribution behaviour of K_2O and that of the silica is quite similar for most of the Jurassic section, which suggests that the concentration of potassium is related in some manner to the supply of sediments. The behaviour of silica and Na_2O do not show any systematic relationship. An exceptionally high concentration of sillica (71.45%) and Na_2O (3.85%) in the clastic section of Fort member of Jaisalmer Formation with a considerably low K_2O content (0.17%), suggest a high degree of cation exchange with sodium replacing potassium.

Titanium

The variation of the titanium contents through out the clastic sequence of Jurassic sediments show in shown on Fig.VII.6, is some what asymmetrical. This asymmetrical distribution of the quartz and the titanium throughout the section is an indication that the transgressive phase was more rapid and prominent than the regressive phase. In general the TiO_2 content in Jurassic clastic sequence varies in from 0.58% to and 0.99,% through out the section. The asymmetrical behaviour of quartz and titanium except in Fort Member of Jaisalmer Formation suggests the presence of authigenic titanium bearing minerals in addition to detrital rutile resulting from the break down of detrital titanium bearing minerals during the weathering process and thus become associated with the clay minerals in the marine sediments through chemical stability.

Phosphate

The presence or absence of phosphate helps in the interpretation of the pH. The variation in P_2O_5 content in the Jurassic clastic sequence is shown in Fig. VII.6.& VII.6A The concentration of phosphate in the clastics is abundant . In general, it ranges from 0.29 to 1.14%. Where the phosphate is abundant, from the work of Krumbein and Garrels (1952) it is thought that it exceeded 7.0. Thus the high content of phosphate throughout the section thought to have significance of PH; which in general exceeded 7.0 even during the regressive phase of deposition.

(b) Carbonate Sediments

The Carbonate sediments in Jurassic sequence chiefly occur in the Jaisalmer Formation. The Jaisalmer carbonates are composed of various minerals, bioclasts and chemicals components which have similarities and dissimilarites in behaviour due to various conditions at the time of their deposition. The geochemical data of the Jaisalmer carbonate rocks and their distribution hehaviour are shown in Table VII.7, VII.11, VII.16, and Fig. VII.7, VII.7A.

Silica

The distribution behaviour of SiO_2 in the Jaisalmer Carbonate indicates that the average SiO_2 content is relatively high (24.47%) in the Badabag Member with an exceptionally high SiO_2 content in samples No. BG-10. The least SiO_2 content is observed in the lowermost Fort Member (12.37%). The concentration of free quartz in the sediments of Badabag Member reflects the relatively high sedimentation rate as compared to underlying

Fort Member and overlying Kuldhar Member. The high content of SiO_2 in Badabag Member may be attributed to the presence of free quartz as well as the hydrous silicates in form of clay minerals. This further suggest the deposition of Badabag sediments during regressive conditions.

Alumina

The maximum variation in the Al_2O_3 content is only observed in the sediments of Badabag Member in which it varies from 4.09 to 9.73%. In other carbonate facies, the Al_2O_3 content varies in between 6 and 7%. The relatively high Al_2O_3 in carbonates sections may be due to the presence of hydrous aluminium silicates in the form of clay minerals.

Iron

A corresponding increase in the concentration of Fe_2O_3 is evident in Kuldhar Member. The Fe_2O_3 in Fort and Badabag Members is around 4% whereas in upper most Kuldhar Member it ranges from 5.96 to 13.31% with an average of 10.70%. The sudden increase in Fe_2O_3 content in Kuldhar Member is indicative of different depositional set up during the Kuldhar sediments.

Manganese

The behaviour of MnO shows a slight decrease from Fort to Badbag Member whereas a sharp increase (6.17%) in Kuldhar Member. The similarity between manganese and Fe_2O_3 is very well illustrated by fig.VII.7 where both of these are shown plotted through the Jaisalmer section.

The increase in the manganese and iron contents correspond with increase in the amount of diagenetic minerals. It is thus apparent that increase in the amount of diagenetic minerals. It is thus apparent that like iron, some manganese was also incorporated into the sediments of Kuldhar Member from solution. The substantial analogous behaviour of Mn to that of Fe suggests common source for the two elements.

Calcium

The average calcium content is relatively high (62.85%) in Fort Member. However, the maximum calcium content is observed in sample K-4 of Kuldhar Member. The relatively low content of calcium and high content of silica in Badabag and Kuldhar members indicates a depositional environment proximate to the shoreline and their rapid sedimentation.

Mangnesium

The relatively higher mangnesium content is recorded in the Fort and Badabag members. The average magnesium content is observed to be decreasing from Fort to Kuldhar members. (Fig.VII.7A)

Sodium

The Na_2O content in general, is high in the Jaisalmer Carbonates. The maximum Na_2O content is evident in Fort Member followed by Kuldhar Member. The relatively high content of Na in Jaisalmer carbonates particularly in Fort and Kuldhar members is indicative of hypersaline condition and may be due to abundant clay fractions.

Potassium

The distribution behaviour of potassium is evident from figVII.7, which indicates a general decrease in its K_2O content from Fort to Kuldhar Member. A relatively higher level of potassium in Kuldhar carbonates can be attributed to lagoonal conditions.

Titanium

The Titanium contents of the Jaisalmer carbonates is relatively high as the TiO_2 % varies from 0.68 to 0.98%. The TiO_2 variation shows a slight decrease from Fort to Kuldhar members. The similarites in the distribution of TiO_2 and SiO_2 sugggests that like SiO_2 the titanium may be also detrital in origin.

Phosphate

Phosphate is abundant in Jaisalmer Carbonates. The P_2O_5 percentage in the limestones varies from 0.90 to 1.55%. It is evident from the variation digram (Fig.VII.7), that there is a continuous decrease in P_2O_5 content from Fort Member to Kuldhar Member carbonate rocks, which suggest the deposition of these carbonate section in a high pH environment ($>$7.00).

THE TRACE ELEMENTS

The distribution behaviour of the trace elements in clastic as well as carbonate sediments of Jurassic sequence is presented in Table VII.12 to VII.14 & VII.16, The environmental interpretation based on the concentration of various trace elements, analysed in the present study for both the clastic as well as carbonate sediments is discussed together. Some of the important indicator elements used in present study are, B, Ga, Ba, Sr, Rb, Cr, Ni, Co, and V.

Boron

Boron is the trace element which is commonly used as geochemical indicator to characterise the sea water and marine sediments. The B and Ga occur in relatively insoluble forms of different combination and therefore suitable for use as environmental indicators (Degens at. al., 1957). It is also established that a close relationship exists between the boron contents of water and the deposited sediments. Horder (1970) reported the higher concentration of B (1000 ppm), in evaporites than in those deposited in normal sea water (around 100 ppm)and of brackish and fresh water sediments ($<$ 80 ppm).

In the present study, the Boron content of the Jurassic sediments (both clastic as well as carbonates) varies from 55 to 105 ppm with the minimum value (55 ppm) in sample of Odania Member of Lathi Formation, maximum of 105ppm in samples of Joyan and Badabag members of Jaisalmer Formation. The concentration of boron in the clastic sediments of Baisakhi and Bhadasar formations indicates that the Rupsi Member of Baisakhi Formation is marine in nature where as the sediments of Baisakhi Member, sediments of Bhadasar Formation are seems to be brackish in their depositional environment. The Ludharwa Member shows a low content of boron suggesting a high influence of fresh water in depositional regime. The clastic rocks of Jaisalmer Formation are generally marine in nature, where a more marine influence are noted during the deposition of sediments of Joyan Member. Though the Lathi Formation are predominantly fresh water, continental deposits but minor marine influx has been noted, in the lower section as well as in the upper part of the section.

The boron content of carbonate rocks of Jaisalmer Formation suggests prevailing marine condition during the deposition of Badabag Member.

Dengens et. al., (1959) used a Cross plot B Vs Ga to distinguish between marine and fresh water shales of Pennsylvania. The similar plot used in the present study (Fig VII.13) indicates that Ludharwa Member of Baisakhi Formation and upper part of Odania Member as well as Thaiyat Member of Lathi Formation are fresh water in nature whereas other sediments are marine.

Strontium

Sedimentary geochemists prefer to use strontium as a tool for facies analysis. In general Sr concentration is more in sea water than in fresh water and therefore, it reflects the nature of ancient depositional basin condition. The Sr has a close geochemical affinity with Ca due to its similar ionic size and occupies Ca positions in calcium bearing minerals, its higher concentration in limestone is quite obvious. Further strontianite is isostructural with aragonite and very large amounts of strontium can be incorporated in aragonite than in the calcite structure (Keith and Degens 1959)

The lower part of Odania Member of Lathi Formation is characterised by a considerably high Sr content (410 ppm) as compared to upper part of Odania as well as overlying Thaiyat Member (79-81 ppm) which indicates a influx of marine depositional environment for lower Lathi sediments

The Sr content in the clastic rocks of Jaisalmer Formation varies

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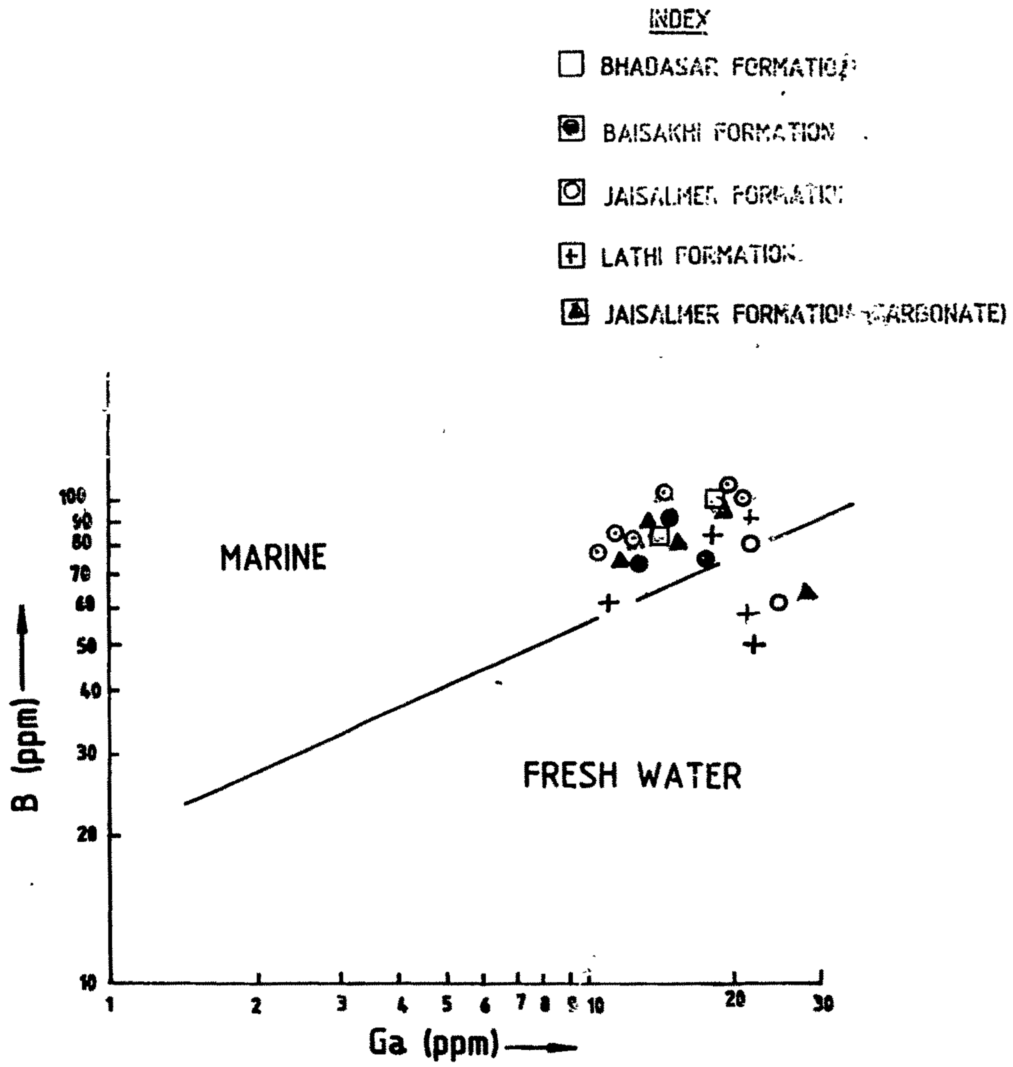

FIG. VII.13 PLOT OF BORON AND GALLIUM OF JURASSIC SEDIMENTS OF JAISALMER BASIN: (After Degens et. al; 1959).

from 231 ppm to 490 ppm and shows an increasing trend from Hamira Member to Fort Member.

In Baisakhi Formation Sr concentration varies from 30 ppm, in the Ludharwa Member to 826 ppm in sediments of Rupsi Member. The average Sr content in Baisakhi and Rupsi member is 454 ppm. and 360 ppm respectively indicating the marine influences during deposition of sediments. The low value of 30 ppm in Ludharwa Member is indicative of fresh water deposition conditions.

The lower part of Bhadasar Formation is characterised by a relatively high Sr. content (66 ppm) as compared to upper part (9-12 ppm).

In the limestones of Jaisalmer Formation the concentration of Sr is relatively high in Fort and Badabag Member (524-589 ppm) than in overlying Kuldhar Member (367-454 ppm) suggesting restricted lagoonal environment of deposition for limestones of Kuldhar Member.

Vanadium

Vanadium is well known for its distribution in sedimentary rocks as it denotes its high concentration in some marine organisms. The bioplile properties of vanadium also control its geochemistry in sediments together with its affinity with iron and its occurrence in the vanadium bearing minerals.

In the present investigation the higher concentration of vandaium is mostly observed in the clastic rocks of Rupsi Member of Baisakhi

Formation. The carbonate rocks of Badabag of Jaisalmer Formation is also characterised by relatively high concentration of vanadium where it is observed that rocks containing more iron are relatively poor vanadium. The richness of vanadium in the sediments may be due to its higher redox potential.

Gallium

Geochemically, gallium is closely related to aluminium and replaces it or is camouflaged in it. In the present findings gallium and aluminium show some erratic behaviour. Though they in general exhibit antipathic relation in a few samples of both clastics and carbonates. Relatively high concentration of Ga in samples of Lathi, Jaisalmer and Baisakhi formation may be related to the decay of organic matter which might have been present during time of deposition.

CONCLUSIONS

On the basis of x-ray mineralogy, heavy mineral assemblage and distribution of major and trace elements in the Jurassic Sedimentary sequence in Jaisalmer basin, the following main conclusions may be drawn.

1. The clastic sequence of upper part of Lathi, basal part of Jaisalmer and lower part of Baisakhi formations show a dominance of kaolinite with common occurrence of illite and traces of chlorite along with minor amount of calcite, dolomite, apart from quartz suggesting influx of saline water during the deposition of the sediments.

2. Quartz overgrowth, pore filling kaolinite, altered muscovite and dissolved feldspar grains observed from quartz arenite of lower part of Lathi Formation and upper part of Baisakhi and Bhadasar Formations as a whole may be explained by their relative instability in acidic conditions.

3. The presence of dolomite along with calcite and quartz as main constituents in Hamira and Joyan members of Jaisalmer Formation indicate influx of fresh water during deposition of sediments in shallow marine to near shore environment.

4. The persistent occurrence of hematite along with occurrence of quartz, calcite, dolomite and kaolinite in sediments of Bhadasar Formation suggest prevailing of Oxidising condition after deposition of sediment.

5. Moderate to poor occurrence of stable minerals like garnet, tourmaline, zircon and rutile along with dominance of opaques in Jurassic sediments suggest probable source for sediments of Lathi Formation is mafic igneous and medium grade metamorphic rocks. The clastic sequence of Jaisalmer Formation have been derived from acid igneous and metamorphic source as well as pre-existing sedimentary rocks. The heavy minerals suites recorded from Baisakhi Formation (Baisakhi and Rupsi member) leads to the provenance towards volcanic and reworked sedimentary rocks. The mixed volcanic and plutonic igneous provenance has been suggested for the sediments of the Bhadasar Formation.

6. The distribution behaviour of SiO_2, Al_2O_3 and other major

oxides suggest different depositional and diagenetic conditions for the various members of the Jurassic clastic sequence. The substantially low SiO_2 content in Joyan Member of Jaisalmer Formation and Baisakhi and Rupsi member of Baisakhi formation with the predominance of argillaceous facies relates with the transgressive phase of deposition.

7. The Al/Ti ratio infers a mixed provenance of igneous and metamorphics as pre-existing sources for the Jurassic clastics except the Kolar Dungar Member of Bhadasar Formation for which relatively low Al/Ti ratio suggest that their dominant constituents are derived from the weathering of pre-existing sedimentary rocks.

8. The triangular diagram Fe_2O_3 + MgO-Na_2O-K_2O of samples of Jurassic clastic sediments falling in eugeosynclinal field exceptinq a few points falling close to the demarcation boundary of exogeosynclinal field and indicate that the sedimentation of Jurassic clastics occurred in tectonics set up where volcanic attributes occured in the filling strata with minor igneous intrusion during orogeny of older sediments.

9. The high concentration of Na_2O in the Jurassic sediments except in Ludharwa Member of Baisakhi Formation is related to high salinity condition of the basin during the formation of these clastics.

10. The consistent presence of Mn in all the samples of Jurassic sediments may indicates that the deposition of the original

sediments took place under relatively high redox potential and relatively high pH conditions.

11 The asymmetrical distribution of SiO_2 and TiO_2 throughout the clastic section is an indication that the sedimentation was more rapid in transgressive phase than in the regressive phase.

12. The high content of phosphate throughout the Jurassic sequence indicates that in general high pH (7.0) prevailed even during the regressive phase of deposition.

13. The concentration of free SiO_2 in the carbonate section of Badabag Member of Jaisalmer Formation reflect the relatively high sedimentation rate as compared to underlying Fort Member and overlying Kuldhar Member. The behaviour of major elements suggests the deposition of carbonates sediments of Badabag Member during some regressive conditions, also.

14. The relatively high content of Na and K in Kuldhar Member of Jaisalmer carbonates is indicative of hypersaline environment due to development of restricted condition in lagoonal regime.