CHAPTER - III

METHODS OF INVESTIGATION

For identification of different lithofacies of Jurassic sediments exposed in Jaisalmer Basin and to understand the depositional environments, sedimentary dynamics, sedimentation pattern and to assess the reservoir characteristics of the sediments, the following investigations were formulated with different aspects of the geological field and laboratory studies.

GEOLOGICAL FIELD INVESTIGATIONS

Field work and sampling

Approximately 3870 sq. km of the area was covered for the present work. Different stratigraphic units were identified in the exposed sections, field data were observed and recorded. The systematic sampling was carried out for all the major exposed stratigraphic units of the Jurassic sediments. All the sediments are well developed, but are poorly exposed due to vast covers of dune sands and recent sediments. During 1987-89, reconnaissance survey was undertaken and major stratigraphic traverses were identified. After demarcating the different formation boundaries on the basis of lithological association, systematic detailed sampling was done. Important field observations were recorded. Sedimentary structures and other field observations along vertical cuestas, river and road cut sections were photographed and recorded in 1989-90. After compiling all the field data, a geological map was prepared on scale 1:63,360 (FIG : III.1)

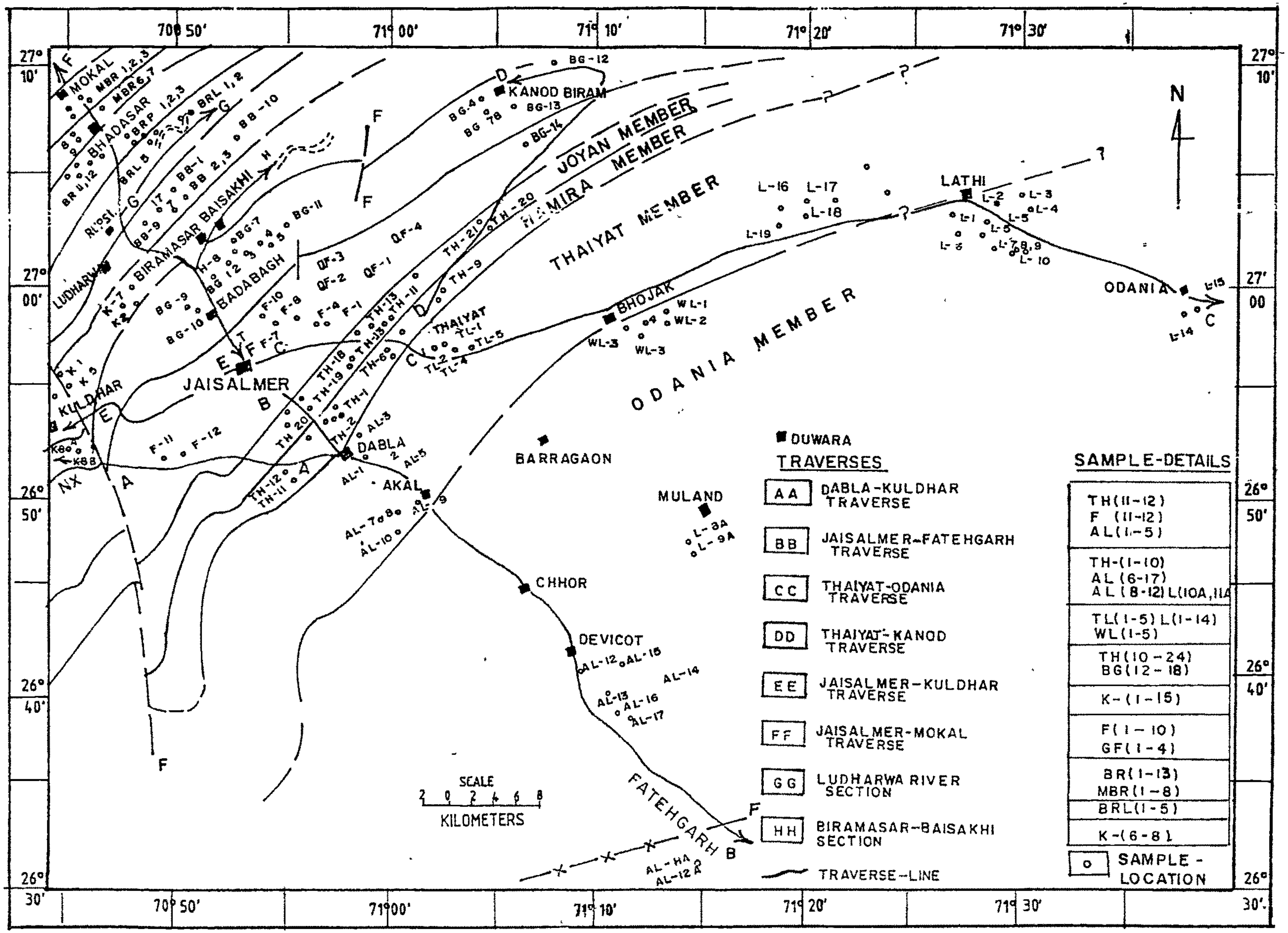


FIG. III-1 SAMPLE LOCATION MAP & TRAVERSES COVERING JURASSIC OUTCROPS IN JAISALMER BASIN

The following procedures were adopted during detailed sampling of the sediments-

1. Systematic sampling was done along major traverses covering different formations of Jurassic sediments in the dip direction, using Brunton compass and tape. Representative samples were collected mostly at regular intervals depending on availability of the outcrops and variation in lithology.(Fig. III.2)

2. Detailed closed sampling was undertaken in several short traverses and along vertical cuestas.

3. Representative samples were also collected from the road and river cut sections, where good exposures were available.

4. Spot sampling was done from Type localities where some good outcrops were observed and could not be covered under systematic sampling.

5. In the course of different traverses, the author also collected representative fossils from the fossiliferous beds, for which reference has been made in the text.

LABORATORY INVESTIGATIONS

In the laboratory the following methods of investigation were adopted.

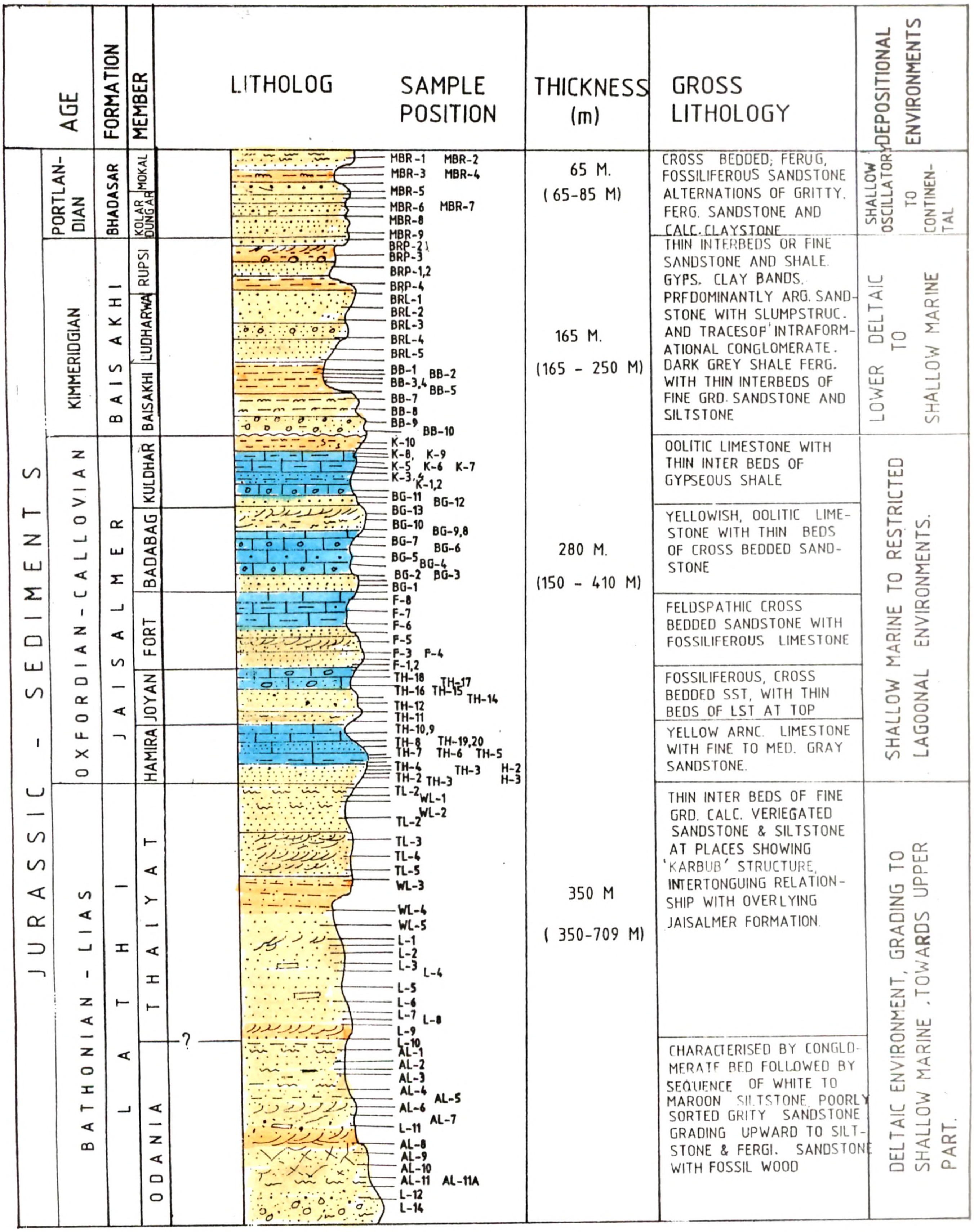


FIG. III.2 GENERALISED LITHOSTRATIGRAPHY OF JURASSIC SEDIMENTS, JAISALMER BASIN, WESTERN. RAJASTHAN

Lithofacies studies

Representative samples collected from the field were examined for establishing lithofacies in different formations and then detailed sampling for different sedimentological parameters were carried out.

Textural analysis of clastic sediments

Granulometric analysis

The purpose of this analysis was to examine the grain size distribution of the clastic sediments as they were deposited. Depending upon the intensity of lithification of sediments, the grain size studies were carried out by the following methods-

(i) Sieve analysis method for those sediments, which are friable in nature.

(ii) Thin section petrographic methods for those sediments which are cemented together by calcareous or ferruginous cement and were indurated.

The clastic grains in the bulk samples were separated from matrix and cement by the process of disaggregation. After removing the cementing material by treating with hydrochloric acid, decantation and drying the material, granulometric analysis was carried out by using 8" diameter, 2"ht, ASTM standard sieve set keeping 1/4 ϕ interval. The samples were weighed to the nearest 0.01 gms and were sieved for 10 minutes using Ro-Tap sieve shaker. The fraction retained on each sieve was weighed and recorded.

In order to interpret sedimentary accomodation, the size distribution data were presented graphically in the form of (1) histograms (2) frequency curves and (3) cumulative frequency curves. The main purpose of graphic presentation was-

(i) computation of statistical parameters of size distribution, and

(ii) interpretation of the data for purpose of inferring environment of deposition.

Cumulative frequency curves were plotted on probability graph paper. Probability plots of cumulative curves are more useful than other curves with arithmetic scale because : (1) they test for normality of a distribution, (2) interpretation for statistical measures is more accurate, (3) the slope of the line is a function of the standard deviation of the distribution, a steep slope means a low value of the standard deviation and a gentle slope means a high value and (4) probable subpopulations if present are identifiable as individual straight line segments.

The cumulative frequency distributions of the particle size of sediments plotted on probability graphs show commonly two or three or even more straight line segments, each having a different slope and separated by a sharp break between the segments. The slope of each straight line segment and position of break between segments reflects the mechanism of deposition.

The statistical measures of frequency distribution was determined graphically. The phi values of various percentile points were determined by using cumulative frequency curves. The values are then inserted into a formula designed to the values computed by using moments (Folk, 1968). The graphic approach is widely used by sedimentologists to generate data useful for comparing suites of samples or for interpreting sedimentary processes (Friedman 1968; Friedman and Johnson 1982).

Phi values from the curve were recorded for various percentile like 5th, 16th, 25th, 50th, 75th, 84th and 95th. For coarsest percentile 1st and for median, 50th percentile were recorded. After recording the various percentile values from probability plots, the statistical parameters were determined using the formulae (Folk, 1968).

Probability curve shapes were compared with the help of modern depositional facies following Visher-1969, and different scatter plots (Friedman 1967, Friedman and Sanders 1978, Moiola and Weiser 1968, Glaister and Nelson 1974) and C-M plots (Passega 1964, 67, Passega and Byramjee 1969) were prepared and interpretation for depositional environments and sedimentary processes of sediments under reference were carried out.

Study of particle-sphericity and roundness

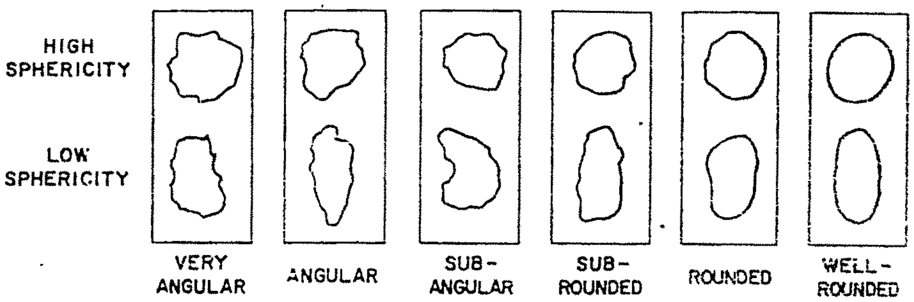
The shape of a sedimentary particle reflects its origin, historv and internal lattice structure. As sedimentary particles are transported away from their place of origin, their original shapes are modified as they collide with one another or with bedrock. Shapes of the particles modified by abrasion during transport depend on (1) initial shape as liberated from bed rock, (2) composition, whether a particle consists of one or several minerals or rock fragments, (3) hardness, (4) cleavage, (5) size (6) agents of transport, (7) rigours of transport including distance and energy of the agent of transport, and (8) other random effects. Particle shapes are expressed in terms of varying sphericity and roundness.

Sphericity defines the degree to which a particle approximates the shape of a sphere, that is, it expresses how nearly equal the three mutually perpendicular dimensions of a particle are. Since sphericity is an indication of how nearly equal the dimensions of a sand particle are, it provides an indication of the original shape of the particle. Many techniques for measuring sphericity have been desired, the most straight forward provided by Power (1953), has been utilised in the present study.

The roundness of the sand size particles has been determined by matching the outlines of the individual particles with the diagram of two sets of standard sand size particles, each set having different sphericity provided by Power 1953 (Table III.1) and has been utilised in the present study.

Petrographic studies

Thin section studies have been carried out for the Jurassic sediments to understand the occurrence of different microfacies in the sequence. The predominant lithofacies in Jurassic sediments are limestone, sandstone, siltstone, shale, claystone and oolitic rocks.



Outlines of Six Roundness Classes of Sand-Size
Particles Having High and Low Sphericity

(After Powers, 1953, Fig. 1, p. 118)

TABLE : III.1A

CLASSIFICATION ACCORDING TO DEPOSITIONAL TEXTURE

DEPOSITIONAL TEXTURE				
Original components not bound together during deposition				Original components were bound together during deposition ... as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are too large to be interstices.
Contains mud (particles of clay and fine silt size)			Lacks mud and is grain supported	
Mud supported		Grain supported		
Less than 10 per cent grains	More than 10 per cent grains			
Mudstone	Wackestone	Packstone	Grainstone	Boundstone

Dunham Limestone Classification

TABLE : III.1B

Carbonate sediments

Although geologists have studied carbonate rocks from various points of view for the past 150 years, surprisingly the first widely adopted classification did not appear in the geologic literature until 1958, 1959 and 1962. The basic constitutents of most limestones are sand size particles. The space between these particles is occupied by (1) a matrix of lime mud whose lithified equivalent is known as micrite, (2) calcite cement or spar, or (3) voids (pores). Micrite is lithified mechanically deposited lime mud (Friedman & Johnson, 1982), which occurs either as a matrix among sand size particles in a limestone or as the only particles in a fine grained limestone. In micrite, the particle sizes are (4) usually between 1 to 3 μ. The void space or pores designates the area between the sand size particles not occupied by micrite or cement. The kinds of sand size particles in limestone are skeletal particles, ooids, intraclasts, grapestones and pellets. As the basis for classifying and naming limestones, all schemes of classification employ (1) sand-size particles, (2) micrite and (3) sparry calcite.

The three classifications which appeared nearly simultaneously were proposed by R.L. Folk (1959), R.J. Dunham (1962) and C. Pendexter and M.W. Leighton (1963). In the present study the scheme of classification by R.J. Dunham (1962) has been adopted. In this scheme of classification, distinction has been made between limestone consisting of two kinds of rocks in which (1) the original components were bound together and (2) in which the original components were not bound together. The first group includes limestones showing evidence of binding during deposition (boundstones). In this group, among others are reefs, stromatolites and travertine. The second group includes several kinds in which the rock consists of coarse particles and micrite. Four classes of limestone of the Dunham classification incorporating particles and micrite have been shown in Table-III.1.

In the Dunham classification, the major criterion for classifying and naming the limestones is the abundance of coarse particles and micrite. In this classification, the term limemud is used instead of micrite and as such estimation of the amount of limemud present between particles in the original depositional environment has been made. The rationality of this classification is that it allows mapping of gradients in the rate of production of sand size particles relative to rate of accumulation of limemud. The relationship between sand size particles and limemud distinguished the original sediment deposited in calm water from that of a sediment deposited in agitated water. The distinction is fundamental and in the Dunham classification is incorporated in the class name.

Two categories are known among limestones not bound together during deposition - (1) those that in the depositional environment consisted of sand size or larger particles which supported one another and (2) those that in the depositional environment consisted of limemud in which particles are floating and did not support one another (mud supported) (Table-III.1).

Clastic sediments

Much of the literature has been summarized by Klein (1963) on classification of sandstones. Krynine, (1948), Folk (1954, 1956) and Pettijohn (1957) have proposed schemes on classification of sandstone based on mineralogy and texture. Grain size and members with all gradations betwen gravel, sand, silt and mud, have been introduced, and 'textural maturity' and 'minerological maturity' concepts have been developed.

In the present study, the classification of terrigenous sands and sandstones by Pettijohn (1954) and modified by Dott (1964) is followed.

Mineralogical and geochemical studies

By studying the mineralogy in more detail one can learn much more about the history of a sediment (Friedman & Johnson 1982). To achieve the objective the following mineralogical studies were carried out:-

Heavy mineral studies

The minerals having higher specific gravities (>2.89) are often referred to as "heavy-minerals" or heavies. The heavy minerals include many kinds of opaques and transparent minerals. The heavy minerals may be separated from minerals of lower density by (1) gravity methods, (2) magnetic methods, or (3) centrifuge methods. In the present study, separation of heavy mineral particles was accomplished by gravity methods using so called heavy liquid Bromoform CHBr). Heavy mineral slides were prepared and based on their optical characters, different heavy minerals were identified and interpreted for provenance using polarising microscope.

Carbonate mineral studies

Jaisalmer Formation predominantly constitutes the carbonate sediments. As such carbonate minerals were studied by the following techniques.

Staining Technique

Staining is a most useful technique in the differentiation of different carbonate minerals like calcite, dolomite, gypsum and anhydrite in the modern and ancient limestone. Alizarin red S liquid was used for staining the thin sections and identification of calcite, dolomite, anhydrite and gypsum in carbonate sequence of area under study.

X-Ray Diffractometry

For identification of different carbonate minerals, powder pack samples were run for x-ray diffraction between 25° to 35° for different carbonate minerals.

Thin Section Petrography

Different types of mud and grains of carbonate minerals are easily identifiable under petrographic microscope. The amount of calcareous mud present can be estimated accurately by their optical properties. These techniques have been utilised in the present study.

Mineral Identification Using X-Ray Diffraction (XRD)

General

X-ray diffraction is a valuable tool in determining the mineralogy of sedimentary rocks. Besides mineral species identification a semi-quantitative determination of mineral constituents can also be made through these techniques. These techniques have been utilised for identification of the clay minerals of matrix and clastic reservoir facies as well as identification of different mineral constituents of carbonate facies of the area under study.

The x-ray diffraction system

The 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 40 KV and current of 30m A, CPS 5000 and time constant of one second.

The principles of the operating technique is that when a sample is radiated, the x-rays are diffracted in a way that is characteristic of the mineral present in the sample under analysis. The angle just measured (which are in term of degress 2θ) must be converted into molecular plane repeat distances (d-spacing) in Angstrom (A^{o}) units. This conversion is based on Bragg's equation ($n\lambda = 2d \sin\theta$) which relates diffraction angle (θ) to wavelength (λ). However, in actual practice, the Bragg calculation is rarely made; prepared tables of 2θ angle versus d-spacing are available for all the common x-ray wave lengths.

Sample Processing

The samples were processed for identification of (1) clay minerals and (2) carbonate minerals of the sediments under reference.

The method for sample processing of clay minerals is based on sedimentation principles by Stoke's law. The following steps were adopted for preparation of the slide using slurry of suspended clay particles-

- Powdering the raw sample with the help of mortar and pestle,
- Disintegration in distilled water.

- Removal of the salts by repeated washing with distilled water.
- Siphoning of the clay particles in suspension and concentration in to slurry.
- Mounting the slurry evenly on glass slide drop by drop with the help of pipette till a meniscus is formed.
- Allowing the clay mount to dry at room temperature.
- Storing of remaining clay slurry for future use and reference.

For processing the sample for carbonate minerals, the following steps are adopted.

- Distintegrating the carbonate sample.
- Soaking the disintegrated sample in distilled water.
- Repeated washing with distilled water to remove the salts.
- Drying the sample at room temperature.
- Powdering the sample with the help of mortar and pestle to the size of 200 mesh.

Sample examination and identification

For clay mineral analysis diffractograms were obtained by scanning the oriented slides from 2°(2θ) to 30°(2θ) . Identifications were made by identifying the peaks in diffractogram. Oriented slides were glycolated and again run for getting diffractograms and identification of the peaks were made.

The procedures of sample examination of carbonate minerals by means of x-ray diffraction method is the almost same as in clay minerals. The powdered sample is packed into sample holder and run for x-ray diffractogram between 25° to 35° (2θ) and identifications were made. However, some of the powdered packs of the bulk samples were also run to analyse the total spectrum of the different minerals between 2° to 65° (2θ) of representative samples, of the fine grained clastic. This study has been also utilised in diagenetic analysis by getting detailed clay mineralogical association of separated fine fractions from both mud rocks and sandstones (Perry and Hower, 1970). The x-ray diffractions has also been utilised to identify authigenic clays following their wide spread recognition in sandstone (Shelton 1964, Wilson and Pitman, 1977).

Major and trace element studies

X-ray Fluorescence Spectrometry also known as XRFS a non-destructive analytical technique, has been utilised to identify or measure the concentration of the major and trace elements present in the sediments under reference.

X-ray spectrometry is based on the fact that individual elements produce unique fluorescence, finger prints comprising radiation at number of specific wavelengths. These can be separated (diffracted) by directing the emitted beam into a suitable crystal. On the basis of the Bragg's law $n\lambda = 2d \sin\theta$ the various wavelengths present can be identified. As the intensity of the radiation at any wavelength is proportional to the concentration of the responsible element in the total sample, the amount present can be quantitatively calculated.

The samples were prepared by pelletizing technique, in which sample is placed in a vibrating disc type grinder mill and ground for a predetermined length of time, then a tablet is pressed into a pellet from the ground material in a hydraulic compression machine. The diameter of the pellet should not exceed 40mm to fit into the sample holder.

The important major and trace elements from selected samples of Jurassic sediments were identified in the Sedimentology Laboratory, ONGC, Dehradun by duly automatic computer controlled x-ray fluorescence spectrometer of Philips Model PW-1402. The system is controlled by analytical software known as x44 soft ware package.

Surface textural study by scanning electron microscopy (SEM)

Considerable progress has been made in the analytical techniques of Scanning electron microscopy since it has extreme depth of focus and wide range of magnification compared to optical microscopy (Krinsley). For surface textural and pore throat studies, the instrument SEM (MK 250 model) in Geological Laboratory, KDMIPE, Dehradun was utilised for analysing the representative samples of Jurassic sediments.

The samples being non-conductive in nature were coated with gold palladium alloy by vacuum coating techniques. The SEM techniques have been used in diagenetic studies of quartz overgrowth morphology and identification of authigenic clays in reservoir matrix also.

Diagenesis and its effects on poregeometry

The study of diagenesis involves the integration of data gathered from range of interrelated disciplines. As such the study is rapidly evolved from routine petrographic analysis to surface textural analysis by SEM, mineralogical and geochemical analysis by XRFS and their proper integration to understand the diagenetic sequence. In the present study, an attempt has been made to justify the object by implementing the main techniques and their scientific integration.

Diagenesis may cause a change of porosity type for example, precipitation of authigenic clay minerals in pores and pore throat, increases surface area, create microporosity, decreases effective intergranular microporosity and lowers permeability. Of course, any porosity type may be partly to completely occluded by precipitation of mineral cements. Diagenesis may also create void space through dissolution of soluble components of the rock. All the parameters have been taken into account while dealing with reservoir petrography of the sediments studied.

SYNTHESIS OF SEDIMENTOLOGICAL DATA AND INTERPRETATION

To evolve depositional model, sedimentary dynamics, sedimentation pattern and to assess the reservoir characteristics of the sediments under reference, major sophisticated sedimentological data were generated and integrated.