This chapter embodies a petrographical description of the various lithological units viz. Chert, Argillaceous, Arenaceous, Calcareous and Quartzite Members respectively of the Tal Formation and the Nilkanth Formation. The study includes the megascopic and microscopic descriptions of the rocks. The petrography of the fine grained rocks was obviously done within the limitations imposed by the resolving power of the petrological microscope. The various rock types distinguished in the Tal Formation include Quartz Arenite, Arenites calcareous cement, Arenites ferruginous cement, Quartz wackes, wackes, siltstones, shales and phosphorites.

The samples for the thin section studies were from the Mussoorie-Masrana road, Gopi Chand Ka Mahal section in the Mussoorie Syncline and Singtali-Kauriyala road section in the Garhwal Syncline. The phosphorite samples were collected from the Maldeota phosphorite mine.

Raha (1973), Pareek (1973, 1976, 1978a,b) and Joshi and Srivastava (1979). Ahluwalia (1980) carried out a detailed petrographic study of the Tal phosphorite and gave a new classification for the phosphorite and phosphate bearing rocks. His classification is based on the apatite percentage in the phosphorites. The phosphorite rock types described by him are orthogjhori tes, orthocalcisphorites, orthopels­phorite, orthosilesphorite, alcalcisphortie, apelsphorite, lithcalcisphorte, lithpelsphorite, orthophosrudite and orthofesphortie. Ramanujam (1983) simply classified Tal phosphorite into massive, pelletal and fragmental phospho­rite. For the present work, Ahluwalia's (1988a) classifica­tion of phosphorites is followed.

The petrography of the Tal Formation was carried out by Auden (1934) in Himachal Pradesh. Kanjilal (1969) and Bhargava (1974) worked out the petrography of the Tal Formation to the south of the village Kotidhaman in Sirmur district and Nigalidhar Sirmur district respectively. Kanjilal (1969) divided the Tal rocks into Lower, Middle and Upper and individually described the rock groups into arkose, protoquartzite and orthoquartzite and calcareous sandstone.

Singh (1979a) recognised a sedimentological break between the Tal quartzite and the Nilkanth Formation in the Nilkanth area. Ramanujam (1983) has made a detailed petrographic study of the Tal Formation and given a new
lithostratigraphic classification. Singh (1986) observed iron balls in the orthoquartzite of upper Tal near Mussoorie.

In the present work only the petrography of the individual members of the Tal Formation has been described in the Mussoorie and Garhwal Synclines including the Nilkanth Formation. The classification of the sandstone can be broadly grouped into two types viz. descriptive and genetic. Descriptive classification has been used for field and/or laboratory description of the rocks while genetic classifications are based on environments of deposition. Pettijohn (1957, 1975) considered provenance, mineralogical maturity and fluidity as the important factors. Texture and mineralogical maturity of clastic rocks were taken as the factors by Folk (1951, 1954). Gilbert (1954) proposed a classification based on texture, degree of sorting and the presence or absence of detrital clay matrix. Primary sedimentary structures were taken as the basis for the classification of sandstones by Packman (1954) and Crook (1960).

Strakhov (1962) considered climatic and weathering conditions as the important criteria for the classification of rocks. Cummins (1962) suggested the importance of post depositional alteration in the classification of sandstones. Generally, there are three main schools of thought (i) Pettijohn-Gilbert school, (ii) Krumbein-Folk school and (iii) Packham-Crook school. The Pettijohn-Gilbert school
considers composition matrix and fluidity as essentials for sandstone classification. This concept was pioneered by many other workers. The Krynine-Folk school based the classification of sandstone on mineralogical composition, which in turn reflects provenance and diastrophism. Folk (1954) redefined the classification of Krynine (1948) by introducing the grain size of the end members. Packham-Cook school laid emphasis on the composition and primary sedimentary structures in the classification of the sandstones.

In the present work, the classification of the Gilbert (1954) has been followed for the description of arenaceous rocks because it takes into account the texture, composition and cement as matrix. This classification has also a genetic significance. The pure or nearly pure sandstone rocks relatively well sorted and containing less than 10% of clay matrix are grouped under arenites. The sandstones containing more than 10% of matrix have been called 'Wackes'. The prefix indicates the dominant mineral constituent while suffix indicates dominant type of cement.

3.1 TAL FORMATION

3.1.1 Chert Member

Megasopic description: The chert member comprises grey to black hard, massive to brittle chert, phosphatic chert, pyritiferous chert, hard massive phosphorite
which may be laminated or structureless. Peloidal, clidal, lenticular or even stromatolitic and alternating black shales. The phosphorites have either carbonate, chert or pyrite or a varied mixture of these three orthochemical constituents as the second most predominant component. There are a variety of vein patterns visible within the phosphorite and these two comprise either phosphate, carbonate, silica or pyrite.

Microscopic description: The phosphorites are a complex combination of few pure end members of orthochemical and terrigenous sedimentary systems, viz., apatitie-like mineral, carbonates, chert, organic matter, pyrite, silt sized terrigenous minerals and authigenic clays (Ahluwalia, 1980). The petrographic types which have been recognised, following Ahluwalia (1980, 1988a) can be categorised as silesphorite, alcalciphorite, microphorite, alsilesphorite and biosphorite. Ahluwalia’s (1980, 1988a) classification is based on $P_2O_5$ content and divides the phosphate rocks into (i) Phosphorite (>10% $P_2O_5$) (ii) phosphate bearing rocks (<10% $P_2O_5$).

The alcalciphorite (Pl.1; Figs 3, 6) comprises light brown to dark brown, rounded, oval, ellipsoidal to elongate phosphatic allochems (Peloids) embedded in a sparry carbonate matrix which also has specks of pyrite as well as phosphate loosely disseminated in it. The
peloids are structureless, more or less opaque due to heavy impregnation of organic matter. The allochems are loosely to moderately dispersed in the matrix and comprise about 40% to 50% of the total volume. The vein fillings of calcareous and ferruginous matter make up to 10%–15%. The minor accessories comprising of pyrite, quartz etc. make about 3%–8%.

In alsilesphorite (Pl.1, Fig.5) phosphate peloids are ill sorted and occur moderately dispersed in a microcrystalline siliceous matrix. Sporadic dolomite rhombs are occasionally noticed with the siliceous cement and seem to have formed in the last as these are mostly hypidiomorphic to idiomorphic. Peloids comprise about 50%–60%, siliceous cement about 10% and dolomite rhombs 20% of the total composition. In microsphorite (Pl.2, Fig.4) idiomorphic dolomite rhombs are noticed in a structureless, primary phosphatic mud admixed with sporadic chert. The siliceous spicules are abundant. The crystals of chalcedonic silica are about 40%–50%. In pyritiferous phosphorite (Pl.2, Fig.5) allochems largely comprising phosphate or pyrite - phosphate segregation (? framboids) occur in a siliceous cum phosphatic matrix. Oblong siliceous spicules filled with microcrystalline, chalcedonic silica and their outlines more or less obliterated occur at times moderately dispersed in a micrasphorite matrix (Pl.2, Fig.6). The spicular layers, alcalcisphorite
layers and microsphorite layers often occur in frequent alternations. Lithoclasts of alorthosphorite can often be observed in an alsilesphorite matrix. Partly to nearly completely obliterated bioclasts of phosphate are often observed with a microsphorite matrix. Structures resembling calcspheres are also very common in the laminated orthosphorite.

Remarks: The Tal phosphorites are frequently associated with carbonate, carbonaceous matter and pyrite. The association suggests that these were accumulated/precipitated in more or less identical chemical environment. Presence of pyrite and carbonaceous matter is suggestive of near-land shallow to moderately deep environment.

3.1.2 Argillaceous Member (wackes)

Megasopic description: The rocks of various shades of colour, steel grey, and purplish grey. On weathered surfaces light-brown colour is prominent. The rocks are generally fine grained and show moderate induration. In some of the specimens, the mica flakes can be identified even megascopically.

Microscopic description: The grains in the wacke are very fine to coarse silt-sized well sorted to poorly sorted and are packed in reorganised clay matrix (Pl.3, Fig.3). The majority of the rocks show disrupted framework (Pl.2, Fig.1). Clustering or polycrystalline and monocrystalline quartz is frequently
seen in thin sections (Pl.3, Fig.2). The mica flakes show parallel linear arrangements (Pl.3, Fig.5). Quartz and chert are the main constituents in the rocks. Monocrystalline quartz grains constitute about 90% to 92% of the total content. Polycrystalline quartz grains having less than three crystals per unit are about 1% to 6%, polycrystalline quartz grains having more than three crystals per unit constitute about 2% to 6% of the quartz content.

The quartz grains showing undulatory extinction on more than 5° rotation of the microscope stage constitute about 80% to 85% and those showing less than 5° rotation of the stage are 5% to 7%. Non-undulatory extinction showing quartz grains are about 6% to 10%. Majority of the quartz grains bear inclusions of various types viz. regular, irregular, acicular and globular. The feldspars constitute about 1.5% to 3%. The feldspar grains occur in altered state. The main feldspar grains are microcline, orthoclase and plagioclase.

The fragments of sedimentary and metamorphic rocks constitute about 4% to 7% and 3% to 8% respectively. Arenites, siltstones, calcareous shales and wackes are the sedimentary parent rocks. Phyllites and mica-schists are the metamorphic rock fragments. Tourmaline, rutile, muscovite, biotite and opaque minerals are the minor components present in the rocks. The clay matrix is the
main cementing material about 17% to 25%. The calcareous and ferruginous cements constitute about 3% to 5% and 2% to 3% respectively.

Remarks: The mineralogy and composition of the rocks under description suggest that there was no major change in the provenance of the rocks during sedimentation. The mechanical weathering in the source area was more and the chemical decomposition also played a subordinate role. The higher proportion of the rock fragments indicates moderate distance of transport. The rapid erosion, short transportation and quick accumulation also indicate low maturity indices of the rocks. The high percentage of the clay matrix also shows a fast pace of sedimentation.

3.1.3 Quartz Wackes (Argillaceous Member)

Megascopic description: The rocks under description are fine grained, well indurated and bear various tints of grey and purple shades. The rocks have a network of veins, which are filled with ferruginous and calcareous cements. Only dark sand-sized and micaceous minerals are identifiable megascopically.

Microscopic description: The rocks are well sorted to poorly sorted. The subangular to subrounded detrital grains are embedded in calcareous (Pl.4, Fig.4) and ferruginous cements (Pl.2, Fig.2). Some of the quartz grains are fractured and the rocks have a disrupted framework (Pl.5, Fig.2). In some of the thin sections, the
mica flakes are bent along the quartz grains by having a regular pattern (Pl.3, Fig.5).

Quartz and chert form about 60% to 67% of the total composition. The quartz grains showing undulatory extinction within the 5° rotation of the microscope stage are 4% to 14% and those showing extinction on more than 5° rotation of the microscope stage are about 70% to 80% of the total content. The quartz grains showing non-undulatory extinction are about 6% to 10%. Monocrystalline quartz grains form about 90% to 95% of the quartz content. Polycrystalline quartz grains with less than 3 crystals per unit and those having more than 3 crystals per unit are 1% to 4% and .5% to 4% of the quartz fraction.

Quartz grains bear various types of inclusions viz. regular inclusion bearing quartz grains are about 20% to 25%, irregular inclusion bearing quartz grains are about 12% to 20%. The acicular and globular inclusion bearing quartz grains make up about 5% to 15% of the quartz content respectively. Feldspars include orthoclase, microcline and plagioclase and represent about 1% to 3%. Most of the quartz grains are altered. Sedimentary and metamorphic rock fragments constitute about 4% to 5% and 5% to 6% respectively. These fragments may represent Quartz arenites. Clay matrix is the main cement and constitutes Quartz arenites. Clay matrix is the main cement and constitutes about 10% to 12% of the rock composition. The clay matrix has been seen mixed with
siliceous, ferruginous and calcareous cements, which may not exceed more than 5% of the rock composition.

Remarks: The mineralogical characteristics of the various constituents indicate that the supply of the sediments for quartz wackes was similar to that which supplied to other rocks. The undecomposed nature of the rock fragments and clay matrix indicate a faster pace of erosion and sedimentation. The chemical cement occurs along with the mechanical clay matrix, suggests that there was no major change between the source and negative areas during the sedimentation of the Quartz wackes.

3.1.4 Arenites ferruginous cement (Arenaceous Member)

Megascoptic description:
The rocks are indurated and composed of fine sand to coarse silt-sized grains. The rocks are traversed by ferruginous veins. The rocks exhibit shades of purplish grey, brownish grey to pale grey. The irregular distribution of the pigment has imparted a patchy look to some of the rocks.

Microscopic description: The rocks generally show original framework, but in some of the thin sections, the disrupted framework is also noticed. The detrital grains are subangular to subrounded, well sorted to very well sorted, coarse silt-sized to fine sand embedded in ferruginous cement (Pl.4, Fig.6). The boundaries of the quartz grains have been corroded. In some of the thin sections, the quartz grains show irregular cracks
and are filled with ferruginous matter. Quartz is the dominant mineral followed by chert, feldspars and rock fragments. About 50% to 60% of the quartz grains are monocrystalline. Polycrystalline quartz grains having less than three crystals per unit are about 1% to 3% and those having more than three crystals per unit are about 2% to 4% of the quartz content.

The quartz grains bear inclusions of various types. The quartz grains which bear regular inclusions are about 15% to 30%. The irregular inclusion bearing quartz grains are about 18% to 30%. The acicular and globular inclusion bearing quartz grains form 4% to 10% and 7% to 18% respectively. About 20% to 30% quartz grains are inclusion free. Orthoclase, plagioclase and microcline are the feldspars which constitute about 1% to 3% of the total rock composition. Most of the feldspar grains are altered and have developed authigenic overgrowth. The fragments of sedimentary and metamorphic rocks constitute about 1% to 3% and 2% to 4% respectively. These rock fragments represent the same source as in the Quartz arenite. Zircon, tourmaline, rutile, muscovite and opaque minerals are the minor mineralogical components which constitute about 1% to 3% of the total rock composition. Ferruginous matter is the main cementing material comprising about 20% to 30% with calcareous cement about 5% to 10%.

Remarks: These rocks indicate a source same as that for
the Quartz arenites and Arenite calcareous cement, except chemical weathering and palaeotectonic set up. Chemical weathering was in these rocks faster than mechanical fragmentation. This is indicated by high percentage of ferruginous matter and lesser proportion of rock fragments. The erosion, transportation and sedimentation took place in oxidising environment. The pigment might have been redistributed during the diagenetic and epigenetic processes.

3.1.5 Arenites calcareous cement (Calcareous Member)

Megascopic description: The rocks are light grey, greenish grey and light black. The veins of calcareous and ferruginous matter traversing the rocks in haphazard directions are frequently seen. Some of the rocks have dark-brown patches on weathered surfaces. It is the upper member of the Lower Tal and unconformably overlain by the Quartzite Member.

Microscopic description: The rocks are well sorted, having subangular to subrounded grains. The grains are very fine to coarse silt sized and packed in dense carbonate cement (Pl.3, Fig.6). The quartz grains have been etched and have developed reaction rims at the contact of quartz and carbonate cement (Pl.4, Fig.4). The quartz grains have irregular outlines (Pl.3, Fig.4) and in some of the rocks, carbonate cement has penetrated
deep into the quartz grains (Pl.4, Fig.2). The microveins of carbonate cement and siliceous cement are frequently seen in the rocks (Pl.3, Fig.1). The dominant minerals in these rocks are quartz and chert—about 60% to 70% of the total composition. Monocrystalline quartz grains constitute about 80% to 95%. Polycrystalline quartz grains having more than three crystals per unit and having less than three crystals per unit area about 3% to 8% and 2% to 6% respectively. The undulatory extinction shown by quartz grains on less than 5° rotation of the microscope stage varies from 5% to 15% and 60% to 75% respectively. About 9% to 15% grains show non-undulatory extinction. The inclusion bearing quartz grains show significant proportion in the rocks. Regular inclusion bearing quartz grains and about 20% to 30%. The irregular, acicular and globular inclusions constitute about 15% to 25%, 8% to 10% and 5% to 10% of the quartz grains respectively. The inclusion free quartz grains are about 20% to 30% of the total composition.

The orthoclase, microcline and plagioclase are the main feldspars and occur in the altered state. These have also developed authigenic overgrowth. The fragments of sedimentary and metamorphic rocks constitute about 1% to 2% and 0.5% to 3% respectively of the total rock composition. The other minor minerals constituting about 1% to 3% of the rock composition include zircon, tourmaline,
epidote, muscovite, biotite and dark opaque minerals. The grains are cemented with calcareous and ferruginous matter which are intermixed with clay matrix. The carbonate cement constitutes about 15% and occurs in finely crystalline form to spary calcite (Pl.24, Fig.4). The ferruginous cement and clay matrix form about 4% to 6% and 2% to 4% respectively.

Remarks: The mineralogical characteristics of the quartz grains and Arenite calcareous cement of the rocks, suggest that there was no significant change in the source rocks and environment of deposition of the rocks. Etching of quartz grains and development of reaction rims at the contact of quartz and carbonate cement, indicate deep burial of the rocks.

3.1.6 Quartz arenite (Quartzite Member)

Stratigraphically, it is the topmost Member of the Tal Formation in the Mussoorie and Garhwal synclines, and overlain by the Shell Limestone (Nulkanth Formation, Singh, 1979b).

Megascopic characters: The rocks of the Tal Quartzite Member are medium to coarse grained, with large-scale cross laminations and high degree of induration. The rocks exhibit different shades of buff, purplish-brown and greyish purple. On weathered surfaces these show light pale brown colour. The rocks show prominent development of large scale cross-bedding, parallel bedding, ripple
marks, lenticular and flaser bedding, herringbone cross bedding, climbing ripple lamination, ripple marks, channels and planes of discordance. These structures suggest a medium to high energy depositional environment for Tal Quartzite.

Microscopic characters: The rocks show partly disrupted to disrupted framework (Pl.5, Fig. 1,6). The quartz grains are closely packed, medium to coarse, sub-angular to subrounded and well sorted (Pl.5, Fig.3). Most of the grains are in contact with one another and show plain, concavo-convex and sutured contacts (Pl.5, Fig.3). Some of the quartz grains are intersected by silica veins. The authigenic growth on quartz and feldspar grains is frequently noticed. Silica and ferruginous matter (Pl.4, Fig.3) are the main cements. Rocks are also traversed by microstylolites. Quartz and Chert make up about 70% to 90% of the rock composition. The majority of the quartz grains show undulatory extinction. The quartz grains showing undulatory extinction on more than 5° rotation of the microscopic stage are 70% to 85% and those showing on less than 5° rotation of the stage make up 10% to 15%. The monocrystalline quartz grains make up about 80% to 90% of the total quartz content. The polycrystalline quartz grains are also present, those having more than three crystals per unit form about 0.85% to 7% and those having less than three crystals per unit are about 1.5% to 6%
of the quartz content. A significant proportion about 70% to 80% of the quartz grains bear regular, irregular acicular and globular inclusions (Pl. 5, Fig. 6). Inclusion free quartz grains make up about 20% to 30% of the quartz content. While those with irregular inclusions form about 15% to 25%; 4% to 10% and 5% to 15% respectively. The quartz grains have well developed authigenic overgrowths (Pl. 5, Fig. 1). Occasionally, the growth has resulted in well developed crystal faces. The orthoclase, microcline and plagioclase constitute about 1% to 3% of the total grains. These grains have also developed authigenic overgrowth. This overgrowth has taken place either in small parts of the grains (Pl. 5, Fig. 1) or may completely envelope the grain (Pl. 4, Fig. 4). In most of the cases, the overgrowth is not in optical continuity with the detrital grain and in no case, the twinning bands continue in the over growth. The feldspar grains show varying degrees of alteration but the overgrowths are comparatively less altered. Fragments of sedimentary rocks make up about 1% to 4% of the rock composition and represent parent rocks such as quartz arenites, arenites calcareous cements, arenites ferruginous cements, wackes, siltstone/shales and rarely limestones. Fragments of metamorphic rocks constitute about 0.12% to 6% of the total composition and may represent schists of various types. The minor components of the heavy minerals including zircon, tourma-
line, rutile, garnet, epidote, biotite muscovite and opaques (Pl.4, Fig.3) constitute about 1% to 3% of the total composition. Cement constitutes about 1% to 5% of the rock composition. Cement is represented by reorganised clay matrix. In some of the thin sections, the presence of siliceous and/or ferruginous cement is also noticed.

Remarks: The high proportion of monocrystalline, polycrystalline and metamorphic quartz grains followed by feldspars and heavy minerals indicate low to moderate relief of the positive areas where physical fragmentation and chemical decomposition was going on simultaneously. The lack of feldspars in these rocks is either due to the poor enrichment in parent rocks or feldspars had been decomposed during denudation and transportation. The altered nature of the feldspars is suggestive of prevalence of warm and humid climate in source area. The fragments of sedimentary and metamorphic rocks provide the evidence about their derivation from the sedimentary and metamorphic rocks. The metamorphic provenance is also indicated by the presence of stretched quartz grains (Pl.5, Fig.4). The proportion of clay matrix and authigenic overgrowth on the quartz and feldspar grains is suggestive of accumulation of the sediments in shallow agitated water in stable palaeodepositional conditions, where these sediments could acquire moderately well-sorted characters.
3.2 NILKANTH FORMATION

The Nilkanth Formation comprises a succession of 20 to 30 metres thick limestone and overlies irregularly on unfossiliferous Quartzite Member of the Tal Formation in the type locality of Nilkanth. The rocks of the Nilkanth Formation are grain supported with a sparse sparry cement. The components of the grainstone (limestone rocks) are a mixture of oolites some of which are superficial oolites, alongwith bioclasts. In the present work, the oolitic rocks are named oosparite. They have oolites >25% in the sparite cement. The rocks which have <25% oolites and more bioclasts are called bioclastic rocks (Biosparite). In the Garhwal Syncline, the Nilkanth Formation has generally been referred as Shell limestone/sandy oolitic limestone/oosparite/calcarenite/bioclastic grain stone/Singtali Formation and Bansi Member respectively by different workers.

Bhatia (1980) has equated all these limestones with the Wilson's (1975) standard microfacies SMF-11 (Facies belt-6) on the basis of the properties of this microfacies i.e. environment is well oxygenated, but the marine life is scarce because of constantly shifting substratum. Spastoliths have also been described here for the first time from a transition bed between the Nilkanth Formation and Subathu Formation about 2 km before Dogadda on the road section. However, some workers have described
these as *Lithothamnium nilkanthensis* from the Nilkanth area, (Kumar, 1969 and Tewari and Gupta, 1978). The petrographic studies of the fossils have also been made from the different localities of the Nilkanth Formation of Garhwal Syncline. The petrography of the oolites of the Nilkanth Formation have been carried out in the Garhwal Syncline. Bassi and Vatsa (1971) were the first to describe the oolites from the southwest of Rishikesh in Pauri Garhwal and named the rock as oosparite, Qureshy and Anantharaman (1984) from the Upper Tal limestone in Garhwal synform. The limestone Formations exposed in these areas belong to the Nilkanth Formation. The thin sections of limestone were stained with Alizarine red-S and potassium ferricyanide. Carozzi's (1960) classification has been followed for classifying the oolites. The fossils under thin sections have already been described by Tewari and Kumar (1967), Saklani et al. (1977) Tewari and Gupta (1978), Kalia 1972, 1976), Mehrotra et al. (1976), Bhatia (1980), Raiverman and Singh (1985) and Singh and Singh (1988) of from Permian and Late Cretaceous ages. Middlemiss (1885) had described some fragmentary, probably Jurassic fossils from the gritty quartzite at Gajwar in the British Garhwal Himalaya. However, Bhatia (1980) has correlated all the above mentioned horizons of Tal limestone under the one formation of Late Cretaceous age. The Permian age assigned by some of the earlier workers to this Formation is due
to the wrong identifications of fossils, which has been discussed in detail by Bhatia (1980).

3.2.1 Oolites

Shape of the oolites: About 90% of the oolites are spherical (Pl. 6, Figs. 1, 2, 5, 6) subspherical (Pl. 6, Fig. 4) or elliptical (Pl. 7, Fig. 5a). A few notched or stretched oolites are also observed. The oolites are moderately to poorly sorted and are loosely packed in a micritic and sparry calcite matrix.

Size of the oolites: The different varieties of oolites vary in size from 0.25 mm to 0.95 mm in diameter. Normally, the oolites range in size from 0.25 mm to 0.40 mm. The maximum diameter of the superficial and pseudo-oolites is 0.75 mm and 0.90 mm respectively. In general, the normal oolites are more uniform in size than pseudo-oolites. The superficial oolites are smaller than normal oolites. The compound oolites are formed with two or more nuclei and bigger than other types of oolites. There is hardly any relationship between the nucleus of the oolite and the size of oolite. Even the bigger oolites have very small quartz nucleus and vice versa.

Colour of the oolites: In general, the oolites are light brown in colour, but the shade varies from core towards the outer rim. The outer rims are much darker in contrast to the inner rims.
Nucleus of the oolites: The nuclei of the oolites vary in shape, size and composition. More than 70% of the oolites have quartz grains as their nucleus, which are subangular to subrounded (Pl.6, Figs. 4,6) and rectangular (Pl.6, Fig.2). The rest of the nuclei have been formed by organic remains (Pl. 7, Fig.4a), intraclasts (Pl.9, Fig.4) and cryptocrystalline calcareous material (Pl.6, Fig.1a, 5). Some of the quartz grains have developed authigenic overgrowth and have inclusions of opaque minerals. In some of the grains, the quartz nucleus has been replaced by carbonate matter and now the quartz grains occur as a minute speck (Pl.7, Fig.2a). In some cases the nucleus is found to be made up of two distinct fractions (Pl.6, Fig.4). The calcite nuclei are generally rounded and show replacement (Pl.6, Fig.5). In some oolites the nucleus has been formed by cryptocrystalline cement. The more growth has been noticed on the sides of the elongated oolites (Pl. 6, Fig.1b).

Concentric rims of the oolites: The concentric rims of the oolites are made up of cryptocrystalline calcareous matter, sometimes partial or complete replacement by silica has taken place. Mostly, the lighter rims are towards the periphery but in some oolites have only one black thick halo around the nucleus. The width of the rims is not uniform and varies from oolite to oolite and also within the same oolite. In general, the outer rims
are wider, some rims show undulations (Pl.6, Fig.4) and in few sections intermediate rims pinch out and the succeeding rim is in contact with more than one rim (pl. 7, Fig.3a). The number of rims varies in oolites and it is an important criteria for the classification of oolites into normal, superficial and pseudo-oolites (Carrasi, 1960). Probably in the concentric oolites the size of the oolite depends upon the nucleus.

Concentric oolites: The concentric oolites (Pl.7, Fig.2b,c) are mostly circular but exceptionally they are elliptical in shape (Pl. 7, Fig. 6a). These oolites are developed due to accretionary growth around the nucleus. They can be with or without nucleus and show as much as 21 concentric rims (Pl.6, Fig.2). Most of these oolites have subangular to subrounded and rectangular nuclei of quartz grains (Pl.6, Fig.2). They may have the nucleus of calcareous matrix etc. The maximum length and breadth of the concentric oolites are 0.7 mm to 0.9 mm respectively.

Concentric-cum-radial oolites: The oolites which have both radial as well as concentric features are called as concentric-cum-radial oolites (Pl.6, Fig.6). This type generally has the cryptocrystalline material as the nucleus and the radial texture, is silicified, but remanents are still preserved.

Composite oolites: The compound oolites are formed as a result of aggregation, cementation, reworking,
recementation and final packing within a common concentric oolite with 3-8 centres of growth (Pl.6, Fig.3; Pl.7, Fig.1). These are also silicified partially or wholly and show the effect of diagenesis. These oolites are light in colour and have undulation or are broken (Pl.6, Fig.4). The maximum length and breadth are 1-2 mm and 0.7 mm respectively.

**Pseudo-oolites**: Pseudo-oolites are elliptical in shape and are made of cryptocrystalline carbonate. These oolites have no internal structures and are almost associated with normal oolites (Carozzi, 1960). The average equatorial diameter is 0.80 mm.

**Siliceous oolites**: In siliceous oolites, the selective silica replacement has taken place in the original carbonate material. Partially, silicified oolites are also observed (Pl. 6, Fig.2). In silicified oolites, the concentric rims and radial fabric imprints have been left. The maximum length and breadth of these oolites are 0.60 mm and 0.80 mm respectively.

**Effects of diagenesis**: The effects of diagenesis on normal oolites are evident from the radial texture, which is superimposed over concentric rims. Sometimes complete recrystallization of oolites has given rise to pseudo-oolite by faint outlines of original concentric rims with carbonaceous inclusions (Kharakwal and Bagati, 1974). The quartz grains as the nucleus of oolite, have developed authigenic overgrowth, which also shows the effect of dia-
genesis. Some quartz grains are generally corroded and have been replaced by the carbonate rims of the oolites. The etching and corroding outer margins of rounded quartz grains by sparry carbonate material also indicate the effect of diagenesis.

3.2.2 Spastoliths

Spastoliths have been reported from the base of Subathu Formation on the road section about 2 km before the Dogadda village. Spastoliths have already been described by Kumar (1969) and Tewari and Gupta (1978) from the Nilkanth area under different names as Lithothamnium nilkanthensis algae. Raiverman and Singh (1985) have also observed chamositic ooliths, oolitic ironstone at the base of the Subathu Formation on the left bank of Tal river section in Nilkanth area. The contact between the Shell Limestone and Subathu is marked by a thin zone of ferruginous shale is exposed on the Gopi Chand Ka Mahal road section.

The oolites which have been squashed and hooked by compaction (Pl. 11, Figs. 1, 3) are chamositic oolites and are called spastoliths or ironstones. Srivastava (1984) described and figured such type of oolites as quiet water oolites from the Garhwal Syncline. These oolites are without radial structure and are notched.

The Phanerozoic chamositic oolites had been squashed during compaction and indicate that they were soft for sometime after their deposition. The chamositic oolites differ from the calcareous oolites by having rigid grains,
which retain their identity. Some compound chamositic oolites (Pl.11, Fig.4) like calcareous compound oolites with three or more nuclei, are also present in the material under discussion. Some of the oolites have been traversed by microveins (Pl.11, Fig.2) and infilled with siliceous or calcareous cement. The majority of the oolites are without nucleus (Pl.11, Fig.2) and some have quartz or cryptocrystalline cement (Pl.11, Fig.5,6). These oolites show low birefringence with dark grey interference colours in cross-polarized light. The chamosite oolites have been replaced at the margins or periphery of the oolites by brown-stained cement. The matrix between the oolites is dark, greenish-brown occurring with small equidimensional crystals with high birefringence.
Table 3.1 Classification of oolites depends upon the number of concentric rims.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Average size range (mm)</th>
<th>%age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal oolites</td>
<td>Oolite with more than one rim</td>
<td>0.20-0.40</td>
<td>60</td>
</tr>
<tr>
<td>Superficial oolites</td>
<td>Oolite with only one rim</td>
<td>0.15-0.35</td>
<td>30</td>
</tr>
<tr>
<td>Pseudo-oolite</td>
<td>Oolite with no rims</td>
<td>0.01-0.55</td>
<td>10</td>
</tr>
</tbody>
</table>

Nuclei of different minerals

<table>
<thead>
<tr>
<th>Composition of the nucleus</th>
<th>Shape of the nucleus</th>
<th>%age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryptocrystalline carbonate</td>
<td>Anhedral to subhedral</td>
<td>70</td>
</tr>
<tr>
<td>Microcrystalline carbonate</td>
<td>Subhedral to subangular</td>
<td>10</td>
</tr>
<tr>
<td>Microcrystalline calcite and dolomite shell fragments</td>
<td>Subangular</td>
<td>10</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>