CHAPTER III

PETROGRAPHY OF DOLOSTONES AND DOLOMITIZATION

3.1 Introduction

This chapter deals with the petrographical studies of uranium mineralized and non-mineralized dolostones, the different radioactive phases present, their association and the paragenetic sequence of ore minerals and associated rock forming minerals. Different types of dolomite seen in the area, different models for dolomitisation and the processes responsible for dolomitisation of Vempalle carbonates are also discussed in this chapter.

The main rock type of Kanampalle area are grey to dark grey, hard and compact impure dolomite which is stromatolitic with crocodile skin like rough surface and has sedimentary structures like desiccation cracks, ripple marks and cross bedding. Borehole Core samples from the area are light grey to dark grey coloured, fine grained, banded, hard and compact rock The host rock for uranium mineralization in Kanampalle area is identified as impure dolostone.

3.2 Petrography

The host rock for uranium mineralization in Kanampalle is impure dolostone. The rock is fine grained and laminated. Dolomite is major component of the rock followed by siliciclastic minerals (quartz, potash feldspar and plagioclase feldspar, mineralized and non-mineralized zircon), collophane and opaques (Fig. 3.1, 3.2, 3.3, 3.4 and 3.5). Dolomite comprises of 60 to 95% of the total mineral composition of rock. Laminations of few mm thicknesses are mainly of dolomite and siliciclastic minerals. The rock display floating texture, with siliciclastic minerals floating in different size of dolomitic groundmass (Fig. 3.6). The mineralogical composition of the dolostone of
Kanampalle is given in Table 3.

<table>
<thead>
<tr>
<th>Mineral Assemblage</th>
<th>Weight percent</th>
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<tbody>
<tr>
<td>1 Carbonates (dolomite major {dolospar &amp; dolomicrite} &amp; Calcite minor}</td>
<td>83.20</td>
</tr>
<tr>
<td>2 Quartz and feldspar clast (± monazite, zircon, tourmaline)</td>
<td>11.30</td>
</tr>
<tr>
<td>3 Collophane</td>
<td>4.55</td>
</tr>
<tr>
<td>4 Pyrite, chalcopyrite, galena, molybdenite</td>
<td>1.20</td>
</tr>
<tr>
<td>5 Magnetite, goethite, ilmenite (± leucoxene)</td>
<td>0.70</td>
</tr>
<tr>
<td>6 Uranium limonite mineral phases</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Fig. 3.1: Photographs of thin section displaying overall microscopic texture of rock (not to scale) Q-quartz, D-dolomite.
Fig. 3.2: Photomicrograph showing the overall texture of impure dolostone, 2x, TL, 1N.

Fig. 3.3: Photomicrograph showing Quartz (Q) and feldspar (F) clasts within the dolomitic groundmass (D). 20X, TL, XN.
Fig. 3.4: Photomicrograph showing Impure dolostone in thin section having dolomite with siliciclastic minerals.

Fig. 3.5: Photomicrograph showing Pure dolostone with less of siliciclastic minerals as in thin section.
Fig. 3.6: Photomicrograph showing the overall texture of the rock, with different sizes of dolomite and floating siliciclastic minerals. 2X, TL, XN.
Some of the impure dolostones of Kanampalle area display colour banding. Dark coloured band is chert dominated (Fig. 3.7) while the light coloured band is dolomite dominated (Fig. 3.8) and both the bands have floating siliciclastic minerals mainly quartz. Detrital siliciclastic minerals are medium sized (0.45mm avg. size), comprising of quartz, microcline and plagioclase. They all together account for 5 to 30% of the rock by volume. Feldspar clasts are smaller in size than quartz clasts (Fig. 3.9). As quartz is more resistant to weathering than the feldspars and hence remain as bigger clasts. Quartz clasts are monocrystalline indicating its source from igneous rocks as well as polycrystalline from metamorphic crystalline source (Fig. 3.10 & 3.11) thus suggesting both a near and far provenance for the siliciclastic minerals. Siliciclastic minerals have embayed grain margins. Authigenic quartz is present in the form of silica overgrowth on detrital clasts and as fracture fillings. Two types of quartz seen in the rocks are detrital and authigenic type.

1. Detrital quartz: These are anhedral to subhedral grains, floating in the dolomitic groundmass (Fig. 3.12). They are derived from outside the basin and have corrugated grain margins.

2. Authigenic quartz: This silica is formed within the basin and is present in the form of silica overgrowth on detrital quartz and feldspar grains indicating that they are later formed (Fig. 3.13). Quartz and feldspar grains are rounded but due to overgrowth it has developed planar surfaces (Fig. 3.14). Along the dust lines of quartz and feldspar very fine limonite and anatase are identified.
3.2.1 Dolomite: Petrographically different types of dolomite have been seen in the area. They are classified based on different aspects like mode of occurrence and time of formation.

3.2.1a Dolomites as per the mode of occurrence: Following types of dolomite are observed by microscopic studies of the rocks.

- **Micritic dolomite** – It is the fine micritic variety of dolomite which is less than 4 micron in size. It is the main constituent of dolostones and are mainly anhedral and turbid in nature to form xenotopic mosaics. (Fig. 3.15)

- **Sparitic Dolomite** – It is formed at a later stage of cementation in which sparry dolomite fills large cavities, where crystal size increases towards the centre of the cavity (Fig. 3.15). They are more than 4microns in size, subhedral to euhedral and clear. Recrystallisation of anhedral, turbid micritic dolomite has also led to the development of sparitic dolomite.

- **Peloids** – These are spherical, ellipsoidal or angular grains composed of microcrystalline carbonate without internal structure. Peloids are present as disseminations in impure dolostone and are composed mainly of micritic dolomite. They are rich in fine grained opaques which are identified as framboidal pyrite. Some of the peloids are rich in organic matter and collophane. They are radioactive due to presence of adsorbed uranium.

- **Ooids** – These are sub-spherical structures having diffused concentric layers, compositionally similar to peloids.
Fig. 3.7: Photomicrograph showing Chert dominated band, with quartz clasts (Q), 2X, 1N, TL.  
Fig. 3.8: Photomicrograph showing Dolomite dominated band, with quartz clasts (Q).
Fig. 3.9: Photomicrograph showing Quartz (Q) and feldspar (F) clasts floating in dolomitic groundmass. 20X, TL, XN.

Fig. 3.10: Photomicrograph showing Mono (MQ) and poly (PQ) crystalline quartz clasts in dolomitic groundmass. 10X, TL, XN.
Fig. 3.11: Photomicrograph showing Polycrystalline quartz (PQ) clast, 5x, TL, XN.

Fig. 3.12: Photomicrograph showing Detrital quartz (DQ) and microcline feldspar (M) clasts with in dolomitic groundmass 5X, TL, XN.
**Fig. 3.13:** Photomicrograph showing Silica overgrowth (Q) on feldspar in impure dolostone, 20x, TL, XN.

**Fig. 3.14:** Photomicrograph showing Feldspar (F) overgrowth on plagioclase (P) TL, XN, 5X, air.
• Fenestrae – It is coarse grained dolomite present as irregular fenestrae (cavity), (Fig. 3.15).

• Second phase: It is formed due to recrystallisation of first type. It is as pervasive as the first type and consists mainly of spar dolomite (Fig. 3.16). Both xenotopic and hypidiotopic textures are common. In this type of dolomite, the relics of original fabric are absent.

• Third phase: The third type of dolomite is cement precipitated, last to form as a thin and clear outer rim or zone around primary dolomite (Fig. 3.17), peloids (Fig. 3.18) and quartz clast (Fig. 3.19). The third type of dolomite is not as important volumetrically as the first (~60%) and second (~45%) type of dolomite and accounts for 1-2% or less of all the dolomites.
Fig. 3.15: Photomicrograph showing Irregular fenestrae (F), sparitic dolomite (S) and micritic dolomite (M) in impure dolostone TL, XN, 2X, air.

Fig. 3.16: Photomicrograph showing first, second and third type of dolomite 2x, TL, 1N.
Fig. 3.17: Type 3 dolomite overgrowth (2) over type 1 dolomite (1)  5X, TL, 1N
Fig. 3.18: Type 3 dolomite overgrowth on peloid rich in carbonaceous matter  10x, TL, XN
Fig. 3.19: Type 3 dolomite overgrowth on quartz clast 5X, TL, XN

Fig. 3.20: Hypidiotopic (A), idiotopic (B) & xenotopic (C) mosaic texture displayed by dolomite
10X, TL, XN,  2X, TL, XN,  20X, TL, XN
Four carbonate lithounits namely massive dolostone, mineralized & non mineralized phosphatic dolostone and cherty dolostone were sampled and analyzed. The carbonate rock classification of Dunham (1962) has been used for both field and petrographic identification.

Pyrite formation is controlled by the chemical and hydrodynamic conditions of the environment. The scattered pyrite in the mineralised dolostone lithofacies are probably formed in a reducing condition that prevailed in the hypersaline environment (Friedman, 1966; Friedman and Sanders, 1967; Braun and Friedman, 1969; Friedman and Radke, 1979). Pyrite is very common in ancient marine rocks and develops within low-energy environments (lagoons, estuaries, and coastal lakes). Under anaerobic conditions and warmer temperatures, certain bacteria that help in the formation of pyrite become active. The activities of this bacteria results in the reduction of sulfate into native sulfur. Iron particles from the preexisting sediments combine with sulfur to produce iron sulfides in form of pyrite framboids (spherules) as an authigenic mineral during the late diagenetic event (Suits and Wilkin, 1998).

3.2.1c Texture: Spar dolomites which are subhedral and euhedral in shapes display hypidiotopic and idiotopic mosaic textures respectively (Fig. 3.20 A & B). Micritic dolomites are mainly anhedral in shape and display xenotopic mosaic texture (Fig. 3.20C). In the study, Friedman’s terminology (1965) of crystallization textures and fabrics in sedimentary rocks as well as the classification provided by Sibley and Gregg of dolomite rock textures (1987) were followed and applied for different types of dolomite textures.
Sparry dolomite consists of euhedral (idiotopic), subhedral (hypidiotopic) to anhedral (xenotopic) crystals whose sizes are more than 4 microns. Almost all the dolomite crystals within this texture exhibit uniform optical properties. According to Friedman and Sanders (1978) and Sibley (1982) the euhedral, unimodal crystals are syngenetic or formed in situ due to a homogeneous distribution of the nucleation-growth rate. Probably the Mg$^{2+}$ cations were absorbed in large quantities onto the growing calcite lattice which resulted in precipitation of high-magnesium calcite to reach equilibrium phase with the sea water causing stability surface. The presence of fine-textured dolomite indicates a supratidal setting under an arid shelf condition of a sabkha environment (Curtis et al 1963; Kinsman 1969; Friedman et al. 1992).

Micritic dolomite forms the primary dolomite component. It is less than 4 microns in size and the grains are mainly anhedral and display xenotopic mosaic texture. Anhedral grains of dolomite reflect >50°C temperature of formation. It may be formed from direct nucleation of crystals in the water column where Mg$^{2+}$/Ca$^{2+}$ ratio is sufficient to permit crystallization of dolomite rhombs (Textoris 1969; Zenger 1972; Land 1985). Friedman and Sanders (1967, 1978) referred to this finely crystalline dolomite as a product that resulted from capillary concentration of hypersaline brines through porous sea-marginal sediments.

Neomorphism of turbid, anhedral micritic dolomite (Type-I) during diagenesis has led to the development of subhedral, clear sparry dolomite (Type-II) of average size of 30 to 40 microns. Spar dolomite is subhedral to euhedral and display hypidiotopic to xenotopic mosaic texture. Micritic dolomite is anhedral and thus display xenotopic mosaic texture formed at >50°C.
Peloids rich in opaques (Fig. 3.21), framboidal pyrites (Fig. 3.22) and carbonaceous matter of an average size of 0.2mm are present as disseminations floating in the micritic groundmass (Fig. 3.23 & 3.24). Some of the peloids are radioactive because of adsorption of uranium on carbonaceous matter. Sparse alpha tracks are noted on CN films over these radioactive peloids after 5 days of exposure.

Zircon, tourmaline, and monazite are the heavy minerals present (Fig. 3.25, 3.26, 3.27, 3.28). They suggest granitic provenance for the detrital siliciclastic minerals. They are present as inclusion in quartz and also as disseminations in the groundmass.

Dolomitisation is the major alteration noted in the area which has affected all the siliciclastic minerals in a major way. As a result of dolomitisation, impurities have embayed grain boundaries (Fig. 3.29). Silicification has led overgrowth of silica on detrital quartz as well as feldspars. Both detrital as well as authigenic quartz are present. Authigenic quartz is present as overgrowth on siliciclasts and in veins. Vein quartz is euhedral and forms a dog tooth type structure.

The rocks are fine grained and laminated. These laminations at places suffered deformation in the form of microfaults. The fracture openings are filled with secondary quartz, chlorite and iron oxide minerals like limonite & goethite (Fig. 3.30, 3.31 and 3.32).
Fig. 3.21: Photomicrograph showing Peloids rich in opaques 2x, TL, 1N.

Fig. 3.22: Photomicrograph showing Framboidal pyrite in peloid 50x, RL, 1N.
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<thead>
<tr>
<th>Fig. 3.23</th>
<th>Photomicrograph showing fine grained framboids of pyrite in the peloids, 5X, TL, 1N</th>
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<tr>
<td>Fig. 3.24</td>
<td>Photomicrograph showing fine grained framboids of pyrite in the peloids, 5X, RL, 1N</td>
</tr>
</tbody>
</table>
Fig. 3.25: Photomicrograph showing rounded zoned zircon grain (Z) in dolomite (D) 10x, TL, XN.

Fig. 3.26: Photomicrograph showing euhedral zoned zircon grain (Z) in dolostone (D) 50X, TL, XN.
Fig. 3.27: Photomicrograph showing Tourmaline (T) grains as inclusion in quartz clasts. 5X, TL, XN.

Fig. 3.28: Photomicrograph showing Monazite (M) grain in impure dolostone TL, XN, 5X, air.
Fig. 3.29: Photomicrograph showing embayed margins of quartz clast (Q) in impure dolostone TL, XN, 5X.

Fig. 3.30: Photomicrograph showing microfaulting along a fracture 2x, Tl, XN.

Fig. 3.31: Photomicrograph showing fracture filled by secondary, fine grained quartz, chlorite and iron oxide 10x, Tl, XN.
Fig. 3.32: Photomicrograph showing microfaulting along a brittle fracture 2X, TL, IN.

Fig. 3.33: Photomicrograph showing spherulitic calcite TL, 5X, XN.
3.2.2 Other Carbonates Minerals

In addition to dolomite as major minerals, calcite and siderite are also present in the dolostone. They are mainly sparry in nature. Calcite is present in spherulitic form (Fig. 3.33). Spherulitic calcite or spherulites are sparry calcite precipitated around cyanobacterial filaments or on bacterial cells to create distinctive crystal aggregates. Thus it is indicative of presence of marine life at the time of deposition. Calcite is also present as secondary mineral in fractures and cross-cutting veins. They are confirmed by high effervescence during carbonate test.

Siderite is the iron carbonate which is present in impure dolostone as spar variety (Fig. 3.34). It is present along with dolomites. They have brown coatings along cleavage planes and show grey interference colour (Fig. 3.35) in thin section unlike other carbonates.

3.2.3 Overgrowth

Authigenic silica in the form of quartz overgrowth on detrital quartz and feldspar and authigenic feldspar in the form of feldspar overgrowth (Fig. 3.14) are seen in the thin section of impure dolostone. Presence of free silica has led to the formation of silica overgrowth whereas hydrothermal fluids enriched in $K^+$, $Al^{3+}$ and $Si^{4+}$ has led to the formation of secondary microcline as overgrowth. Marine waters are necessary for the formation of secondary feldspar. Feldspar with overgrowth indicates marine origin.

3.2.4 Provenance

Dolostone has on an average upto 10% of siliciclastic minerals. Thus it is termed as impure dolostone due to the presence of quartz, plagioclase and microcline feldspar. They together form siliciclastic mineral component. These sediments are suggestive of
mixed provenance. Presence of rounded and monocrystalline quartz clasts are indicative of far provenance whereas presence of feldspar and polycrystalline quartz are indicative of closer source for the sediments.

In addition to siliciclastic minerals, presence of heavy minerals like zircon, tourmaline and monazite also indicate granitic provenance for the sediments. Zircon (Fig. 3.25 and 3.26) and monazite (Fig. 3.28) are present as euhedral disseminations in the dolomitic groundmass. Tourmaline (Fig. 3.27) grains are present as inclusion in quartz. These above mentioned heavy minerals point to granitic provenance for the sediments.
Fig. 3.34: Photomicrograph showing Siderite (S) in dolostone 1N, TL, 10X.

Fig. 3.35: Photomicrograph showing Siderite (S) in dolostone XN, TL, 10X, Air.
3.2.5 Ore minerals

Sulphides are the principal ore minerals with pyrite accounting to about 1% of the whole rock. Chalcopyrite, galena and sphalerite are the other sulphide phases present (Fig. 3.36 and 3.37). Pyrite is fine to medium grained, subhedral to euhedral and present as disseminations and aggregates in the rock. Framboidal variety of pyrite is the dominant variety and is formed due to biogenic activity at the time of rock formation. Size of framboids varies from few microns to 0.01mm. Framboidal pyrite in association with carbonaceous matter is suggestive of low temperature of formation (~65°C) and sedimentary environments. Chalcopyrite and sphalerite are later formed and replaces pyrite.

The presence of framboidal pyrite in association with peloids indicates a period of bacterial sulphate reduction during early diagenesis (Raiswell, 1982: Berner & Westrich, 1981). If iron is present, the H₂S generated during sulphate reduction usually precipitates at or near the site as pyrite.

Oxides of iron and titanium are the other ore minerals present throughout in the rock. Anatase is present mainly as disseminations whereas limonite generally occupies the intergranular spaces and fractures.

3.2.6 Radioactive Phase minerals

In thin section radioactive minerals are identified by solid state nuclear track detection (SSNTD) technique. In this method thin sections are exposed with an alpha sensitive cellulose nitrate film for 72 hours. Due to radiation, CN film gets damaged by alpha tracks. This is further etched overnight in 10% NaOH solution to increase the
damage size so that it can be viewed under microscope. The density of alpha tracks is a
good indicator of the radioactive source. If these tracks are due to primary radioactive
minerals phase they give dense tracks. If they are caused due to adsorbed uranium phase
or U-Ti complex, the density decreases.

By examination of the alpha tracks different radioactive phases have been
identified in the area. They are described as follows.

3.2.6a Pitchblende: It is uranium oxide (U₃O₈) and an amorphous variety of uraninite
formed at lower temperatures. It gives dense alpha tracks on cellulose nitrate film (Fig.
3.38a). Fine to ultra fine grains of pitchblende are present in association with pyrite (Fig.
3.38b). Pitchblende is formed later to sulphide as it replaces pyrite (Fig. 3.39 and 3.40).
In general pitchblende is very fine grained (few microns). Upto 0.08mm sizes of
pitchblende grains are present in impure dolostone of the area (Fig. 3.41 and 3.42).

3.2.6b Coffinite: It is uranium silicate [U(SiO4)1-x(OH)4x] with lower concentration of
uranium. It also forms at lower temperature especially in areas which have sufficient free
silica. Coffinite is present in close association with pyrite and gives high density alpha
tracks on CN films. They too are very fine grained upto few microns in size (Fig. 3.43a,
b, c and d).
Fig. 3.36: Photomicrograph showing Galena (G) as dissemination 50X, RL, 1N.

Fig. 3.37: Photomicrograph showing Chalcopyrite (cpy), pyrite (py) and sphalerite (s) in impure dolostone 50X, RL, 1N.
3.2.6c U-Ti complex: U-Ti complex gives low to medium density alpha tracks on CN films after 5 days of exposure. Here no uranium mineral is formed but instead sufficient amount of uranium is adsorbed on titanate to call it as U-Ti complex. Under reflected light in one nicol it shows brown internal reflections. Uranium is present in association with anatase in thin veinlets (Fig. 3.43 and 3.44).

3.2.6d Adsorbed uranium: Adsorption is the adhesion of atoms, ions, biomolecules or molecules of gas, liquid, or dissolved solids to a surface. By this process uranium in hexavalent (U^{6+}) state from solution is adsorbed on the surface of limonite, collophane and organic matter. Adsorbed uranium is weakly radioactive and thus show weak and sparse density alpha tracks on CN film. In impure dolostone of Kanampalle area, uranium is adsorbed on limonite (Fig. 3.46 and 3.47), collophane (Fig. 3.48 and 3.49) and carbonaceous/organic matter (Fig. 3.50). SSNTD study reveals the presence of low density alpha tracks on these minerals.
Fig. 3.38a: Alpha tracks on pyrites in impure dolostone 20x, TL, 1N.

Fig. 3.38b: Corresponding opaques (pyrites) in impure dolostone 20x, TL, 1N.
Fig. 3.38c: Photomicrograph showing opaques as pyrite (py), chalcopyrite (cpy) and pitchblende (p) in impure dolostones from Kanampalle. 50x, RL, 1N.

Fig. 3.38d: Photomicrograph showing opaques as pyrite (py), chalcopyrite (cpy) and pitchblende (p) in impure dolostones from Kanampalle. 50x, RL, 1N.
Fig. 3.39: Photomicrograph showing Pitchblende with corresponding alpha tracks (offset) RL, 1N, 10X.

Fig. 3.40: Photomicrograph showing Pitchblende (P) replacing pyrite (Py) RL, 1N, 50X.
Fig. 3.41: Photomicrograph showing Radioactive opaque mineral (OM) TL, 1N, 20X.

Fig. 3.42: Photomicrograph showing Pitchblende (0.08mm)(P) with pyrite(Py) TL, 1N, 20X.
Fig. 3.43a: Photomicrograph showing Medium density alpha tracks (offset) 10X, TL, 1N.

Fig. 3.43b: Photomicrograph showing Previous fig under reflected light 10X, RL, 1N.
Fig. 3.43c: Photomicrograph showing Block A of Fig-71b in 50X.

Fig. 3.43d: Photomicrograph showing Block B of Fig-71b in 50X P- pyrite, C-coffinite (grey).
Fig. 3.44: Photomicrograph showing Alpha tracks on U-Ti complex, 10X, TL, 1N.

Fig. 3.45: Same as previous fig under reflected light at 20x magnification.
Fig. 3.46: Photomicrograph showing U adsorbed on limonite, RL, XN, 20X

Fig. 3.47: Photomicrograph showing Alpha tracks due to adsorbed U on opaques TL, 1N, 10X.
Fig. 3.48: Photomicrograph showing Collophane in impure dolostone 5X, TL, XN.

Fig. 3.49: Photomicrograph showing Low density alpha tracks on collophane 5X, TL, XN.
Fig. 3.50: (A) Peloid having opaques, 20x, TL, 1N (B) Sparse tracks due to adsorbed uranium on carbonaceous matter, 20x, TL, 1N & (C) peloid having pyrite and carbonaceous matter, 20x, RL, 1N.

Fig. 3.51: Photomicrograph showing Metamict mineral with pleochroic halo, TL, XN, 10X.
3.2.7 Refractory phase minerals: Monazite (Fig. 3.28) and zircon (Fig. 3.25 and 3.26) and metamict minerals (Fig. 3.51) contribute radioactivity to dolomite of the area and are present as disseminations in the ground mass. In some cases it is difficult to identify these radioactive minerals due to metamictisation. In this process due to radiation the internal crystal structure of the mineral is damaged and as a result the mineral is difficult to be identified in thin section. They have distinct pleochroic haloes around them.

Uranium phase is later to sulphide phase as it replaces pyrite. Coffinite indicates the presence of sufficient free silica in the system, which is well supported by the presence of authigenic silica in the form of overgrowth and chert in the groundmass. The source rock for uranium in the area is the fertile basement granite. Uranium has come along with siliciclastic minerals from granites. Primary uranium minerals are present as disseminations and along microfractures and are syn-diagenetic in nature.

The major difference observed in the mineralized and non-mineralized impure dolostone is in the amount of organic matter and impurities. Impure dolomite is more favourable for uranium concentration as it is more permeable and thus provides an easy pathway for uranium rich fluid to move through. Presence of impurities slows down the fluid movement, hence increasing the interaction and residence time. Biogenic activity is high in mineralized samples and thus has played a major role in uranium concentration in the host rock due to reducing environment. It is present as carbonaceous matter in peloids and as thin bands, which are a part of stromatolites. They give sparse density alpha tracks on cellulose nitrate film due to presence of adsorbed uranium. Nash et al, (1981) suggested that concentration of uranium by adsorption onto organic matter or a mineral surface preceded reduction and accelerated the process of reduction of uranium. In
addition it has also provided the reducing environment necessary for uranium precipitation. Impurities in dolostone have also reduced the eh-pH conditions favourable for uranium precipitation.

The photomicrographs of entire lithounits representing the Vempalle Formation of the study area are shown in fig. 3.52.
<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Description</th>
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<tbody>
<tr>
<td>Cherty dolostone</td>
<td>The rock is composed primarily of micritic dolomite (~95%).</td>
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<tr>
<td>Purple shale</td>
<td>The rock is coated with iron oxide. Calcite (C) and detrital quartz grains (DQ) are noted.</td>
</tr>
<tr>
<td>Impure dolostone</td>
<td>The rock is composed chiefly of dolomite (60-80%) with floating siliciclastic minerals (20-40%) and opaques (1-5%).</td>
</tr>
<tr>
<td>Grey shale</td>
<td>They are well laminated, fine grained rock composed of argillaceous minerals. The bands are rich in quartz and clay minerals.</td>
</tr>
<tr>
<td>Conglomerate</td>
<td>Conglomerate has clasts of chert/ recrystallised quartz, feldspar, chalcedony, euhedral dolomite. Size of the quartz clast is 4 to 5mm. Clast to matrix ratio is approximately 50:50.</td>
</tr>
<tr>
<td>Massive dolostone</td>
<td>The rock is fine grained composed of ~ 70 to 80% dolomite, followed by siliciclastic minerals (10-20%) and opaques.</td>
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Fig. 3.52: Photomicrographs of rocks representing stratigraphic column of Kanampalle
3.3 Paragenetic sequence of ore minerals and associated rock forming minerals

Minerals in the area can be divided into three categories: 1) detrital, 2) authigenic and 3) ore stage mineralisation. Silt to sand sized, subrounded to elongated detritus consisting of quartz and feldspar were deposited in the Middle Proterozoic. Detrital minerals are derived from granite present on the western margin of Papaghani sub-basin. It was a small and shallow basin having arid climate. Penecontemporaneous dolomitization has resulted in the formation of micrite dolomite. Aragonite, followed by calcite and dolomite is the sequence of carbonate minerals to form in the basin. Neomorphism (recrystallisation) of micritic dolomite has led to the development of secondary spar dolomite. Authigenic minerals such as silica and dolomite replace detrital phases and also occur as overgrowths. These are formed during the diagenesis of dolostone.

The ore-stage mineral comprises chiefly of pyrite that occurs predominantly as fine grains disseminated in the rock and in peloids. It is of biogenic nature. Chalcopyrite is anhedral and replaced by bornite, digenite and covellite. Pitchblende replaced pyrite and carbonaceous matter. Precipitation of the ore stage sulphides precedes formation of primary uranium minerals. Galena postdates the uranium minerals. Adsorbed uranium phase is present in all the stages. Paragenetic sequence of ore minerals and associated rock forming minerals is given in the table 4.

3.4 Dolomitisation

Dolomite was first described from the Tyrol. The specific name dolomite (French, dolomite) was applied to these rocks in 1792 by Saussure in honour of Dolimieu, one of the earliest investigators. Dolomite is widespread in both time and space and is one of the
most important rocks in the earth’s crust. It is also called as dolostone (Shrock, 1948). Dolostones are those varieties of limestone containing more than 50% carbonate, of which more than one half is dolomite. Dolostone is more commonly a near shore facie whereas limestone is the product of offshore and perhaps more normal marine waters. The near-shore area is presumed to be more saline. In many places dolomite shows a close association with evaporites, particularly gypsum and anhydrite. In some cases, sulphates are present as scattered crystals in dolomite.
<table>
<thead>
<tr>
<th></th>
<th>Pre ore stage</th>
<th>Ore stage</th>
<th>Post ore stage</th>
</tr>
</thead>
<tbody>
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<td><strong>Detrital</strong></td>
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<td>Quartz</td>
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<td>Feldspar</td>
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<td><strong>Authigenic minerals</strong></td>
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<td>Micritic dolomite</td>
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<td>Spar dolomite</td>
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<td>Collophane</td>
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<td>Authigenic quartz</td>
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<td><strong>Ore-stage minerals</strong></td>
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<td>Pyrite</td>
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<td>Chalcopyrite</td>
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<td>Bornite</td>
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<td>Digenite</td>
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<td>Covellite</td>
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<td>Pitchblende</td>
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<td>Galena</td>
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<td>Coffinite</td>
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<td>Adsorbed uranium</td>
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<td>Anatase</td>
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**Table 4:** Paragenetic sequence of ore minerals and associated rock forming minerals in dolostones of Kanampalle area.
3.5 Dolomitisation models

Dolomitisation is a process in which an original calcium carbonate rock is converted into the double calcium magnesium carbonate either wholly or in part. Dolomitisation may occur at two stages, early and late diagenetic stage. The early diagenetic dolomites form concurrently with deposition or immediately after this process and reflect the conditions of environment in which they occur. Evaporitic dolomites (Deffeyes et al., 1964; Illing et al., 1965; Behrens and Land, 1972; Patterson and Kinsman, 1982), mixing water dolomites (Hanshaw et al., 1971) and marine dolomites (Land, 1985) are examples for this type. Evaporitic dolomites occur widespread in supratidal environments (sabkha) characterized by excessive evaporation under continental climatic conditions. Mixing water dolomites (sea water-fresh water) have been formerly proposed as a theoretical model (Dorag type dolomitization; Badiozamani, 1973). This type is mostly used to explain the dolomitization of platform-type limestones that are not accompanied by evaporites. In addition to these, some workers put forward that high Mg required for the formation of thick and massive platform dolomites is directly supplied from sea water and established a dolomitization model by sea water (Varol and Magaritz, 1992). It appears to be in many cases the result of a reaction between hypersaline marine brines and calcite.

It is thought that dolomite is a diagenetic facies and not original sediment. However in recent years dolomite has been found in rather small volume, in somewhat restricted environments. Dolomite is found in supratidal crusts in Florida Bay and Bahamas, in the sabkha flats of Persian Gulf and in certain Pacific atolls. These modern occurrences although small in volume seem to support the inferences drawn from the fine grained and laminated dolomites of the geologic record regarding the conditions of
dolomite formation. They seem to be tropical, in arid or semi-arid environment, commonly in a tidal lagoon or flat. They seem to involve hypersaline brines enriched in magnesium. The close association of older dolomites with gypsum, their algal laminations, structures, mud-cracks and the evidence of exposure of hypersaline brine are consistent with the observations on modern dolomite development.

Experimental studies and observations on modern dolostones suggest that the waters from which dolomite precipitated was not normal sea-water. It was probably richer in magnesium (relative to calcium) and had a higher than normal pH and also a higher than normal temperature. These conditions are found in shallow, hypersaline lagoons or tidal flats of warm arid regions.

There is still much debate and argument over the origin of dolomite, particularly concerning the pervasive dolomitization of extensive carbonate platforms. Two principal models for massive dolomitization are the hypersaline brine model and the mixing zone model (Fig. 3.53). Dolomite formed by the (1) mixing zone model is medium grained (10-100µm) stratabound replacement dolomite typically developed as replacements in marine carbonates. Whereas dolomite formed by the (2) hypersaline brine model is fine grained (<10 µm), stratiform syngenetic dolomite. Crystal size may increase during later burial. Unless recrystallised by later burial re-equilibration, the unit preserves fine grain size.

3.6 Dolomitisation of Vempalle Formation

Uranium mineralisation around Kanampalle area in Kadapa district is associated with the dolostone. Dolomite forms in a variety of physical and chemical environments. For example, dolomite forms in subtidal and hypersaline waters of both marine and
continental origin as well as in hypsaline waters derived from mixing between groundwater and seawater (Land, 1980). Most carbonate geologists agree that primary dolomitization (precipitation of dolomite without a precursor carbonate) is extremely rare; therefore, the existence of precursor carbonate sediment is necessary for extensive dolomitization. There are several models for the process of dolomitization.

Dolomitization in any setting requires three essential elements (Morrow (1982b) and Land (1985): (a) Source of reactants (Mg and usually CO$_3$). Considering the extensive development of dolostone development in the Vempalle Formation of Papagni Sub basin, seawater and/or its derivatives (evaporated seawater, seawater mixed with freshwater, seawater modified by sulfate reduction, etc.) can be considered as the only viable Mg sources. Similar explanation was rendered for the extensive dolomites found on or below carbonate islands (Land, 1985). (b) Fluid flow mechanism by which reactants and by products (Ca and perhaps CO$_3$) can be transported to and from the site of dolomitization. There are numerous types of fluids in the surface or near surface environment that are saturated or oversaturated with respect to dolomite, and these fluids may circulate through carbonate sediments and rocks by any number of mechanisms. However, dolomitization does not occur in most settings in which all the necessary elements are seemingly present. Understanding why a dolomite formed, or did not form, is thus a kinetic problem. (c) Kinetic and thermodynamic conditions favorable to dolomitization. The most critical of these elements is now believed to be reaction kinetics (Hardie, 1987; Chai et al., 1995).

The distribution of resistant detrital minerals in the dolostones of Vempalle Formation is a consequence of sedimentological processes that distribute the grains by
size and density. The proportion of resistant detrital minerals (quartz, rutile, ilmenite and zircon) will largely determine the abundance of SiO₂, TiO₂, Al₂O₃ and zirconium. High detrital concentrations suggest its proximity to shore line. High Mn contents together with Mn/Sr > 2 in the dolostones around Kanampalle area can be attributed to the influence of diagenetic alterations in carbonate rocks. The abundance of these elements, unchanged relative to chemical changes in the depositional environment is caused by the presence of organic carbon, varying redox conditions, or early diagenetic processes.

The whole column of Vempalle Formation in Papaghani sub-basin is dolomitised right from cherty dolostone to massive dolostone. Papaghani sub-basin was a shallow small basin lying close to the shore in arid conditions. Presence of sedimentary features like mud-cracks and ripple marks indicate its shallow nature. Mudcracks and stromatolitic development are further indicators of shallow water and even exposure. The high salinity suppresses the normal fauna and leads to precipitation of associated evaporitic sulphates (Phansalkar, 1991). Aragonite/calcite is the primary mineral to form. Due to intense evaporation, there was supersaturation of water. It is enriched in magnesium by the continuous inflow of normal sea water and by the precipitation of CaCO₃ and sulphate. Enrichment in this manner have formed heavy brine and led to penecontemporaneous dolomitization of the whole column of sediments in the basin (Fig. 3.54). Penecontemporaneous dolomite forms as a result of evaporite related brines that increase the Mg/Ca ration of sea water (Mg/Ca=5.0), by the precipitation of evaporates to a ratio of 10.0 or greater (Folk and land, 1975). Geologic features characteristic of Penecontemporaneous dolomitization includes laminations, mudcracks, fenestrae and the association with evaporites.
The dolomitization may be promoted by the presence of metastable aragonite and high Mg calcite precursors and by changes in pore water chemistry associated with degradation of organic matter. Dolomite is formed as disseminated rhombs and pore-filling cement in suboxic to anoxic (sulfate reduction zone) sediments, overlapping and extending below sediment depths of
Fig. 3.53: Two principal models for massive dolomitization.

Fig. 3.54: Penecontemporaneous dolomitization of the whole column of Vempalle sediments.
phosphorite formation. Dolomite can also form contemporaneously with phosphorite in adjacent depositional environments that lack phosphorite formation, such as shallow water lagoonal environment (Compton et al, 1994). Early diagenesis of cuddapah sediments (Fig. 3.55) can be subdivided into four zones based upon the work of Compton et al, 1994.

A. Organic matter burial increased from higher surface productivity resulting from increased upwelling during periods of rising or high sea level.

B. Degradation of organic matter in the sediments led to the formation of phosphorite and dolomite.

C. Dolomite is proposed to have formed early, at sediment depths extending below.

D. Phosphorite formation largely within the sulfate reduction zone as dispersed rhombs and pore filling cement. H$_2$S produced during sulfate reduction either reacts with iron to form pyrite or diffuses to overlying bacterial mats that oxidize the H$_2$S back to sulfate.

When we see in detail into the fig. 3.55, it also describes the mechanism of phosphate precipitation. The processes taking place in the zone A, B and C of this diagram is magnified and shown in figure 3.56. Phosphate precipitation in marine sediments has been reported from three geochemical zones: sub-oxic zone, the zone of sulfate reduction associated with the formation of diagenetic pyrite; and the zone of microbial methanogenesis, commonly associated with siderite (Fig. 3.56).

A. The majority of P in the ocean is removed by marine organisms (phytoplankton) living in surface waters. However, some of the P is released back into the ocean
as the organic matter decomposes while decending through the water column. Clay particles settling out of suspension, adsorb REE and P onto their mineral surfaces. At the sediment-sea water interface, REE and P may also be adsorbed onto Fe-(hydr-) oxide surfaces. Organic matter is decomposed by organisms using oxygen, releasing CO₂, water, nitrate and phosphate. In the oxic zone, pore water phosphate released from degraded Organic matter in deeper layers and phosphate from sea water may in part be adsorbed onto the surfaces of Fe-(hydr-) oxides. The REE released in underlying geochemical zones and from sea water may also be captured and adsorbed onto the surfaces of Fe-(hydr-) oxides.

B. In the zone of sulfate reduction, organic matter is decomposed by bacteria using sulfate as an electron acceptor, producing hydrogen disulfide and phosphate, as well as ammonia, CO₂ and water. Iron and manganese oxides are reduced (releasing REE and P) and combine with hydrogen disulfide to form Pyrite. REE and P adsorbed onto detrital clay surfaces are released during clay transformation and locally nucleate and precipitate on substrates releasing Al (for example, detrital clay, feldspar and mica). Yttrium and P combine and Precipitate on isomorphous templates (for example, zircon).

C. Decomposition of organic matter continues within the zone of methanogenesis, with the release of phosphates, as well as methane and CO₂. In the presence of Fe, siderite or Fe-rich carbonates may form. Aluminophosphate precipitation and crystal growth continues with the ongoing transformation of detrital clay (releasing adsorbed P, REE and Al) and dissolution and alteration of detrital
aluminosilicate grains (releasing Al). Yttrium and P continue to precipitate, enlarging xenotime overgrowth on detrital zircon grains.

Evaporite minerals or their pseudomorphs were not observed frequently, except occasional presence of very thin layers of gypsum (Fig. 3.57a & b). The absence of evaporite minerals may reflect the unlikeness of their preservation in reworked sediments.

Thus the whole column of Vempalle Formation in Papaghani sub-basin is dolomitised right from cherty dolostone to massive dolostone, by penecontemporaneous dolomitization of the whole column of sediments in the basin.
Fig. 3.55: Model showing the formation of dolomite as disseminated rhombs and pore-filling cement after Compton et al, 1994.
Fig. 3.56: Model showing the Phosphate precipitation in marine sediments, near sediment water interface.
Fig. 3.57a: Photograph showing Gypsum layers in the shale unit just above phosphatic dolostone in core samples from Kanampalle.

Fig. 3.57b: Photograph showing Gypsum layers in the transition zone just above phosphatic dolostone in core samples from Motuntalapalle, indicating hypersaline condition.